Booklet of Abstracts

"1st International Conference on Mathematical Modelling in Mechanics and Engineering"

Mathematical Institute of the Serbian Academy of Sciences and Arts
Belgrade, 08.-10. September 2022.

Editors: Ivana Atanasovska, Milan Cajić, Danilo Karličić

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PREFACE

It's our pleasure to be the chairs of the '1st International Conference on Mathematical Modelling in Mechanics and Engineering', organized by the Mathematical Institute of the Serbian Academy of Sciences and Arts, and co-organized by the Faculty of Mechanical Engineering, University of Belgrade; the Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac; and Institute for Information Technologies, University of Kragujevac. The conference will be held in hybrid form at the Mathematical Institute of the Serbian Academy of Sciences and Arts, Belgrade, Serbia, from 8^{th} to 10^{th} of September, 2022.

This conference is planned as the first event in the series of conferences which will be held every two or three years and bring together leading academic scientists, researchers and research scholars to exchange and share experience and research results on various aspects of mathematical modelling in mechanics and engineering. It will bring an interdisciplinary platform for researchers, practitioners and educators to present and discuss the most recent innovations, theories, algorithms, as well as practical challenges encountered and solutions adopted in the fields of Classical Mechanics, Solid and Fluid Mechanics, Computational Mechanics, Biomechanics, Applied Mathematics and Physics, Structural Mechanics and Engineering. A considerable number of prominent scientists and professors submitted their abstracts and confirmed their attendance at the conference. The scientists and researchers from different countries in Europe and the world (Netherlands, UK, Norway, Greece, Spain, USA, Kazakhstan, Italy, Montenegro, India, Malaysia, Slovenia etc.) also have confirmed participation at the conference. We expect that the conference presentations will cover modelling with analytical/numerical and data driven solutions to study complex media, composite aerospace and periodic structures and metamaterials, and capture essential features of linear and nonlinear dynamics and wave propagation behaviour that can lead to new designs of such systems. Some presentations will include new experimental setups to study engineering materials and novel control strategies based on classical or fractional derivative models used to control the dynamics of multibody, flexible and/or electromechanical systems. Finally, we believe that the sessions' discussions will have high potential to give significant contribution to the developments of new and advanced mathematical models of real-world engineering mechanical systems.

We're very proud to announced that the number of accepted contributions to be presented at this Conference is 106, with 7 plenary and 4 invited lecture presentations. We would like to express our gratitude to the institutions that support conference financially: The Ministry of education, science and technological development of the Republic of Serbia; METALFER STEEL MILL doo, Serbia; and SHIMADZU, Serbia. We are especially grateful to the members of the Scientific committee and participants who gave their contribution to this international scientific meeting with their advices and abstracts' reviews. We also thank to the support of the co-organizers of this Conference: The Faculty of Mechanical Engineering, University of Belgrade, Serbia; The Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Serbia; and Institute for Information Technologies, University of Kragujevac, Serbia.

We hope that this conference will be success beginning of a recognized series of international conference events during next decades. We use the opportunity to wish to all participants a successful presentation of their scientific results.

Cordially,

Ivana Atanasovska, Conference Chair
Milan Cajić, Conference Vice-Chair
Danilo Karličić, Conference Vice-Chair

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SPECIAL SESSION 1

PLENARY LECTURES

MODELING OF STRUCTIONAL MATERIALS

H. Altenbach[1]

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Keywords: Material modeling, Continuum mechanics, Rheology, Thin-walled structures.

ABSTRACT

Material modeling is big challenge in engineering. There are different concepts for which there are numerous applications in practice. Three fundamentally different concepts are currently being used [1]:

- the deductive concept (top-down principle),
- the inductive concept (bottom-down modeling), and
- the method of rheological modeling.

Within this paper the details of each approach will be discussed and the advantages and disadvantages are presented. It is obvious that the first approach is close to continuum mechanics. On the highest level the thermodynamical consistency will be shown. That means all special case which are included are also consistent. in the second case, it must be verified again at each extension level that the thermodynamic consistency is given. The third way is a compromise. Simple rheological models are established. The thermodynamic consistency is checked. The combination of simple models defined in this way can be used to reproduce complex material behavior with the help of rheological circuits [2].

The last method will be discussed in the context of classical and avanced material models. Some advanced models will be presented [3].

REFERENCES

[1] Altenbach, H. (2018), Kontinuumsmechanik, Springer, 4th edition, 2018.

[2] Altenbach and J. Eisentrager. Rheological modeling in solid mechanics from the beginning¨ up to now. Lecture Notes of TICMI, 22:13-29, 2021.

[3] Altenbachh. and Eisentrager. Introduction to creep mechanics. In H. Altenbach and A. Ochsner, editors, Encyclopedia of Continuum Mechanics, pages 1337-1344. Springer Berlin¨ Heidelberg, Berlin, Heidelberg, 2020.

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FURTHER RESULTS ON ADVANCED CONTROL AND STABILITY ISSUES OF FRACTIONAL-ORDER DYNAMICAL SYSTEMS

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Keywords: robot control, stability, fractional order, neutral time delay, iterative learning control

ABSTRACT

Recently, fractional calculus has attracted the increased attention of scientific society where fractional operators are often used for complex dynamical systems,[1]. Iterative learning control (ILC) is one of the recent topics in control theories and it is a powerful intelligent control concept that iteratively improves the behavior of processes that are repetitive in nature. Here, we present recently obtained results as well as new results on open-closed loop type ILC, [3-5] for a given class of integer order and fractional order regular systems. We discuss $PIDD^2$/ PID, PD^2D^{α},PD^{α}/PD types ILC, particularly ILC schemes with D type which is more flexible for practical implementation. Sufficient conditions for the convergence in the time domain of the proposed ILC for a class of fractional and integer order systems are given by the corresponding theorems together with its proof. Finally, the simulation results, including an application to the suitable robot system and Neuro-Arm robot, are presented to illustrate the performance of the proposed ILC schemes.

Also, some attention will be devoted to the finite-time stability/stabilization problem of fractional-order (uncertain) neutral time-delay systems. By use of the generalized Gronwall inequality and its extended form, new sufficient conditions for finite-time stability of such systems are obtained. Finally, numerical examples are given to illustrate the effectiveness and applicability of the proposed theoretical results.

Acknowledgment

The author gratefully acknowledges the support of the Ministry of Education, Science and Technological Development of the Republic of Serbia under the contract 451-03-68/2022-14/200105

REFERENCES

[1] Lazarević,M.(2014)“Advanced Topics on Applications of Fractional Calculus on Control Problems,System Stability And Modeling”, *Sci. Int. Mon.,WSEAS*, ID9028,ISBN:978-960-474-348-3 pp.202.

[2] Čović , V., Lazarević, M. (2009), “Robot Mechanics”, *Belgrade,Serbia: Faculty of Mechanical Engineering*, (in Serbian).

[3] Lazarević,P.M.,Mandić D. P., S.Ostojić , (2020), “Further results on advanced robust iterative learning control and modeling of robotic systems”, *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science,* November 3, https://doi.org/10.1177/0954406220965996, p.1-16.

[4] Cvetković B., Lazarević, M., Mandić P., T. Šekara, P. Lino,(2021),”Open closed-loop type ILC control of neuroarm robotic system PDα/ PD”, *8th Int. Cong.of Serbian Society of Mech. Kragujevac,* ISBN 978-86-909973-8-1, Serbia, June 28-30,

[5] Cvetković B., Lazarević P. M., (2021), "Fractional-Order Iterative Learning Control for Robotic Arm-PD2Dα Type", *Filomat* 35:1 (2021), 1–10 https://doi.org/10.2298/FIL2101001C
[6] Lazarević M., D. Radojević,Stj. Pišl, G. Maione, (2020),"Robust finite-time stability of uncertain neutral nonhomogeneous fractional-order systems with time-varying delays", Dec.2020,*Theoretical and Applied Mechanics* (TAM), Vol. 47 (2020) Issue 2, 241–255 DOI: https://doi.org/10.2298/TAM201203016L

MODELLING OF COMPOSITE STRUCTURES: USING BUCKLING FOR MORE FLEXIBLE AND SUSTAINABLE AIRCRAFT

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Keywords: Aerospace Composite Structures, Finite Element Modeling.

ABSTRACT

For next generation of more flexible and sustainable aircraft, a paradigm shift in the design of aircraft structures can be explored, considering buckling no longer as a phenomenon to be avoided, but as a design opportunity.

The first part of the lecture will present the analysis of thermoplastic composite stiffened panels designed to sustain loads in the post-buckling range. They contain an initial damage, so to investigate the damage tolerance in the presence of large non-linearity. Finite element analysis using the virtual crack closure technique are conducted before the tests to predict the structural behavior. The panels show an initial buckling shape, with damage propagation starting shortly after buckling. A combination of relatively stable and unstable damage propagation is observed until final failure. The numerical prediction is compared to test results and shows great agreement for both the buckling and failure behavior.

The second part of the lecture will present a study aims to design novel tailorable and effective mechanisms by controlling buckling behavior in structural elements of a composite wing for future morphing application. The idea is to embrace this built-in instability by using the nonlinear post-buckling response to control stiffness changes which redistribute the load in the wing structure. Numerical studies of buckling-driven mechanisms are at first conducted on a composite plate and later integrated to control twisting of a simplified thin-walled composite wing box, offering effective design opportunities of multi-stable configurations for more flexible and sustainable aircraft.

REFERENCES

[1] Van Dooren K.S., Labans E., Tijs B.H.A.H., Waleson J.E.A. and Bisagni C. (2019), “Analysis and testing of a thermoplastic composite stiffened panel under compression”, Proceedings of 22nd International Conference on Composite Materials (ICCM22), Melbourne, Australia, August 11-16, 2019, paper number 5108-2.

[2] Zhang J. and Bisagni C. (2021), “Buckling-driven mechanisms for twisting control in adaptive composite wings”, *Aerospace Science and Technology*, 118(2021)107006.

UNCERTANITY QUANTIFICATION IN STRUCTUREAL DYNAMICS

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Keywords: Uncertainty Quantification, Polynomial-Chaos, Reduced-Order Galerkin Projection

ABSTRACT

Propagation of uncertainties in complex engineering dynamical systems is receiving increasing attention. When uncertainties are taken into account, the equations of motion of discretised dynamical systems can be expressed by coupled ordinary differential equations with stochastic coefficients. The computational cost for the solution of such a system depends on the number of degrees of freedom and the number of random variables. Among various numerical methods developed for such systems, the polynomial-chaos-based Galerkin projection approach shows significant promise because it is more accurate than the classical perturbation-based methods and computationally more efficient than the Monte Carlo simulation-based methods. However, the computational cost increases significantly with the number of random variables, and the results tend to become less accurate for a longer length of time. In this talk, new approaches will be discussed to address these issues. Reduced-order Galerkin projection schemes in the frequency domain will be discussed to address the problem of a large number of random variables. Practical examples will be given to illustrate the application of the proposed Galerkin projection techniques.

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ON THE GENERALITY OF SMEARED FINITE ELEMENT APPROACH TO MODEL FIELD PROBLEMS AND MECHANICS IN BIOLOGICAL TISSUE

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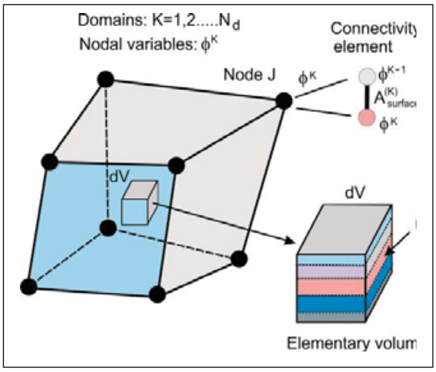
Keywords: Composite Smeared Finite Element, Field Problems, Kojic Transport Model, Biomechanics, Tissue

ABSTRACT

Computational modeling of biological processes and biomechanics remains a challenge due to their extreme complexity. In order to have models applicable in experimental and clinical research, and in medical practice, the generality and robustness of the models are desirable features. Here, we outline the methodology formulated by the author in last several years and summarized in reference [1] (as Kojic Transport Model –KTM) based on a composite smeared finite element (CSFE) shown in Fig.1. The generality of the CSFE relies on the three original fundamental concepts: transport within 1D systems (capillaries, neural fibers) is transformed into a 3D form by the transport tensors, domains within the element participate according to the volumetric fractions, and the domains are coupled by the connectivity elements representing biological barriers. Following the same concept, a multiscale CSFEM finite element is formulated for mechanics of tissue as composite medium.



The multiscale KTM has been applied to gradient driven problems, such as diffusion, biofluid flow through capillaries and tissue or electrical conduction, while the CSFEM has been employed for tumor growth problems. This methodology has been built by the author into the FE code PAK-BIO, with the participation of his collaborators in Serbia and USA; and supported by the interface CAD developed by researchers of the BIOIRC. The focus of this presentation is on the generality of the smeared concept, illustrated by a number of examples.

REFERENCES

[1] Kojic, M., Milosevic M., Ziemys, A. (2022), "Computational Models in Biomedical Engineering – Finite Element Models Based on Smeared Physical Fields: Theory, Solutions, and Software, Elsevier, in press.

MATHEMATICAL MODELS OF PURELY NONLINEAR OSCILLATORS: FROM SOLUTIONS TO PHENOMENA

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Keywords: Purely Nonlinear Oscillators, Special Functions. Exact Solutions, Approximate Solutions, Nonlinear Phenomena.

ABSTRACT

This lecture is concerned with purely nonlinear oscillators, whose restoring force is of a singleterm power-form, the power of which can be any non-negative real number. This involves: a quasiconstant restoring force, which corresponds to the case when this power is zero [1, 2], then the restoring force whose power is a fraction smaller or higher than unity [3, 4], as well as a pure cubic restoring force [5]. An overview of a variety of special functions that one can use to define the solutions for a regular response of such oscillators is given. This includes wave functions, Lyapunov's functions, Rosenberg's Ateb functions and Jacobi elliptic functions [6]. It is then demonstrated how some of these solutions can be utilized to get insight into phenomena arising in purely nonlinear oscillators with different types of arrangements or excitations [6], such as bifurcations, entrainment, local and global chaos, etc.

REFERENCES

[1] Kovacic, I. (2021), On the use of Jacobi elliptic functions for modelling the response of antisymmetric oscillators with a constant restoring force, *Communications in Nonlinear Science and Numerical Simulation*, Vol. 93, Art. No. 105504.

[2] Kovacic, I. (2016), On the response of antisymmetric constant force oscillators: exact and approximate solutions, *Communications in Nonlinear Science and Numerical Simulation*, Vol, 32, pp. 305-316.

[3] Kovacic, I. (2021), The method of multiple scales for forced oscillators with some real-power nonlinearities in the stiffness and damping force, *Chaos, Solitons and Fractals*, Vol. 44, pp. 891-901.

[4] Kovacic, I. (2011), Forced vibrations of oscillators with a purely nonlinear power-form restoring force, *Journal of Sound and Vibration*, Vol. 330, pp. 4313-4327.

[5] Kovacic, I., Cveticanin, L., Zukovic, M., Rakaric, Z. (2016), Jacobi elliptic functions: a review of nonlinear oscillatory application problems, *Journal of Sound and Vibration*, Vol. 380, pp. 136.

[6] Kovacic, I. (2020), *Nonlinear Oscillations: Exact Solutions and their Approximations*, Springer.

FEM-BASED REAL-TIME SIMULATIONS – VIRTUAL REALITY AT ITS BEST

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ABSTRACT

Over the previous several decades, the finite element method (FEM) has imposed itself to structural analysts and engineers as the most powerful, highly efficient and quite versatile numerical method. It is very well established, and the procedures of development and application are well understood. Typical applications are the so-called off-line applications, characterized by a substantial time that separates the process of setting up the FE model loads and observation of the resulting deformation. On the other hand, many novel but also some existing fields of application call for real-time FEM computations. Such computations offer a whole new virtual world to the engineers and other interested users. An interaction with virtual objects allows to test different scenarios, for instance in optimizing structural behavior, assembling structures, education, surgery, to name but a few of numerous fields of applications. Herewith we summarize some already existing and originally developed formalisms that aim at real-time or nearly real-time computations based on the FEM. The formalisms range from strongly simplified models such as mass-spring systems, via reduced models like those based on modal superposition, up to full range FE models that cover nonlinear effects. A coupled-mesh technique is also addressed as a promising solution for managing interactive simulation of objects with complex geometries using FE models based on relatively rough meshes. Originally developed software enabling interactive real-time simulation on conventional hardware components is used to demonstrate the development in different fields of application.

INVITED LECTURES

SERPENTINE MOTION IN ROBOTICS: WIND CAR, TRIMARAN, SNAKEBOT.

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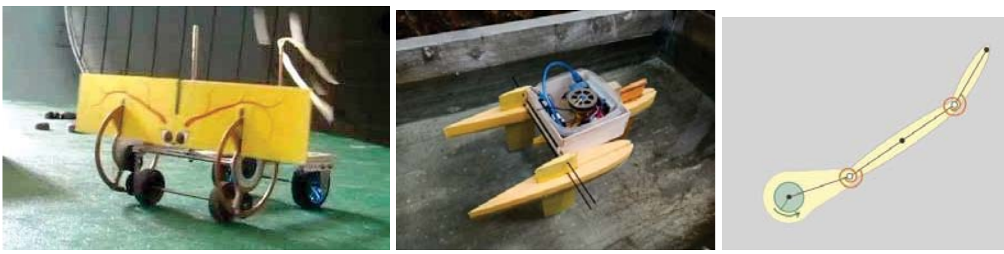
Keywords: Robotics, Periodic motion, Aerodynamic force, Friction.

ABSTRACT

One of the most common problems of robotics is organizing motion of an object towards a prescribed direction. However, certain restrictions may prevent progressive motion along a given line. In some cases, serpentine motion might be a promising way to solve the problem. In this talk, we consider several examples of such situations.

Suppose that a sailboat needs to move upwind. Then it should tack, i.e., perform a kind of serpentine motion. This fact encourages one to propose one more wind-powered mechanism capable of upwind motion: consider a wind-powered car equipped with a sail that can perform motion similar to tacking. The corresponding prototype is constructed and tested in the wind tunnel (Fig. 1*a*), and proved to be able to move upwind.



a *b* *c*

Fig. 1. Examples discussed in the work

Another example is a trimaran robot that is controlled by a single internal flywheel. Rotation of the flywheel causes oscillations of the body of the robot. In the result, a trust force is produced due to the interaction between floats and water. This force ensures propulsion of the body along a serpentine trajectory. The prototype of the trimaran is constructed and tested (Fig. 1*b*).

Finally, a three-linked snake robot is designed that is controlled by a single internal flywheel (Fig. 1*c*). Spiral springs are installed in joints of the robot. Each link contacts with a supporting surface in a single point. Anisotropic dry friction is applied at these points of support. Oscillations of the inner flywheel provide wave-like motions of the body, and the robot performs serpentine motion in the prescribed direction.

The work is partially supported by Russian Science Foundation (project No. 22-21-00303, 22-29-00472).

ALGEBRAIC MESH GENERATION IN SPUR GEAR DRIVES

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Keywords: Gear drives, Mesh generation, Finite element analysis.

ABSTRACT

The determination of the maximum contact and bending stresses is an important step in the calculation of the load carrying capacity of a gear drive. Traditionally, these stresses were determined using analytical methods but, as the strength demands of the gear drives increased, more comprehensive methods were required to determine the stress field over the gears. For such a purpose gear designers started to rely on the finite element analysis, which requires the discretization of the gear geometries into finite elements. In this line, several gear meshing strategies have aroused during the last decades, being the most relevant that one developed by Argyris [1] (see Fig. 1a).

Argyris meshing strategy has the advantage of being fast and easy to implement but it has two important limitations. On the one hand, it does not allow to perform local mesh refinement, which is negative from the point of view of the computational efficiency of the mesh. On the other hand, it tends to produce distorted elements in parts of the gear tooth that usually are exposed to elevated stresses, which can lead to numerical errors and inaccurate results.

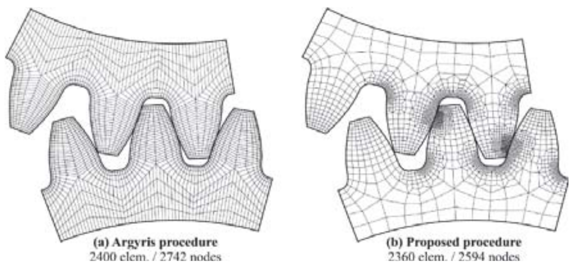

Figure 1: Two different meshing procedures for gear drives

In this work a new meshing procedure to perform the automated generation of quadrilateral meshes over gear tooth sections was developed. This meshing procedure is fast and easy to implement, and it allows to perform local mesh refinement and minimizes the appearance of distorted elements in the mesh. An example of the mesh obtained using this procedure is shown in Fig. 1b.

REFERENCES

[1] Argyris J. *et al* (2002), “Computerized integrated approach for design and stress analysis of spiral bevel gears,” Comput. Methods Appl. Mech. Eng., 191 (11–12) , pp.1057-10957

ENERGY BALANCE FOR FRACTIONAL WAVE EQUATIONS

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Keywords: Fractional wave equation, Hereditary and non-local fractional constitutive equations, Energy dissipation and conservation.

ABSTRACT

The method of a priori energy estimates is used in order to establish the energy balance properties of the fractional wave equations. More precisely, energy dissipation properties are established for the class of hereditary fractional wave equations, while energy conservation properties are established for the non-local fractional wave equations, with the reinterpreted notion of the potential energy. Fractional wave equations are obtained from the system of partial differential equations consisting of the equation of motion of the one-dimensional deformable body, strain, and fractional-order constitutive model by reducing the system of equations to a single equation expressed in terms of displacement. The hereditary kernel, appearing in the fractional wave equation is expressed either through the relaxation modulus or through the creep compliance, while the non-local kernel is proved to be model dependent.

The fractional-order models of viscoelastic body include classes of thermodynamically consistent linear fractional models having the differentiation orders not exceeding the first order, distributed-order model, as well as the thermodynamically consistent fractional Burgers models, having the orders of fractional differentiation up to the second order. Hooke- and Eringen-type non-local constitutive models of fractional order are used in formulation of non-local fractional wave equations.

The above mentioned results are published in [1].

REFERENCES

[1] Zorica, D. and Oparnica, Lj. (2020), “Energy dissipation for hereditary and energy conservation for non-local fractional wave equations,” Philosophical Transactions of the Royal Society A, 378:20190295–1–24.

SYNTESIS FRAMEWORK FOR NEW BREED OF ROBOTS. SOFT LOCOMOTION ROBOTS

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Keywords: Soft Robotics, Robot Locomotion, Optimal Design, Software-Based Synthesis

ABSTRACT

Recent investigations into how soft materials can be utilized to develop simple yet highly functional autonomous systems, lead to birth of a new research filed called soft robotics. Different concepts of soft robots have been introduced over time, like continuous robots in form of manipulators (pick and place tasks or inspection), robotic grippers for object manipulation, for realizing terrestrial locomotion (exploration/inspection) like walking, crawling, running/galloping, jumping, multimodal locomotion gaits, or swimming and soft robots for underwater exploration. Soft robots offer many benefits over traditional ones: safe human robot interaction, more degrees of freedom in compact design, maneuvers and motions that are difficult to achieve with classical robotic systems, easy and low cost to realize. But the synthesis of various types of soft robotics systems have mostly relied on designer intuition and experience. This constrains the possibility to explore vast design space, often leading to soft robotics solution with limiting performance and capabilities. The general tool how to optimally design soft robotic systems through automatic algorithmic is lacking. Herewith we present a synthesis framework for automated optimal design of soft robots, focusing on the example of locomotion robot development. We demonstrate how the software-based synthesis can lead to various optimal design of soft locomotion robots that outperform the state-of-the-art robotic systems. Furthermore, we show how the similar synthesis approach can be utilized for development of a new MEMS based micro-robots. Capabilities of the realized robot properties in real world environment are presented to validate the developed software tool and overcome the reality gap. The introduced method and synthesis framework allow to design a wide variety of soft locomotion robots for different desired applications.

GENERAL SESSIONS

COMPUTATIONAL FRACTURE MECHANICS

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Keywords: Computational Mechanics, Fracture Mechanics, Finite Element Method

ABSTRACT

An overview of computational fracture mechanics is presented, focused on application of the Finite Element Method (FEM). Some specific aspects of numerical simulation are presented including complex geometries, material nonlinearity, and heterogeneity, and especially if crack growth is considered. Micromechanical modelling of elastic-plastic crack growth is presented as new and promising approach to overcome some of the shortages of traditional approach. Fatigue crack growth, using the empirical laws for crack growth rates is also presented, using results obtained by the extended FEM.

As an example of FEM application in micromechanical modelling of crack growth in a welded joint, Figure 1 shows von Mises stress distribution in fine grain heat affected zone (FGHAZ).

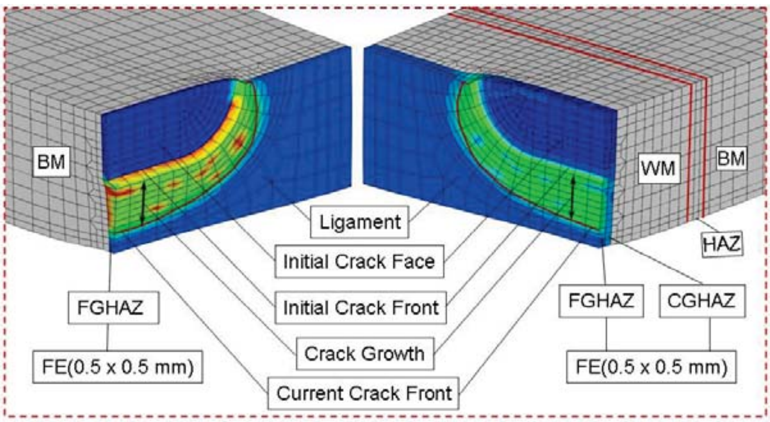

Figure 1. Distribution of void volume fraction, indicating crack growth in FGHAZ

REFERENCES

[1] Sedmak A. Computational fracture mechanics: An overview from early efforts to recent achievements. Fatigue Fract Eng Mater Struct. 2018; 41:2438–2474.
https://doi.org/10.1111/ffe.12912

AGING OF SOLAR CELLS UNDER OPERATING CONDITIONS

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Keywords: Solar energy, Photovoltaic, Aging, Conventional energy, Exponent of life span

ABSTRACT

Disproportionate prices of electricity obtained from solar energy sources and conventional energy sources is the best indicator that the energy consumed in the production of solar (photovoltaic) cells (per kW) is significantly higher than the corresponding energy consumed in conventional energy sources (per kW). This fact is the essential part of the question of whether solar energy (and the same goes for wind energy) will ever become cost-effective compared to conventional energy sources. Namely, it is logical that the energy price increase from conventional energy sources will proportionally lead to an increase in the price of energy from solar cells (this proportionality can be partially mitigated by improving the technological process of making solar panels). From this perspective, the issue of aging of photovoltaic cells is especially interesting. Namely, if it turns out that the aging of solar cells is so fast that they fail to return the energy invested in their production, they would become, objectively, uninteresting from the aspect of the energy system (which, allegedly, would not eliminate them from use in special circumstances). Thus, their mobility and environmental acceptability come to the fore. In this paper, the exponent of life span approach is applied to the estimation of the aging rate of solar cells in laboratory conditions.

REFERENCES

[1] Nanaki,Evanthia, A., Xydis,G. (2010), "Exergetic Aspects of Renewable Energy Systems : Insights to Transportation and Energy Sector for Intelligent Communities", *Engineering & Technology, Environment & Agriculture, Journals Taylor &Francis Online,* Pub. location: Boca Raton, eBook Published: 31 July 2019, pp 4-31.

[2] Greco, G., Giannazzo, F., Roccaforte, F.(2017), „Temperature dependent forward current-voltage characteristics of Ni/Au Schottky contacts on AlGaN/GaN heterostructures described by a two diodes model", *Journal of Applied Physics, American Institute of Physics (AIP),*Volume 121, Issue 4, 045701.

[3] Werner, S., Lohmuler, E., Wolf, A., Clement, F., Extending the limits of screen-printed metallization of phosphorus- and boron-doped surfaces, Solar *Energy Materials and Solar Cells, Volume 158, Part 1, December 2016*, pp.37-42.

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OPTIMIZATION OF ENGINEERING DESIGN PROBLEMS USING HONEY BADGER ALGORITHM

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Keywords: Optimization, Engineering, Honey Badger

ABSTRACT

In design of mechanical elements, designers usually consider certain objectives that are related with cost, time, quality and reliability of product depending on the requirements. In this paper, parametric optimization of disk brake design problem, pressure vessel design problem, 3D beam and cantilever beam design problem has been carried out using Honey Badger Algorithm (HBA for short). The results obtained using HBA are compared with the results reported by other researchers.

INTRODUCTION

Honey Badger Algorithm (HBA for short) is a population-type (p-type) metaheuristic algorithm, which draws inspiration from the animal of the same name [1] . Honey badger (figure 1) is a dog-like animal living in semi-deserts and rainforests of Africa and Southwest Asia. It prefers a solitary type of living in holes which digs, and the main ingredient of its diet is honey. This species is fond of honey, but has trouble locating it. For this reason, honey badges cooperate with a species of birds, called honey-guides, in order to locate honey, dig it out, and share it with honey guides.

Fig.1. Honey Badger

In this paper, the Honey Badger Algorithm is used to solve the following engineering problems. The first problem to be solved is disk brake optimization, having the goal of minimizing the brake mass and the stopping time in the design of a multiple-disk brake. The second problem is pressure vessel optimization. The goal of this problem is to minimize material, welding and shaping costs. The third engineering problem is cantilever beam optmization, where minimal weight that fulfills the constraints is sought after. The last problem consists of minimizing cross-section heights of all elements of a 3D beam.

RESULT AND CONCLUSIONS

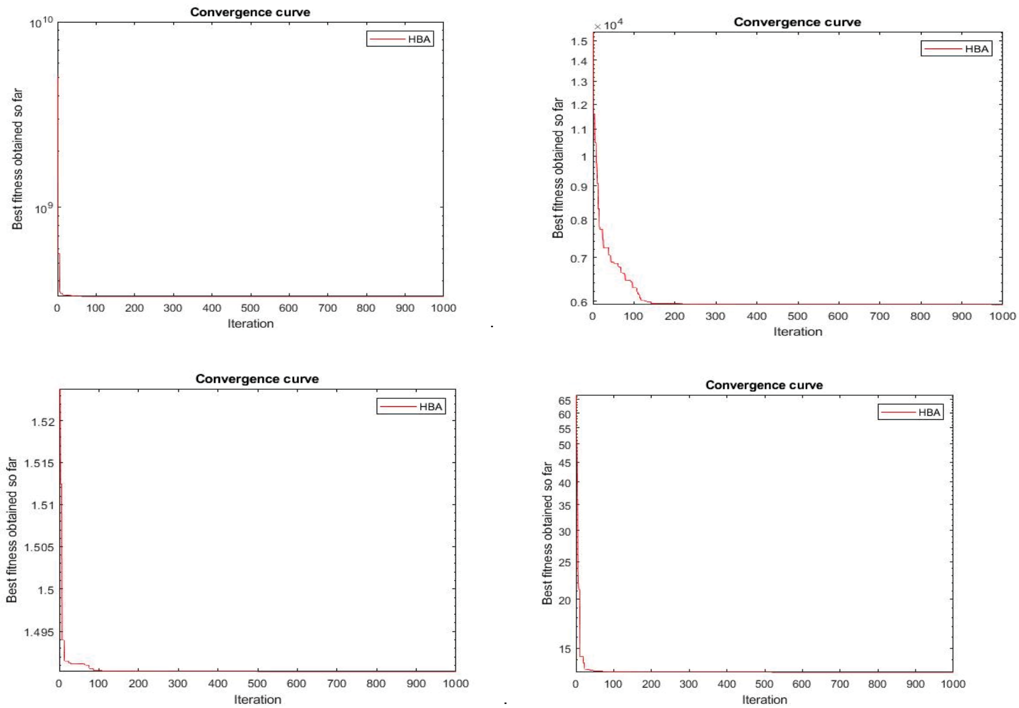

Fig.2. Convergence rates of HBA algorithm respectively for finding the best possible fitness of disk brake, pressure vessel, 3D beam and cantilever beam design problem

In this paper, HBA algorithm was used to optimize engineering problems with constant number of variables. For this algorithm, 30 search agents and 1000 iterations were chosen as input parameters. During the course of the research, it has been noted that increasing search agent and iteration count did not yield better solutions. Therefore, this combination of input parameters was chosen, since it gives minimal execution time. Applying HBA algorithm, we obtained optimal or near-optimal results. By further development of this algorithm, this method can be modified and improved in order to obtain better results.

REFERENCES

[1] Hashim, Fatma A., Essam H. Houssein, Kashif Hussain, Mai S. Mabrouk, Walid Al-Atabany. "Honey Badger Algorithm: New Metaheuristic Algorithm for Solving Optimization Problems." Mathematics and Computers in Simulation, 2021.

EXTREMAL THRUST FOR BRACHISTOCHRONE PROBLEM

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Keywords: Singular Arc, Thrust Control, Brachistochrone Problem, Non-linear Drag.

ABSTRACT

The motion of a point mass in a vertical plane under the action of gravity force, non-linear drag force, support reaction of the curve and the thrust is considered. The slope angle and the thrust are considered as control variables. The amount of the propellant is given. The modified Brachistochrone problem formulated as follows: find a curve connecting two points in the vertical plane along which a material point in the field of gravity and non-conservative force and the thrust moves from the initial to the final point in the shortest time [1]. For the case of frictionless motion, it is shown that optimal thrust control is bang-bang-type, and trajectory consists of two arcs, starting with maximum thrust, and ending with zero thrust. Optimal synthesis in the three dimensional space “mass-velocity-slope angle” is designed. For the case of non-linear drag force the extremal trajectory could include the arc with singular thrust. The domain in the plane slope angle – velocity, where it is possible to design the optimal synthesis is determined. It is shown that optimal thrust program consists of either two arcs, maximum thrust at the beginning and zero thrust at the end, or three arcs: maximum thrust at the beginning, then intermediate (singular) thrust and zero thrust at the end. The control logic of the thrust is similar to the Goddard problem [2]. The results of numerical simulation for the case of linear viscous friction illustrating the theoretical conclusions are presented.

REFERENCES

[1] Vratanar, B., Saje, M. (1998), “On the Analytical Solution of the Brachistochrone Problem in a Non-conservative Field,” *Int. J. Non-Linear Mechanics* 33(3) pp. 489-505
[2] Menon, P.K.A., Kelley, H.J., and Cliff, E.M. (1985) “Optimal Symmetric Flight with an Intermediate Vehicle Model,” *J. Guidance* 8,(3) pp. 312-319

COMPUTATIONAL MODELING OF AIR FLOW IN THE COOLING TOWER

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Keywords: Wet cooling tower, Forced draft, Numerical modeling, CFF.

ABSTRACT

Forced-draft cooling towers are commonly encountered in industry as equipment for removing heat from water as working medium and discharging it to the environmental air. Modern thermal powerplant represent a common example where heat is removed from water by means of direct-contact vaporization water and air in counterflow. The efficiency of such wet cooling towers is enhanced with increasing the surface of the interfacial contact between water and air, which requires a desirably uniform distribution of both fluids. The intensive heat and mass transfer takes place in counterflow mostly in cooling tower packings. While, the distribution of cooling water falling down across horizontal cross-sections in cooling towers is commonly uniform enough, the distribution of air flow generated by the fan depends on the inlet conditions and the geometry of the cooling tower. In the present contribution the turbulent air flow in a cooling tower of a powerplant is determined by means of numerical simulations. The cooling tower packing is treated as porous medium and the air flow within is modeled by relating the mean flow velocity and the generated pressure drop in the mean flow direction. Real geometry and inlet conditions are taken from the existing measured data and the computational results are validated by the existing pressure drop measurements in the cooling tower. Due to the huge geometry of the cooling tower and to avoid high computational costs the computations are performed as two-dimensional. Turbulence is modeled with the standard k-ε model and the numerical method used is Computational Fluid Dynamics (CFD) with cell-center based finite volume implemented in the software OpenFOAM®. Results of the numerical simulation provide detailed insight into the air flow field within the cooling tower. The numerical results reveal a non-uniform recirculating zone in the air flow in the cooling tower beneath the cooling tower packing, preventing an amount of air to flow uniformly upwards, which is a consequence of the improper inlet conditions of the air. Such unfavorable behavior of the air affects the efficiency of the tower cooling and should be avoided. In order to prevent the zone of recirculation of air and to promote a more uniform distribution of air flow, additional computations were performed by using modified inlet conditions by routing air into the tower at an angle, which simulates flow routing devices at the inlets. In such a scenario the numerical results show a more uniform distribution of air in the cooling tower, which is attributed to a better cooling tower efficiency. Flow routing devices are recommended to achieve a desirable air flow in the cooling tower, whereby the exact optimum angle of the air flow at the inlet may be determined by means of additional numerical simulations.

INHIBITORY POTENCY OF USNIC ACID TOWARD PHOSPHODIESTERASE TYPE 5

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Keywords: Usnic acid, Molecular docking simulations, Phosphodiesterase type 5.

ABSTRACT

Pulmonary arterial hypertension (PAH) is a relatively uncommon condition with a significant fatality rate. It's a chronic condition marked by unusually high blood pressure in the pulmonary artery, which delivers blood from the heart to the lungs, eventually leading to heart failure and death[1]. Several effective medications, notably cyclic nucleotidephosphodiesterase-5 (PDE5) inhibitors, have been approved for the treatment of these disorders. For the treatment of PAH, the FDA has approved sildenafil and tadalafil as PDE5 inhibitors responsible for precisely cleaving cyclic guanosine monophosphate (cGMP). One more inhibitor of PDE5 that has been authorized in clinical trials is udenafil [2]. Usnic acid is a natural compound with a variety of pharmacological activities, including anti-inflammatory, antimicrobial, antiviral, antioxidant, and anticancer activities. This compound was submitted to a SwissTargetPrediction analysis, which revealed that usnic acid has the ability to inhibit PDE5. Usnic acid, as well as three, mentioned FDA approved PDE5 inhibitors were put through molecular docking simulations against PDE5A. The three-dimensional crystal structure of PDE5A was downloaded from the Protein Data Bank (PDB ID: 6IWI). The molecular docking simulations were performed with sindenafil, tadalafil, udenafil, and usnic acid. The AutoDock 4.0 program was used to complete the molecular docking simulation. The calculated values of free energy of binding (ΔG_{bind}= -7.25kcal/mol) and inhibition constant (K_i = 4.89μM) of usnic acid are between obtained values for sindenafil and tadalafil (ΔG_{bind}= -9. 96 kcal/mol and K_i = 49.70 mM) and udenafil (ΔG_{bind}= -2.65 kcal/mol and K_i = 11.44 mM). Interestingly, the same values of ΔG_{bind} and K_i are obtained in molecular docking simulations with sindenafil and tadalafil. The achieved results indicate that usnic acid can be subjected to further examination as a potential inhibitor of PDE5A.

REFERENCES

[1] Wilkins, M.R., Aman, J., Harbaum, L., Ulrich, A., Wharton, J., Rhodes, C.J. (2018), "Recent advances in pulmonary arterial hypertension," *F1000Research*, pp. 7.

[2] Ahmed, W.S., Geethakumari, A.M. and Biswas, K.H. (2021), "Phosphodiesterase 5 (PDE5): Structure-function regulation and therapeutic applications of inhibitors," Biomedicine & Pharmacotherapy, 134, pp. 1111

TOWARDS NOVEL COMPUTATIONAL ROBUST GEAR TCA SOLUTION WITH PARAMETRIC STUDY OF MISALIGNMENTS AND PROFILE MODIFICATION

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Keywords: Non-linear equations, Surface contact problem, Novel convergent method, Crowning, Misalignment.

ABSTRACT

In this work the quasi-static model of non-conjugate the three-dimensional geometrical contact problem for two C^1 surfaces have been studied. The set of contact equations is formulated by using a new parameterisation that enables to reduce the conventional system of five non-linear equations with five unknowns to a system of only two equations with two unknowns. The novel model is computationally efficient and demonstrates increased accuracy and stability of the numerical solution, compared to the traditional model described by Litvin, which suffers from convergence problems and requires a high computational effort. The new model is developed for crowned spur gear tooth surfaces to parametrically estimate the sensitivity for various misalignments on the contact pressure, transmission error and path of contact. Three types of crowning modification functions are defined and compared for out-of-plane misalignments.

REFERENCES

[1] Litvin, F., & Fuentes, A. (2011). *Gear geometry and applied theory*. New York: Cambridge University Press.
[2] Bracci, A., Gabiccini, M., Artoni, A., & Guiggiani, M. (2009). Geometric contact pattern estimation for gear drives. *Computer Methods in Applied Mechanics and Engineering*, *198*(17), 1563–1571.
[3] Lin, C.-H., & Fong, Z.-H. (2015). Numerical tooth contact analysis of a bevel gear set by using measured tooth geometry data. *Mechanism and Machine Theory*, *84*, 1–24.

[4] Spitas, C., & Spitas, V. (2011). Fast unconditionally stable 2-D analysis of non-conjugate gear contacts using an explicit formulation of the meshing equations. *Mechanism and Machine Theory*, *46*(7), 869–879.
[5] Kumar, P., Hirani, H., & Kumar Agrawal, A. (2019). Effect of gear misalignment on contact area: Theoretical and experimental studies. *Measurement*, *132*, 359–368.
[6] Gurumani, R., & Shanmugam, S. (2011). Modeling and contact analysis of crowned spur gear teeth. *Engineering Mechanics*, *18*(1), 65-78.
[7] Bergseth, E., & Björklund, S. (2010). Logarithmical Crowning for Spur Gears. *Strojniski Vestnik/Journal of Mechanical Engineering*, *56*.
[8] Litvin, F., Sheveleva, G., Vecchiato, D., Gonzalez-Perez, I., & Fuentes, A. (2005). Modified approach for tooth contact analysis of gear drives and automatic determination of guess values. *Computer Methods In Applied Mechanics And Engineering*, *194*(27), 2927-2946.
[9] Litvin, F., Vecchiato, D., Fuentes, A., & Gonzalez-Perez, I. (2004). Automatic determination of guess values for simulation of meshing of gear drives. *Computer Methods In Applied Mechanics And Engineering*, *193*(33-35), 3745-3758

DELAY DIFFERENTIAL EQUATIONS GOVERNING DYNAMICS OF A LANDSLIDE MECHANICAL MODEL

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Keywords: time delay, friction, landslide

ABSTRACT

In present paper we analyze dynamics of a mechanical model of accumulation landslide, initially proposed by Davis [1] using standard bifurcation analysis:

$$m_1\dot{V}_1 = W_1 sin\beta_1 - S_1 - F$$
$$m_2\dot{V}_2 = W_2 sin\beta_2 - S_2 + F$$
$$\dot{F} = k(V_1 - V_2) + c(\dot{V}_1 - \dot{V}_2) \qquad (1)$$

where W - block weight; g - acceleration of gravity; S - sliding resistance on failure surface,; F - combined elastic and viscous forces; k - spring constant; c - dash pot constant; and β_i = slope angle. In our analysis, starting model (1) is expanded by introducing the effect of time delay between the motion of accumulation and feeder slope, and the heterogeneous friction conditions along the potential sliding surface (Coulomb-like and cubic friction force):

$$\frac{dU_1(t)}{dt} = V_1(t)$$
$$\frac{dV_1(t)}{dt} = \frac{1}{m}\left[k\big(U_2(t-\tau) - U_1(t)\big) - \left[1-\alpha+\sqrt{N(V_0+V_1)}\right]\frac{(V_0+V_1)}{\sqrt{\varepsilon+(V_0+V_1)^2}} + \left[1-\alpha+\sqrt{N(V_0)}\right]\frac{V_0}{\sqrt{\varepsilon+V_0^2}}\right] \qquad (2)$$
$$\frac{dU_2(t)}{dt} = V_2(t)$$
$$\frac{dV_2(t)}{dt} = \frac{1}{m}\left[k\big(U_1(t-\tau) - U_2(t)\big) - [a(V_0+V_2)^3 - b(V_0+V_2)^2 + c(V_0+V_2)] + a(V_0)^3 - b(V_0)^2 + cV_0\right]$$

where $N(V) = \varepsilon = 4max(|V|-p,0)^2 + \alpha^2 max(p-|V|,0)^2$, and α and ε are friction parameters (Coulomb like friction force), a, b and c are friction parameters (cubic friction force). Results obtained indicate the occurence of irregular aperiodic behavior with the increased values of parameter a and time delay τ, providing the conditions for which the slope instability is triggered. Further increase of parameter a leads to stabilization of sliding, while the increase of parametrs b and c leads to occurrence of periodic oscillatory regime. Similar effect is observed for the action of parameters ε and α.

REFERENCES

[1] Davis, R.O. **(**1992**)**, Modelling stability and surging in accumulation slides. *Engineering Geology*, 33, 1-9

PARALLEL COMPUTATIONS IN FLUID DYNAMICS USING MULTICORE/MANYCORE PROCESSORS

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Keywords: CFD, CUDA, OpenACC, multicore, manycore.

ABSTRACT

Recent development and increase in performance of graphical processing units, together with their low power consumption and cost, made them an interesting option for scientific computing, especially in areas where it is possible to achieve massive parallelism. Most solvers used in CFD are usually based on Gauss-Seidel or similar method, highly recursive by its nature, such as the tridiagonal matrix algorithm, Stone's strongly implicit procedure, etc. To overcome this limitation different solver adaptations are applied to better adapt these algorithms to the multicore and manycore processor architectures. The basic idea of these methods is to use the most recent available data in each iteration, which gives improvements in calculation speed especially on the single core. On the other hand, the Jacobi's method uses the data from previous iteration, it is independent from the current one, but it is also the most inefficient method. The data independence between neighboring elements allows full parallelization over the entire domain. This method implementation on a processor with any level of parallelism is straightforward, and the results are easily compared between platforms.

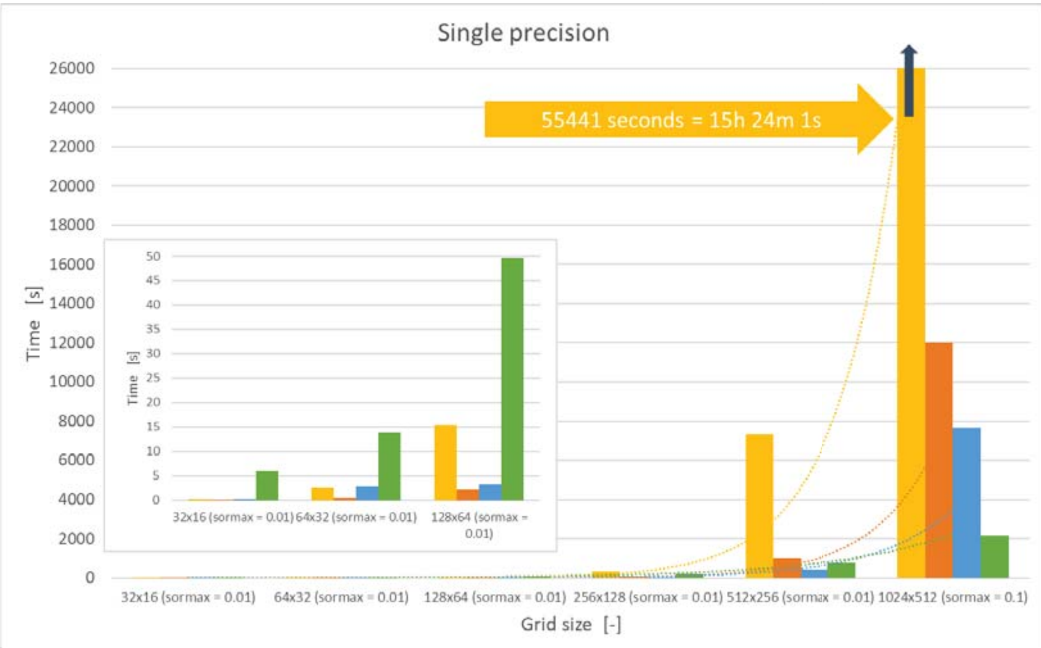
Here, we replaced the TDMA solver with Jacobi's in a CFD program for a 2D simulation of incompressible turbulent flow. To parallelize the program in FORTRAN, we use the OpenACC programming directives, as it allows higher portability of the code, compared to a specialized code for single platform, with minimum impact on performance. The code is modified to allow for more parallelism in execution of subroutines. Base case is established with no compiler optimization for both single and double floating-point precision. Three more versions were compiled (numerical grids ranging from 32x16 to 1024x512), one with optimizations enabled (providing 3,3x to 7,2x improvement over the base case), the other one with full parallelism enabled on an Intel Xeon E5-1620 v3 multicore processor (improvement in range 0,3x to 17,2x), and the last one, compiled for NVIDIA Quadro RTX 4000 GPU manycore architecture (performance ranged from negative values to a 25,6x).

The best performance for grid up to 128x64 were on the single core with enabled compiler optimizations for both single and double precision. The multicore CPU simulations gave best

performance for single precision with grid sizes 256x128 and 512x256, and for double precision at 256x128 grid. At finer grids best performances are achieved on the GPU, overcoming memory overhead costs and performance impact due to significantly slower individual CUDA cores.

Future research should focus on implementation of the multigrid applied to Jacobi's solver.

Figure: Calculation time to full convergence



Base case (no optimization) enabled

Compiler optimizations

Multicore on (Xeon E5-1620 v3)

Manycore (Quadro RTX 4000)

FRAMEWORK FOR MODELLING GENUINE GROUND REACTION FORCES DUE TO WALKING

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Keywords: pedestrian loading, human-induced vibrations, footbridges, biomechanics, robotics.

ABSTRACT

Contact forces between the feet of a walking person and the supporting ground, so called "ground reaction forces (GRFs)", have increasingly been attracting a wide spectrum of research disciplines [1]. In the civil engineering context, they are dynamic loading of pedestrian structures, e.g. footbridges and floors. Equal in amplitude but acting in the opposite direction, such forces are relevant in medicine for design of prosthetics and artificial hips, while in robotics they are used to optimize gait of humanoid robots.

Natural variability between successive footfalls means that the walking GRFs are a random narrow band process. However, they are commonly portrayed in the literature as deterministic and perfectly periodic, yielding considerable errors in their numerous applications. This study aims to describe mathematically intra-personal variability of the walking GRFs using an example of continuously measured vertical force signals due to the left and right feet generated by an individual walking on a state-of-the-art double-belt instrumented treadmill.

The signals were sliced into successive footfalls to study variability of their durations and the corresponding force amplitudes. Characteristic M-shape of the walking forces was extracted using dynamic time warping method, then fitted by a sum of Gaussians. Variation of footfall timing on a stride-by-stride basis was described via the auto spectral density of the process and random phases. Two synthetic GRF signals would be generated only by chance due to the random nature of the modelling parameters.

The presented framework can be applied to a comprehensive database of GRF signals recorded from a large number of test subjects with diverse age, race, gender and fitness, yielding a numerical generator of random quasi-periodic synthetic GRFs that can be used reliably in various engineering and medical applications.

REFERENCES

[1] Racic, V., Pavic, A., Brownjohn, J.M.W. (2009) "Experimental identification and analytical modelling of human walking forces: literature review", *Journal of Sound and Vibration* 326, 1-49.

[2] García-Diéguez, M., Racic, V., Zapico-Valle, J.L. (2021) "Complete statistical approach to modelling variable pedestrian forces induced on rigid surfaces", *Mechanical Systems and Signal Processing* 159, 107800.

SIMULATING FLOW IN SILICON Y-BIFURCATED MICROCHANNELS

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Keywords: Silicon, Pyrex glass, Microchannels, Fluid flow.

ABSTRACT

Microfluidic devices are excessively used for various biomedical, chemical, and engineering applications. The most common microfluidic platforms are obtained from polydimethylsiloxane (PDMS). Platforms based on etched silicon wafers anodically bonded to Pyrex glass are more mechanically rigid, have better sealing and there is no gas permeability compared to those obtained from PDMS [1,2]. The aim of our work is to numerically analyze fluid flow in anisotropically etched silicon microchannels sealed with Pyrex glass. We present simulations of fluid flow in Y-bifurcated microchannels fabricated from the etched {100} silicon in 25 wt% tetramethylammonium hydroxide (TMAH) water solution at the temperature of 80°C [3]. We have explored two symmetrical Y-bifurcations that are defined with acute angles of 36.8° and 19° with the sides that are along the <310> and <610> crystallographic directions in the masking layer [3], respectively. The angles between obtained sidewalls and {100} silicon of two ingoing microchannels for the first and second Y-bifurcation are 72.5° and 80.7°, respectively. The sidewalls of outgoing microchannel in both cases are defined with <100> crystallographic directions and they are orthogonal to the surface of {100} silicon wafer. The appropriate widths of ingoing and outgoing microchannels are 300 and 400 µm, respectively. The depth of microchannels is 55 µm. All simulated flows are three-dimensional (3D), steady and laminar [4], while the investigated fluid is water. Velocities and pressure values are defined at the inlet and outlet boundaries, respectively. The resulting flows are illustrated by velocity contours. The obtained conclusions from fluid flow simulations of presented simple Y-bifurcations provide guidance for future fabrication of complex microfluidic platforms by a cost-effective process with good control over microchannel dimensions.

REFERENCES

[1] Kang, CK., *et al.* (2014), “Pressure-driven deformation with soft polydimethylsiloxane (PDMS) by a regular syringe pump: challenge to the classical fluid dynamics by comparison of experimental and theoretical results,” *RSC Advances*, 4, pp. 3102-3112.

[2] Merkel, T.C., *et al.* (2000), “Gas sorption, diffusion, and permeation in poly (dimethylsiloxane),” *Journal of Polymer Science: Part B: Polymer Physics*, 38, pp. 415-434.

[3] Smiljanić, M.M., *et al.* (2021), “Silicon Y-bifurcated microchannels etched in 25 wt% TMAH water solution,” *Journal of Micromechanics and Microengineering*, 31(1), art. no. 017001.

[4] Sarkar, S., *et al.* (2014), “Numerical simulation of mixing at 1-1 and 1-2 microfluidic junctions,” *Chemical Engineering and Processing: Process Intensification*, 85, pp. 227-240.

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FREE VIBRATIONS OF FGM PLATES WITH IMPERFECTIONS USING LAYERWISE FINITE ELEMENT

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Keywords: Free vibrations, FGM plates, Geometrical imperfections, Layer wise Finite element, MATLAB computer program

ABSTRACT

The initial geometrical imperfections, as deviations between the actual and intended shape, are in most cases randomly distributed in real structures and their real shape is not known in advance. Most of the studies reported up to date are based on simplified assumption that the initial geometric imperfection has a similar form to the deformed shape of the plate or sinusoidal form. Moreover, most of the mentioned studies present the analytical solutions for imperfect plates, restricred to simply supported boundary conditions. In wish to fulfil the lack of free vibration solutions based on Layer Wise (LW) plate theories, which will be able to include general form of geometrical imperfection and arbitrary boundary conditions, in this study a LW finite element solution is presented for free vibrations of geometrically imperfect FGM (Functionally Graded Material) plates.

After establishing the accuracy of the present layer wise model for linear and geometrically nonlinear bending, vibration and buckling analysis of laminated composite and sandwich plates subjected to mechanical load, as well as for thermal bending and buckling of laminated composite and sandwich plates, in this paper, free vibration of geometrically imperfect FGM plates is presented. The mathematical model, based on Layer wise theory of Reddy, assumes layer wise variation of in plane displacements and constant transverse displacement through the thickness, linear strain displacement relations and isotropic/orthotropic material properties. The material properties of FGM plates are assumed to be constant in xy-plane and vary through the thickness by a power law function in terms of the volume fraction of the constituents. The effective materials properties are given by the rule of mixture. The Koiter's model for initial geometric imperfection is adopted. In order to include various possible imperfection modes, such as sine type, local type and global type, an imperfection function in the form of the product of trigonometric function and hyperbolic function in (x,y) plane is used. The principle of virtual displacement (PVD) is used to derive Euler-Lagrange differential equation of motion. The weak form is discretized using nine node Lagrangian isoparametric finite element. The original MATLAB computer program is coded for the finite element solution. The effects of imperfection mode and amplitude on fundamental frequencies is analysed. The accuracy of the numerical model is verified by comparison with the available results from the literature. It is found that geometric imperfection greatly affect the free vibration behaviour of FGM plates and should be taken into account when designing safe and functional structures.

REFERENCES

[1]J.N. Reddy, E.J. Barbero, J.L. Teply (1989), A plate bending element based on a generalized laminated plate theory, International Journal for Numerical Methods in Engineering, 28, 2275–2292.

[2] Rafiee, M., He, X.Q., Liewa, K.M. (2014), Non-linear dynamic stability of piezoelectric functionally graded carbon nanotube-reinforced composite plates with initial geometric imperfection, International Journal of Non-Linear Mechanics, 59, 5937–51.

[3] Fung, C.P., Chen, C.S. (2006), Imperfection sensitivity in the nonlinear vibration of functionally graded plates, European Journal of Mechanics A/Solids, 25, 425–436.

[4] Gupta, A., Talha, M. (2016), An assessment of a non-polynomial based higher order shear and normal deformation theory for vibration response of gradient plates with initial geometric imperfections, Composites Part B, 107, 141–161.

[5] Cetkovic, M., Vuksanovic, Đ. (2009), Bending free vibrations and buckling of laminated composite and sandwich plates using a layer wise displacement model. Composite Structures, 88(2), 219–227.

[6] Cetkovic, M., Vuksanovic, Đ. (2011), Large deflection analysis of laminated composite plates using layer wise displacement model. Structural Engineering and Mechanics, 40(2), 257–277.

[7]Cetkovic, M. (2015), Thermo-mechanical bending of laminated composite and sandwich plates using a layer wise displacement model. Composite Structures, 125, 388–399.

[8] Cetkovic, M. (2016), Thermal buckling of laminated plates using layer wise displacement model. Composite Structures, 142, 238–253.

[9] Cetkovic, M. (2022), Influence of initial geometrical imperfections on thermal stability of laminated composite plates using layerwise finite element. Composite Structures, 291, 115547.

[10] Cetkovic, M. (2011), Nonlinear behavior of laminated composite plates. In: PhD Thesis (in Serbian), Faculty of Civil Engineering University of Belgrade, Serbia.

A SIMULATION-INFORMED MODELING OF DEPTH OF PENETRATION OF RIGID RODS INTO QUASIBRITTLE SOLIDS

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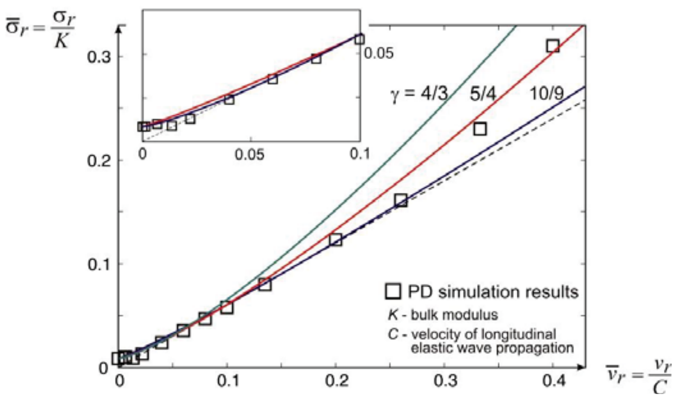
Keywords: Penetration depth, Particle dynamics, Cylindrical cavity expansion.

ABSTRACT

The present study proposes a model aimed to provide a rational estimate of the penetration depth of rigid projectiles into quasibrittle solids. Penetration at normal incidence into massive targets, made of materials predisposed to microcracking, is marked by a high level of aleatory variability and epistemic uncertainty. This inherent stochasticity is addressed by the model developed based on the particle dynamics simulations that provide the key modeling ingredient – the estimate of the radial traction required to expand a cylindrical cavity at a prescribed rate

$$\bar{\sigma}_r = \mathcal{B} + \mathcal{A}\cdot\bar{v}_r^{\gamma}, \quad \gamma \in \Re^+, 1 < \gamma < 2 \tag{1}$$



Considering Eq. (1), the expression for the depth of penetration

$$D = \frac{KE}{\alpha}\cdot {}_2\mathrm{F}_1\left(1, \frac{2}{\gamma}, 1+\frac{2}{\gamma}, -\frac{\beta}{\alpha}\left(\frac{v}{C}\right)^{\gamma}\right), \quad KE = \frac{1}{2}mv^2 \tag{2}$$

can be derived for the conical-nose rods using Newton's second law of motion. In Eq. (2), m and v designate the projectile mass and striking velocity, respectively, and α and β – the model parameters defining the penetration resistance based on the ansatz (1). The use of the power law radial traction dependence upon the expansion rate (1) yields both the penetration-resistance force and the penetration depth (Eq. (2)) defined in terms of the hypergeometric functions ${}_2\mathrm{F}_1\,(a, b; c; f(z))$. These expressions are readily evaluated and offer a reasonable estimate of the penetration depth.

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LES OF FLOW AROUND NACA 4412 AIRFOIL AT HIGH ANGLE-OF-ATTACK

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Keywords: Airfoil, Turbulence, LES.

ABSTRACT

The flow field around a NACA 4412 airfoil is numerically investigated by means of large eddy simulation (LES), an advanced mathematical model for turbulent flows which solves for the low-pass filtered numerical solution. A subgrid-scale model is used to account for the effects of unresolved small-scale turbulent structures on the resolved scales, while the flow behavior near walls is modeled by wall functions [1]. Here, the investigated operating conditions are a chord Reynolds number of 1.5 million and a Mach number of 0.2 at a high angle-of-attack of 14°, where strong separation at the aft part of the airfoil suction side can be observed. This validation case is chosen from the experimental dataset described and available in [2]. The finest computational grid contains approximately 9 million control volumes. Fluid flow computations are performed by the second-order low-dissipation finite-volume solver charLES developed by Cascade Technologies, Inc. The Dynamic Smagorinsky subgrid-scale model is employed, while a no-penetration stress-based algebraic equilibrium wall model is applied along the airfoil walls. Velocity and pressure values are defined at inlet and outlet boundaries, respectively, while periodic walls are used in the span. The obtained numerical results are validated through comparison to experimental data. Fig. 1 illustrates the pressure coefficient distributions. In addition, the instantaneous velocity field visualized in Fig. 2 illustrates that the flow structures resolved by the LES exhibit a wide range of length scales.

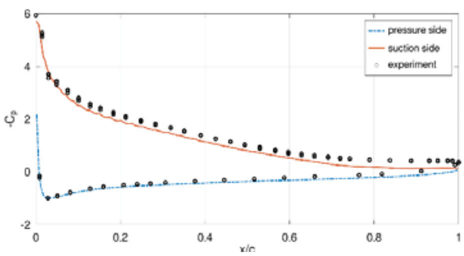

Fig. 1. Pressure coefficient distribution

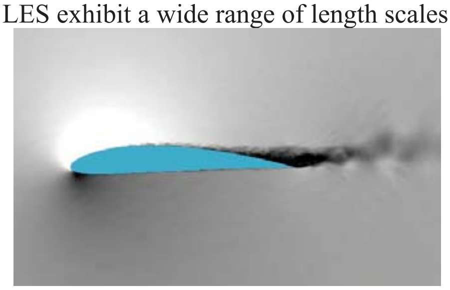

Fig. 2. Instantaneous velocity field

REFERENCES

[1] Moin, P., Bodart, J., Bose, S., Park, G.I. (2016), "Wall-modeling in complex turbulent flows," *Notes on Numerical Fluid Mechanics and Multidisciplinary Design,* 133, pp. 207-219.

[2] Wadcock, A. (1978), "Flying-hot-wire study of two-dimensional turbulent separation on an NACA 4412 airfoil," PhD thesis, California Institute of Technology, Pasadena, California.

NUMERICAL INVESTIGATION INTO THE INFLUENCE OF THE CORE PLUG REPLACEMENT PROPERTIES ON THE FLEXURAL PERFORMANCES OF REPAIRED HONEYCOMB SANDWICH PANEL

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Keywords: Honeycomb sandwich structure, Composite repair, Finite element analysis, Three-point bending test.

ABSTRACT

Honeycomb sandwich structures are common in many lightweight applications, especially in aerospace, due to their low weight, high bending stiffness and strength, and high energy absorption capacity. Nevertheless, these structures are very prone to damage caused by foreign object impact. In this study, finite element analysis was carried out to investigate the influence of the core plug replacement properties on the repaired honeycomb panel behavior subjected to three-point bending load. The effect of those properties on the stepped repair patch was also examined.

The non-linear FE model of sandwich panels with carbon/epoxy facesheets perfectly tied to Nomex™ honeycomb core were developed in Abaqus/Explicit. The damaged panel was designed by creating an open hole in center of the panel. To repair the damaged panel, core plugs replacement with different densities (ρ [kg/m^3]), material stiffnesses (E [MPa]) and material yield stresses (σ [MPa]) were used to replace the damaged core. Finally, patch plies were stacked and bonded to the panel using the cohesive contact interaction. 3D models of the different panel configuration are represented in Fig. 1.

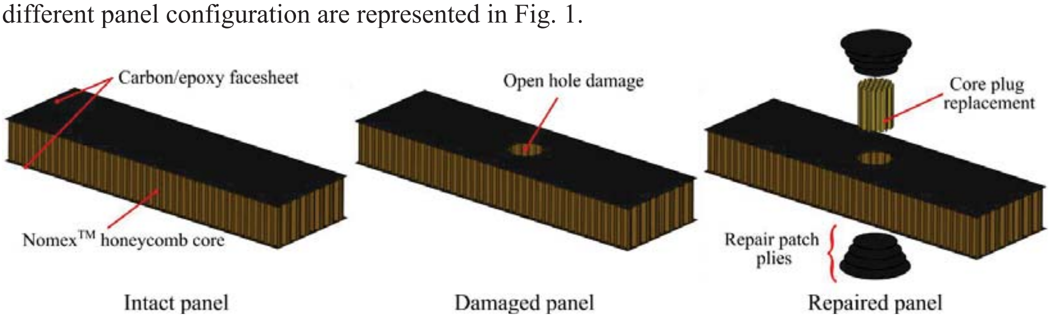

Figure 1. 3D models of intact, damaged and repaired panels.

The load-displacement curves of the repaired panel with variation of one parameter of the core plug replacement (two other parameters were held constant at their mean values) are shown in Fig. 2. It can be clearly seen that the damage strongly affects the flexural performances. The flexural elastic modulus and peak force of the damaged panel decrease respectively by 16.46% and 25.91% compared to the intact one. Moreover, it is noticeable that for restoring the structure's original performances, the most important influence is ρ, then σ and finally E.

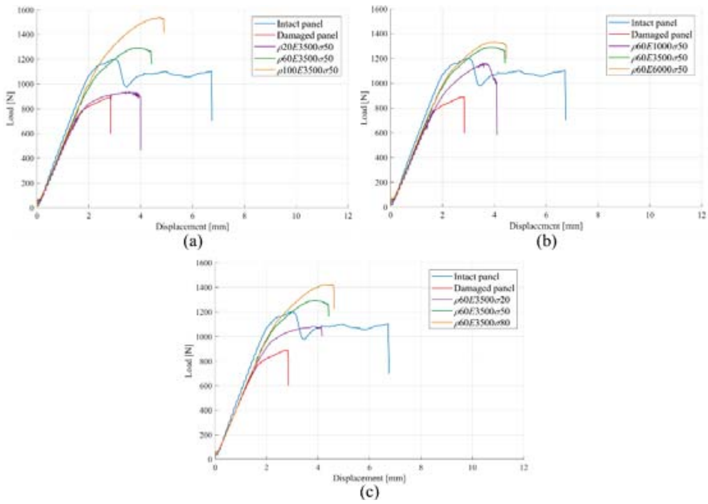

Figure 2. Load-displacement responses: (a) ρ variation; (b) E variation; (c) σ variation.

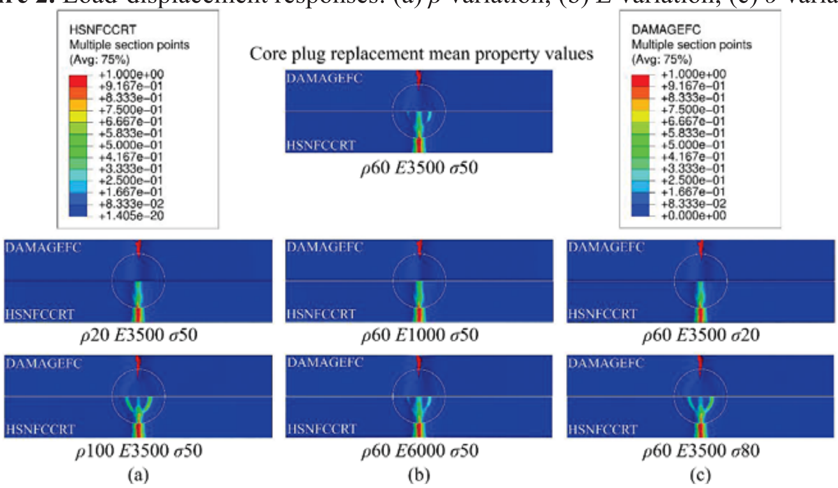

Figure 3. HSNFCCRT and DAMAGEFC distribution: (a) ρ variation; (b) E variation; (c) σ variation.

The facesheet compressive failure mode is predominant for all panels. The distribution of the Hashin's maximum value of the fiber compressive initiation criterion (HSNFCCRT) and fiber compressive damage variable (DAMAGEFC) at the total failure of the panel are presented in Fig. 3. The value HSNFCCRT =1 indicates that the initiation criterion has been met and the value DAMAGEFC =1 means that the material is completely damaged. It is illustrated that the properties of the core plug replacement act differently on the repair patch. The core plug replacement with lower values of those properties weakly damaged the patch. However, increasing the values of ρ and σ causes more patch deteriorations compared to increasing E. Thus, increasing the values of core plug replacement properties lead to restore a large amount of structure's original performances but excessive values induce considerable damages to the repair patch.

INHIBITION POTENTY OF 1,2,4-TRIHYDROXYANTHRAQUINONE AND 1,2,4-TRIHYDROXYXANTHONE TOWARD PENICILLIN-BINDING PROTEIN 1A

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Keywords: Purpurin, 1,2,4-trihydroxyxanthone, PBP1a protein, Molecular docking

ABSTRACT

Treatment of *Streptococcus pneumonia* is based on the use of antibiotics, but there is significant resistant of this bacteria to penicillin, amoxicillin, and cephalosporin [1]. In the cell wall of *S. pneumonia* there is penicillin-binding protein 1A (PBP1a), that is involved in homologous DNA recombination mechanism, repair, and chromosome segregation of bacteria cells [1]. The development of agents that enable the inhibition of this protein leads to the apoptosis of *S. pneumonia* cells, and decreases *antibiotic resistance.*

Docking analysis is performed to evaluate the possibility of 1,2,4-trihydroxyanthraquinone (purpurin, PU) and 1,2,4-trihydroxyxanthone (XA) to inhibit PBP1a protein [2]. Their inhibition potency is compared with inhibition potency of lactivicin (LA), the drug already used in the treatment of *S. pneumonia.* The three-dimensional (3D) crystal structure of PBP1a protein was downloaded from the Protein Data Bank (PDB ID: 2C6W) [1]. AGFR (AutoGridFR) software indicated binding site with the lowest expected binding energy. Molecular docking simulations were carried out using AutoDock 4.0 software [2]. The analysis of obtained results indicated that the highest inhibition potency possess PU (ΔG_{bind} = -7,40 kcal/mol; K_i = 3,80 μM), then XA (ΔG_{bind} = -7,06 kcal/mol; K_i = 6.63 μM), and the least has LA (ΔG_{bind} = -6,01 kcal/mol; K_i = 39,22 μM). Each of the three considered ligands achieves at least five protein-ligand interactions, among which the most important are conventional hydrogen bonds and $\pi - \pi$ stacking. It can be concluded that PU and XA may be further considered as potential inhibitors of PBP1a protein.

REFERENCES

[1] Contreras-Martel, C., Job, V., Di Guilmi, A.M., Vernet, T., Dideberg, O., Dessen, A. (2005), "Crystal structure of penicillin-binding protein 1a (PBP1a) reveals a mutational hotspot implicated in beta-lactam resistance in Streptococcus pneumoniae," *Journal of Molecular Biology*, 355 (4) 684-696.

[2] Morris G.M., Huey R., Lindstrom W., Sanner M.F., Belew R.K., Goodsell D.S., Olson A.J. (2009), "AutoDock4 and AutoDockTools4: Automated docking with selective receptor flexibility," *Journal of Computational Chemistry*, 30 (16) 2785-2791.

MODAL PARAMETERS IDENTIFICATION AND DYNAMIC PERFORMANCE OF A STEEL FOOTBRIDGE WITH A SIGNIFICANT 3D BEHAVIOUR

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Keywords: Footbridges, Dynamic performance, Modal identification, Experimental testing.

ABSTRACT

Footbridges are rather slender structures with relatively high live load to self-weight ratios. Truss bridges composed by hollow elements become into low mass, high flexibility and, generally, low damping structures, able to accomplish strength and stiffness design requirements, but prone to experience high vibration levels under pedestrian loading. Recent advances in construction materials and technology, and modern aesthetic trends, aggravate this situation. This may affect the comfort of walkers, runners and cyclists and may lead to structural fatigue problems in the long term. In this work, a particular steel footbridge that crosses the CV10 highway near Castellon´ (Spain) is studied with the aim to (i) experimentally identify the modal parameters; (ii) analyse its dynamic response under different uses; (iii) determine the modeling parameters that have the greatest effect on the footbridge dynamic properties. The footbridge, which was prefabricated and mounted in place, consists of a main steel truss span supported on two four-arm piles and two access ramps. The deck is formed by a steel plate connected to longitudinal and transverse rectangular hollow stringers and cross-beams.

Two experimental campaigns are performed. First, the free vibration response of the structure is obtained under a set of impact hammer tests. Eight high sensitivity accelerometers are installed in two set-ups. The modal parameters are estimated from the Cross Power Spectral Density in the frequency domain. Also, modal dampings are obtained using the Half Power Bandwidth method. Several records are used to get a high degree of confidence in the results. Second, forced vibration tests are performed with a different number of pedestrians walking at several paces, running and bouncing. The footbridge performance is assessed in terms of acceleration levels in reference to present regulations and recommendations [1, 2].

On the other hand a detailed Finite Element model of the footbridge is implemented in Patran. The model is updated in order to reproduce with a fair level of accuracy the bridge modal properties. A sensitivity analysis is performed on some of the model parameters paying special attention to the effect of the supports modelling. Final recommendations are provided in this regard.

REFERENCES

[1] CEN, EN 1990:2002 (2005), ”Eurocode: Basis of structural design. Annex A2: Application for bridges”.

[2] SETRA - Association Francaise de Genie Civil (2006), “Footbridges. Assessment of vibrational behaviour of footbridges under pedestrian loading”.

GENERATIVE ADVERSARIAL NETWORKS FOR THE ESTIMATION OF 3D TURBULENT FIELDS WITH WALL-MEASUREMENTS

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Keywords: Turbulence, Flow Estimation.

ABSTRACT

The objective of this work is to test the capability of generative adversarial neural networks (GANs) for direct estimation of 3D turbulent channel flows from wall measurements of wall-shear stress and pressure. The work builds upon on previous works for the estimation of wall-parallel planes of the flow, and aims to extend it to full 3D estimation. Although the target output to be predicted in this work is much more demanding computationally, it is shown that a similar network with a moderate increment of training parameters can provide a prediction with an accuracy comparable to that of the previous 2D implementations, thus providing a comparatively cheaper alternative for flow estimation.

INTRODUCTION

An accurate prediction of the flow state from sensors is relevant in the implementation of active control techniques. In wall-bounded flows, the most natural place to locate sensors is the wall. In the estimation of turbulent fields of channel flows from wall measurements, linear methods have been used to carry out successful reconstructions from the wall to the logarithmic region [1]. More recently, models with an improved accuracy, including non-linear effects, were obtained employing deep neural networks [2] [3] [4]. Generative Adversarial Neural networks (GANs) have recently shown to outperform standard convolutional neural networks in this task.

In Ref. [4] the flow estimation from wall measurements was carried out in two-dimensional wall-parallel planes. The estimation required separate training for each wall-parallel plane. In this work, we aim to optimize this process by parameter sharing, with a full training based on a three-dimensional GANs architecture. The main advantages are that with a single network we can simplify the training to one process, reducing the number of parameters and the overall computational cost, and providing directly a 3D characterization of the flow.

METHODOLOGY

GANs are composed by two networks that compete against each other in the training process. The wall measurements of pressure and wall-shear stress are the input for the generator network, which aims to generate the 3D velocity field most likely to correspond to the input. Meanwhile, the discriminator network is trained to detect if a given flow field is original or if it was created by the generator.

The GANs implemented in this work is similar to that from Ref. [4], with the difference that 3D convolutional layers are used in this case, to deal with this alternative setup. The main elements in the generator network are the residual blocks, where these convolutional layers are included.

The results from a direct numerical simulation (DNS) were used to define the data set. It is a turbulent open-channel flow with dimensions πh in the streamwise direction, $\pi/2h$ in the spanwise direction and $2h$ in the wall-normal direction, with 64, 64 and 128 grid points respectively. The channel is simulated with friction-based Reynolds number equal to 200.

RESULTS

The diagram in Fig. 1 is the result of a prediction of the volume contained in the domain of the DNS up to $y^+ = 40$, based on the the first 32 wall-normal layers from the wall. The normalized mean squared error is only slightly higher than the results in Ref [4]. It must be remarked, however, that the 3D GANs is a comparatively lighter architecture, with a moderate increase in parameters if compared to the increased size of the output (in this case, predicting 32 layers simultaneously instead of 1).

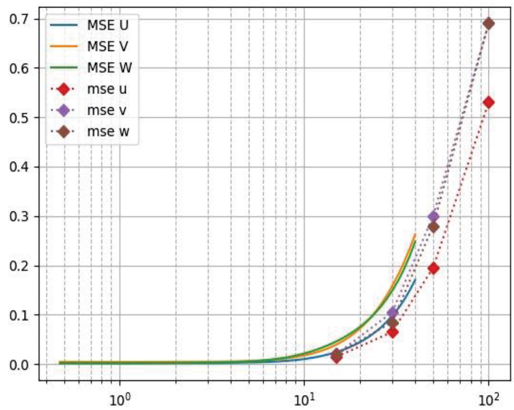

Figure 1: MSE of the prediction of the three components of the velocity fluctuations as a function of the inner-scaled wall-normal coordinate y^+. The 3D prediction (solid lines), and the 2D prediction from the Ref. [4] (dotted lines) at $y^+ = [15,30,60,100]$.

The flow velocity is predicted with high accuracy in the viscous layer, and then become progressively worse through the buffer and logarithmic layers.

A reconstruction of the flow field at two different wall-normal distances is reported in figures 2 and 3, capturing how the patterns and structures on the field are predicted. As one might expect, the prediction ability of the network improves towards the wall, while the error increases towards the centre of the channel, mainly because of the attenuation of the intensity of the structures and the filtering of smaller scales. These small scales cannot be recovered beyond some point, as it depends on the distance to the wall and the patterns present in the wall-measurements.

As another way of visualization of structures, we include maps of products of the velocity components in figure 4, which clearly report the correlation between the patterns estimated and those present in the original field. The main vortexes, aligned in the streamwise direction, are present there.

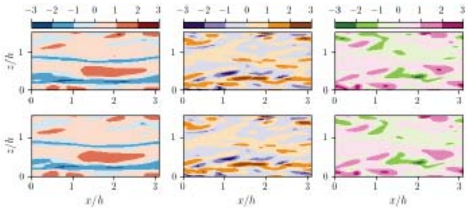

Figure 2: (Top) Reference and (bottom) predicted instantaneous fields of (left) u, (middle) v and (right) w, for $y^+ = 10$.

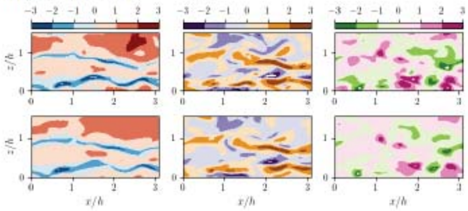

Figure 3: (Top) Reference and (bottom) predicted instantaneous fields of (left) u, (middle) v and (right) w, for $y^+ = 40$.

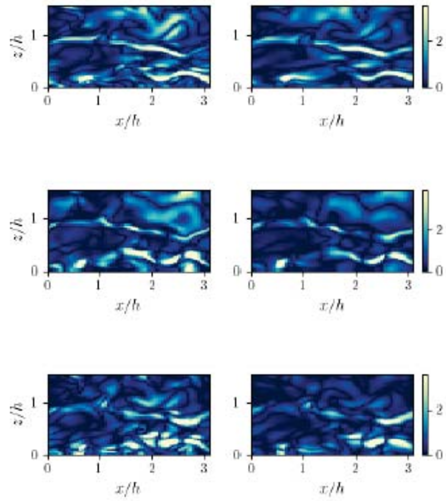

Figure 4: (Left) Reference and (right) predicted maps of products of velocity components at $y^+ = 40$, showing (top) $|uv|$, (middle) $|uw|$ and (bottom) $|vw|$.

CONCLUSIONS

In this work we demostrate that full 3D reconstruction of a wall-bounded flow from wall data can be obtained with a 3D GAN, being developed with comparable computational resources and with a level of error that is still similar to that GANs carrying out 2D predictions at individual wall distances. The main limitation observed is that estimation accuracy decreases with increasing wall distance, issue that was also observed in the 2D setup [4] and that can be ascribed to the progressively decreasing correlation between the input (the wall sensor data) and the output.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Encinar M. P. and Jimenez J. (2019) "Logarithmic-layer turbulence: A view from the wall". *Physical Review Fluids*, vol. 4, no. 11, pp. 114603.

[2] Guemes A. *et al*. (2019) "Sensing the turbulent large-scale motions with their wall signature". *Physics of Fluids*, vol. 31, no. 12, pp. 125112.

[3] Guastoni L. *et al*. (2021) "Convolutional-network models to predict wall-bounded turbulence from wall quantities". *Journal of Fluid Mechanics*, 928

[4] Guemes A. *et al*. (2021) "From coarse wall measurements to turbulent velocity fields through deep learning". *Physics of Fluids*, vol. 33, no. 7, pp. 075121.

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FEATURES OF BODY BALANCE ON HINGED AND MOVABLE SUPPORTS

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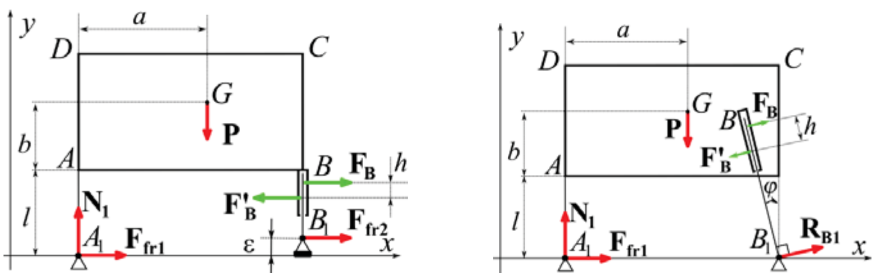
Keywords: Movable supports, Reactions of constraints, Balance conditions.

ABSTRACT

When building objects on supports, large values of undetermined tangential reactions may occur. Such problems, in particular, can be associated with prestresses during assembly of the structure or with unequal thermal contractions / expansions of materials.

In practice, to combat these difficulties, movable articulation elements are used. The equilibrium of systems combining rigid and sliding (telescopic) supports is considered (Fig.1).



a b

Fig. 1. Introduction of deviations in a planar problem with a potentially movable support. a) a stand under a movable support; b) rotation of the movable support.

It is shown that the inclusion of a potentially sliding joint in the system leads to an acute conflict with those constraints that have remained "rigid" and can cause infinitely large reactions of the rigid constraints.

The work is supported by the Russian Science Foundation (project No. 22-21-00303).

ROTATION IN HORIZONTAL PLANE OF THE FRICTION-POWERED ROBOT WITH UNBALANCED ROTOR AND FLYWHEEL

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Keywords: Vibration robot, Unbalanced rotor, Flywheel, Plane-parallel motion.

ABSTRACT

Plane-parallel motion of a vibro robot is considered, the body of which contains one unbalanced rotor and one flywheel (Fig. 1). In previous studies, the possibility of such a motion was substantiated, and the controlled accelerated rotation of the unbalance rotor provides the separation of the body from the supporting surface to the minimum (zero) altitude. The flywheel is designed to stabilize the horizontal orientation of the body in the longitudinal direction. To carry out the rotation of the body in the horizontal plane the axis of rotation of the unbalanced rotor is inclined by a given installation angle from the horizontal.

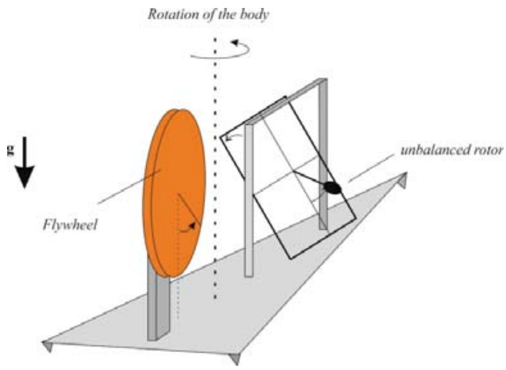

Fig. 1. Diagram of the mechanical system.

A mathematical model of a plane-parallel motion is constructed taking into account the possibility for the body to lose its contact with a support surface. During liftoff from the surface, the body of the robot moves and performs a turn in the specified direction. The dependence of the angle of the turn on the initial position of the unbalance rotor and the mounting angle of the frame is described. The conditions of the full stop for the robot after the turn are determined. It is shown that the rotation of the robot body is associated with a general displacement of the body in the longitudinal and lateral directions.

The work is supported by the Russian Science Foundation (project No. 22-21-00303).

GALLOPING-BASED WIND POWER HARVESTER WITH SEVERAL MOVING MASSES

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Keywords: Wind power harvesting, Oscillations, Limit cycles, Galloping.

ABSTRACT

Galloping is a well-known phenomenon which represents flow-induced oscillations of a bluff body in the direction perpendicular to the flow. Such oscillations are intensively studied in civil engineering, where they are considered undesired and harmful. However, since recently, using galloping for flow energy harvesting is actively discussed.

Here we consider a system comprising several masses (Fig. 1) which are connected with springs and can move translationally across the incoming flow in horizontal plane. The body M_1 represents a square cylinder. It is rigidly connected with a magnet M_0 that can move inside a coil, thus producing electric current.

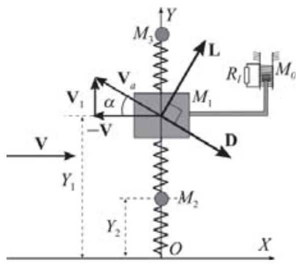

Fig. 1. Galloping based wind power harvester

Numerical investigation of the limit cycles arising in the system is performed. For simulation, the standard Runge-Kutta-Fehlberg method was used, along with the parametric continuation method. The evolution of limit cycles with the change in the parameters (such as stiffness and damping of springs) is discussed.

It is shown that appropriate selection of parameters allows for considerable decreasing of the critical wind speed corresponding to the onset of the galloping as compared with the system with one moving mass.

Amplitude of oscillations increases with the increase of the wind speed. In order to avoid damage to the device, a parametric control is considered aimed at diminishing the amplitude of oscillations in case of high wind speeds. The obtained results can be useful for the development of galloping-based wind power generators.

The work is supported by the Russian Science Foundation (project 22-29-00472).

LIGHT-WEIGHT DESIGN OF AN OVERHEAD CRANE'S GIRDER WITH A NON-SYMMETRIC BOX CROSS-SECTION

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Keywords: Overhead Crane, Optimal Design, Steel Girder, Eurocodes, Metaheuristic.

ABSTRACT

The proper choice of material and geometric properties of the bridge crane main girder can significantly reduce its weight and production cost. This research presents the optimization of the weight of the double-beam bridge crane main girder with an asymmetric box-like cross-section. The strength analysis in characteristic points of the critical cross-section and the local stability of plates were conducted using Eurocodes [1]. This study aimed to prove that a proper choice of geometry for the cross-section plates and their additional design elements can have a meaningful impact on the main girder weight and, by that, on the overall weight of the double-beam bridge crane. The optimization procedure was done using Water Evaporation Optimization (WEO) algorithm [2], with the implementation of all necessary criteria and conditions which must be fulfilled. This study revealed that the application of the lightweight design philosophy to the steel structure of the bridge crane main girder could significantly reduce its weight, which is verified in the existing examples of double-beam bridge cranes.

Achieved savings in girder weight are between 24,43% and 34,73%, dependingly on the considered example. Also, the study showed the influence of the chosen material on the optimum weight and geometric parameters of the steel girder.

Depending on the studied example of the bridge crane and selected material, the WEO algorithm gave the same solution through simulations. The value of the objective function (optimum weight) had a slight deviation at the second decimal place, which is neglectable. The algorithm successfully avoided the trap of getting into the local minimum during the search.

In the end, it can be stated that the application of the WEO algorithm was successful in the considered engineering problem since it was the optimization of a complex steel structure with 11 variables and more than 20 constraint functions.

REFERENCES

[1] European Committee for Standardization (2010), "Eurocode 3 - prEN 13001–3–1, Cranes – General design – Limit states and proof of competence of steel structures".
[2] Kaveh, A., Bakhshpoori, T. (2016), "Water Evaporation Optimization: A novel physically inspired optimization algorithm", *Computers & Structures,* Vol. 167, pp. 69-85.

MATHEMATICAL MODELING OF THE CHAOTIC DYNAMICS OF POROUS NANOBEAMS INCLUDING GEOMETRIC NONLINEARITY AND ELASTIC-PLASTIC DEFORMATIONS

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Keywords: mathematical model of porous nanobeams, chaos, nonlinear dynamics, scenarios of transition from harmonic vibrations to chaotic, deformation theory of plasticity, geometric nonlinearity.

ABSTRACT

The purpose of the study is to create a mathematical model of nanobeams from a porous material, taking into account elastic-plastic deformations and geometric nonlinearity.

Using the Hamilton's principle, Von-Karman nonlinear theory and kinematic hypotheses of the first approximation (Euler-Bernoulli) a mathematical model was created. For modeling size-dependent factors of the composite beam, modified couple stress theory was used. Governing equations of beam motion as well as boundary and initial conditions by the energetic Hamilton's principle have been derived. The properties of the porous medium material depend on coordinates, time, and stress-strain state, which give a chance to apply the deformation theory of plasticity.

An algorithm for reducing non-linear partial differential equations to the Cauchy problem by the finite difference method with second-order approximation is developed. The Cauchy problem is solved by several methods such as Runge-Kutta and Newmark. The convergence of the solution depending on the number of partition points in spatial and temporal coordinates was investigated. At each time step, the Birger's method with variable parameters was applied. Unloading, secondary plastic deformation and cyclic loading were taken into account. The constructed algorithm and software allow solving both problems of nonlinear statics and nonlinear dynamics. Static problems with the help of the establishment method, which, in fact, is the method of continuation by parameter, have been solved. The Mises criterion was adopted as a criterion for plasticity. With the help of the obtained algorithm and software, static problems for some types of boundary conditions and the value of material porosity were solved. For dynamic problems, scenarios for the transition from harmonic to chaotic oscillations, depending on the amplitude and frequency of the perturbation of a transverse alternating load have been studied. Charts of the nature of vibrations depending on the control parameters were built.

Conclusions: New scenarios for the transition of vibrations of nanobeams from harmonic to chaotic, which are a modification of the known three scenarios were created. The modification of the scenario for the transition of vibrations from harmonic to chaotic depends on the diagram of the dependence of the stress intensity on the strain intensity, the nanocoefficient porosity.

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OPTIMIZATION OF ADHESIVE JOINTS BY TOPOLOGICAL OPTIMIZATION METHODS

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Keywords: Topological optimization, Shear stresses, Soldered connections, Method of sliding asymptotes.

ABSTRACT

In this paper, the problem of the strength of adhesive joints under the action of mechanical loads based on topological optimization methods is considered. Methods for increasing the strength of the adhesive joint described in the scientific and engineering literature include adding edges and changing the geometry of the adhesive by rounding or narrowing the adhesive edges. However, this approach is both time-consuming and does not give great benefits from optimization. A methodology of topological optimization for finding the minimum peak values of shear stresses by modifying the structure of elements connected by an adhesive layer while maintaining a given amount of modeling material was proposed. To optimize the topology area on finite elements was divided. According to the well-known methods SIMP, the role of the control variable is played by an artificially introduced density associated with the Young's modulus and the bulk density of the material. With her help there is a gradual redistribution of material. This leads to minimization of stresses both in the connected elements and in the adhesive layer.

As an example, the optimization of the soldering of a three-layer sandwich structure consisting of two duralumin beams connected in an overlap (Fig. 1). Two engineering designs with lap joints and the optimal design are shown in Fig. 1(B), (C), and (A), respectively. The beams were made of duralumin with Young's modulus equal to $E_1 = 73.1 * 10^6$ Pa and silver solder with $E_2 = 2.26 * 10^6$ Pa. Also in Fig. 1, the distribution of shear stress along the length of the solder $\sigma_{12}(X)$ for structures (A), (B), and (C) are shown. The mechanical load $F = 1 * 10^5 \frac{H}{м^2}$ acts on the right side of the beam, and the left boundary is pinched. To solve the problem, the finite element method with the approximation of the area by triangular elements was applied. Optimization based on the sliding asymptote method was performed. The results show that in solder joints, due to the small thickness of the solder, the shear stresses are basic. The maximum peak stresses for the optimum design (A) are reduced by 20% compared to the standard designs (B) and (C). The great efficiency of the topological optimization method for creating reliable adhesive joints are shown.

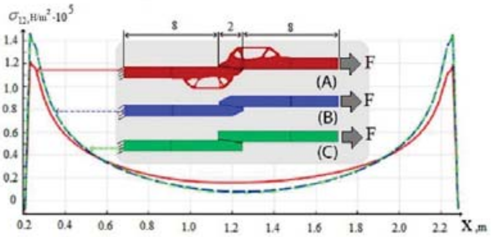

Fig.1. Shear stresses

Funding. The authors express their sincere appreciation for the financial support by RSF under project № 22-11-00160

WRINKLING OF THIN ELASTIC FILMS ON COMPLIANT VISCOELASTIC SUBSTRATES UNDER COMPRESSIVE LOADS

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Keywords: wrinkling, viscoelasticity, growth, substrate, film

ABSTRACT

Wrinkling of a thin elastic film attached on a compliant viscoelastic substrate subjected to a compressive load is a very convenient system for studying interaction between the effects of kinematic nonlinearity and viscoelasticity. This system can be simple enough for numerical and sometimes, under certain assumptions analytical treatment of the nonlinear viscoelastic evolution of deformations. In such a system, evolution of deformations can become highly complex and more strongly dependent on initial conditions, perturbations and boundary conditions.

To show these effects, we combine visco-hyperelastic finite strain theory with growth theory and use the finite element method to solve the system of nonlinear time dependent equations using dynamic relaxation method. We find that if the initial energy dissipation during rearrangement of wrinkles is too large the system can become “frozen” in a non-equilibrium deformation state, which can be distinctly different from the purely elastic one. The system can remain there permanently if the system loses more energy than needed to overcome an energy barrier. Alternatively, the system can also transition so slowly that the environmental parameters change during the process and it can therefore remain in the out-of-equilibrium state permanently. Note that in general, these deformation states are unreachable for elasticity alone [1]. In fact, this deformation patterns are very common in nature, e.g. in microbiology [2-4] and morphogenesis [5].

Furthermore, we show that viscoelastic properties of the material are crucially important for the final development of the pattern even though they seemingly affect only the transient behavior. The interaction between the viscoelastic material properties with the nonlinear kinematics produces interesting deformation patterns otherwise unattainable for purely elastic systems. The theory and the principles described are also useful in engineering applications because they may enable simpler fabrication of smart surfaces and coatings that at some point in fabrication behave viscoelasticity.

REFERENCES

[1] D. A. Matoz-Fernandez, et al.: Wrinkle patterns in active viscoelastic thin sheets. Phys. Rev. Research 2(2020) p. 013165

[2] T. Ruiz-Herrero, et al.: Dynamics of Growth and Form in Prebiotic Vesicles Phys. Rev. Lett. 123(2019) p. 038102

[3] M. Nelson, et al.: Growth-induced buckling of an epithelial layer. Biomech. Model. Mechan. 10(2010) p. 883–900.

[4] D. Espeso, et al.: Differential growth of wrinkled biofilms. Phys. Rev. E, Stat. nonlin. soft matt. Phys. 91(2015) p. 022710 [5] R. de Rooij and E. Kuhl: Constitutive Modeling of Brain Tissue: Current Per-spectives. Appl. Mech. Rev. 68(2016) p. 010801

EQUILIBRIUM OPTIMIZER FOR OPTIMIZATION OF TRUSS STRUCTURE WITH DISCRETE DESIGN VARIABLES

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Keywords: Civil engineering, Equilibrium optimizer algorithm, Physical-based algorithms, Constrained optimization, Mechanical design problems.

ABSTRACT

In this paper, a new meta-heuristic approach named Equilibrium Optimizer (EO) is employed to search for the optimal design of truss structures with discrete design variables. The objective function is to minimize the mass of the ten bars. Finite element analysis (FEA) is used to determine the elemental stresses and nodal displacements. The bar structure is modeled by two-node linear elements. To deal with discrete variables, the index method is adopted. The performance of the EO is compared with various advanced optimization algorithms. Simulation results indicate that EO is effective in comparison with other existing optimization approaches in solving structural engineering design optimization problems.

REFERENCES

[1] Faramarzi, A., Heidarinejad, M., Stephens, B., Mirjalili, S. (2020), Equilibrium optimizer: A novel optimization algorithm, Knowledge-Based Systems, 191, 105190.
[2] Abderazek, H., Yildiz, A. R., Sait, S. M. (2021), Optimization of constrained mechanical design problems using the equilibrium optimization algorithm, Materials Testing, 63(6), pp. 552-559.

OPTIMIZATION OF TURNING PROCESS PARAMETERS USING A HYBRIDE VOLUTIONARY ALGORITHM

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Keywords: Multi-objective optimization, Eco-Friendly machining, Turning, Meta-heuristics.

ABSTRACT

This paper presents an effective hybrid algorithm based on the adaptive differential evolution (ADE) and Nelder-Mead local search (NM) (referred to as ADENM in this article). The ADENM is used to optimize the main cutting parameters during the turning operation of EN-GJL-250 cast iron. The fitness functions are the tangential cutting force, the surface roughness, and the cutting power. The mathematical expressions of the three objectives have been created based on the Artificial Neural Network (ANN). Moreover, the performance of the proposed algorithm is numerically tested using several mechanical problems. The optimization results obtained by the developed variant are compared with those of the literature using different algorithms. The comparison results illustrate that the proposed method has fast convergence speed and is more successful for most test problems in terms of solution quality and computational efficiency.

REFERENCES

[1] Hamza, F., Ferhat, D., Abderazek, H., Dahane, M. (2020), A new efficient hybrid approach for reliability-based design optimization problems, Engineering with Computers, pp. 1-24.
[2] Abderazek, H., Yildiz, A. R., Sait, S. M. (2019), Mechanical engineering design optimisation using novel adaptive differential evolution algorithm, International Journal of Vehicle Design, 80(2-4), pp. 285-329.
[3] Laouissi, A., Nouioua, M., Yallese, M. A., Abderazek, H., Maouche, H., Bouhalais, M. L. (2021), Machinability study and ANN-MOALO-based multi-response optimization during Eco-Friendly machining of EN-GJL-250 cast iron, The International Journal of Advanced Manufacturing Technology, 117(3), pp. 1179-1192.

INVESTIGATION OF EEG SIGNALS OF PATIENTS WITH ALCOHOL DEPENDENCE BY METHODS OF NONLINEAR DYNAMICS

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Keywords: EEG, nonlinear dynamics, Lyapunov exponents, wavelet analysis, neural networks, genetic algorithm, support vector machine (SVM), machine learning.

ABSTRACT

This work is devoted to the creation of a methodology for the study of electroencephalogram (EEG) signals of patients based on the methods of nonlinear dynamics [1] and machine learning in order to identify patients with alcohol dependence. An important problem is to identify the characteristic features of the brain that accompany the disease. EEG recordings were made at the Mental Health Research Institute of the Tomsk National Research Medical Center of the Russian Academy of Sciences using 16 channels of the "10-20" layout. It is proposed to study EEG fragments of the control group and patients with alcohol dependence by Fourier and wavelet analysis methods. The search for characteristic patterns on EEG fragments is based on the calculation of several types of entropy. The proposed methodology includes a study of the type of signal chaotization by calculating the spectrum of Lyapunov exponents. The use of several methods at once to calculate each characteristic allows you to ensure the reliability of the results. The obtained characteristics are transmitted to the input of an artificial neural network (ANN) using a genetic algorithm and a convolutional neural network (CNN) using a support vector machine (SVM) to classify patients with alcohol dependence and a control group. The created methodology and the results obtained on its basis are in good agreement with the medical conclusion.

REFERENCES

[1] Tatiana V. Yakovleva, Ilya E. Kutepov, Antonina Yu Karas, Nikolai M. Yakovlev, Vitalii V. Dobriyan, Irina V. Papkova, Maxim V. Zhigalov, Olga A. Saltykova, Anton V. Krysko, Tatiana Yu Yaroshenko, Nikolai P. Erofeev, Vadim A. Krysko, "EEG Analysis in Structural Focal Epilepsy Using the Methods of Nonlinear Dynamics (Lyapunov Exponents, Lempel–Ziv Complexity, and Multiscale Entropy)", *The Scientific World Journal*, vol. 2020, Article ID 8407872, 13 pages, 2020. https://doi.org/10.1155/2020/8407872

EFFECTS OF DYNAMIC ABSORPTION CAUSED TO CURVATURES IN GEOMETRY OF COUPLED NANO-STRUCTURES

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Keywords: Forced vibrations, Nonlocal elasticity, Modal analysis, Dynamic absorption, Coupled nano-structures

ABSTRACT

One characteristic example composed from elastically connected nano-plate and nano-shell elements will be considered in this paper. The nano-plate and the doubly-curved shallow nano-shell are made of orthotropic materials. The both nano-elements are simply supported, and embedded in Winkler-type elastic medium. In this paper forced vibration responses are conducted. Based on the Eringen constitutive elastic relation [1,2], Kirchhoff-Love plate theory [3] and Novozhilov linear shallow shell theory [4,5], the system of four coupled partial differential equations of motion is derived. For the forced vibration response standard modal analysis solution procedure [6] is used. The main contribution in the work is the discovery that the upper excited element of the nano-system (in this case nano-plate) has the smaller amplitude-vibrations of transverse responses only if the lower element is curved, (in this case nano-shell). The phenomenon is observed by comparing the amplitude-vibration of forced transverse responses for elastically connected system, from two nano-plates with elastically connected system composed from nano-plate and nano-shell. It has been proven that such a phenomenon can occur within linear nano-systems. Also, dynamic absorption or amplitudes decrease of the excited upper nano-plate of the presented nano-system is related to increasing nonlocal parameter and decreasing radii of curvature of nano-shell. The proposed mathematical model of sandwich nano-structure can serve in application in creation of new nano-sensor and nano-antenna to which it corresponds to the occurrence and tuning of dynamic absorption due to geometry of nano-shell element.

REFERENCES

[1] Eringen, A. C. (1972), *Linear theory of nonlocal elasticity and dispersion of plane waves,* International Journal of Engineering Science, 10(5), 425-435.
[2] Eringen, A. C. (2002), *Nonlocal continuum field theories,* Springer Science & Business.
[3] Reddy, J. N. (2006). *Theory and analysis of elastic plates and shells*. CRC press.
[4] Amabili, M. (2008), Nonlinear vibrations and stability of shells and plates, New York: Cambridge University Press
[5] Ghavanloo, E., Fazelzadeh, S. A. (2013), *Free vibration analysis of orthotropic doubly-curved shallow shells based on the gradient elasticity*, Composites Part B: Engin. 45(1), 1448-1457.
[6] Kelly, S. G. (2012), *Mechanical vibrations: theory and applications,* Cengage learning.

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COMPLEMENTARY TOPOLOGICAL METHODS FOR THE ANALYSIS OF NONLINEAR TIME SERIES

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Keywords: Simplicial complexes, Algebraic Topology, Nonlinear time series .

ABSTRACT

In order to understand and predict the behavior of complex systems arising from diverse areas of science, many interesting and advanced models, as well as methods, have been developed. Topological data analysis [1], alongside the other tools originating from the algebraic topology, has a substantial influence on the fast evolution of new methods for extracting not-so-apparent properties of complex systems. Computations revealed new knowledge which eluded well-established approaches. Simplicial complexes have become a prominent part of the modern applied physics framework based on the increased use of methods of algebraic topology in multifarious areas of physics and other scientific areas as well [2].

On the other hand, the time series of data related to the dynamics of a complex system appears as an object of interest from which the system's properties can be extracted. In this context, the reconstruction of time series using simplicial complexes can be performed in various ways depending on the information we want to extract about the system under study, see for example [3, 4]. Different types of simplicial complexes may provide rich knowledge about the complex system. Furthermore, simplicial complex analysis reveals hidden geometry and topology of higher-order that are not observed via standard methods of graph analysis and statistical mechanics.

For the purpose of the current work, we analyzed the well-known model of the dynamical system, called the Lorenz system, using recurrent [5] simplicial complexes and the reconstruction of the time series of the Lorenz system using a visibility algorithm [6] into the simplicial complex. The aim is to apply comparative methods in order to present the scope of the topological framework and topological properties that can be inferred from this analysis. The applications of algebraic topology, persistent homology [1], and Q-analysis [7] in particular, to nonlinear dynamical systems, reveal possibilities for future applications in engineering.

REFERENCES

[1] Epstein, C. et al. (2011), ”Topological data analysis”, Inverse Probl. 27, pp. 120201.
[2] Battiston, F. et al. (2020), ”Networks beyond pairwise interactions: Structure and dynamics”, Physics Reports 874, pp. 1-92.
[3] Maletic S. et al. (2016), ”Persistent topological features of dynamical systems”, Chaos, 26(5),´ art. no. 053105.
[4] Andjelkovic, M. et al. (2015) ”Hidden geometry of traffic jamming”, Phys. Rev. E 91(5), pp.´ 052817.
[5] Marwan, N. et al. (2009), ”Complex network approach for recurrence analysis of time series”, Physics Letters A 373(46),pp. 4246-4254.
[6] Lacasa, L. et al. (2008), ”From time series to complex networks: The visibility graph”, PNAS 105(13), pp. 4972-4975.
[7] Johnson, J. H. (1981), ”Some structures and notation of Q-analysis”, Environment and Planning B 8, pp. 73.

WAVE PROPAGATION CHARECTERISTICS OF CURVED HEXAGONAL LATTICE

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Keywords: Hexagonal lattices, Curved beams, Bloch waves, Phononic bandgaps.

ABSTRACT

Lattice structures are widely used in engineering practice due to their unique properties. Their applications range from static load-bearing, energy absorption, biomedical, transportation, and soft electronics to wave attenuation. In-plane wave propagation of hexagonal and re-entrant lattices is the focus of this research. The microstructure of the constituent members of the periodic unit cell dictates the dispersion characteristics of the lattice metamaterials. It is observed that zig-zag and curved beams as the constituent elements can be crucial for lowering and the emergence of new band-gaps [1,2] unlike their conventional lattice counterparts with straight elements. In this work, we explored the in-plane wave propagation in hexagonal and re-entrant lattices with curved constituent beam members [3]. Bloch theorem is applied to study in-plane wave propagation and obtain the unique dispersion properties of the new novel lattices. The incorporation of curved beam elements in the hexagonal lattice includes a new geometric parameter, curvature angle. The effect of constituent curved beams is explored for the dispersion characteristics, generation of new bandgaps, and wave directionality through iso-frequency contours of dispersion surfaces. The curvature angle of the curved beam plays an important role in the emergence and widening of new bandgaps in all frequency regions, especially in the lower one. The number of the new band-gaps is proportional to the increasing curvature angle for the lattice with both positive curvature angles. Also, the width of the band-gaps increases for most of the gaps for hexagonal as well as the reentrant lattice. The promising results could be useful for further guidelines of the hexagonal metamaterials and serve as benchmark results for future investigation in this domain.

REFERENCES

[1] Y.-F. Wang, Y.-S. Wang, C. Zhang. (2014), “Bandgaps and directional properties of twodimensional square beam-like zigzag lattices,” *AIP Advances,* 4, (12), 124403.

[2] G. Trainiti, J. J. Rimoli, M. Ruzzene. (2016), “Wave propagation in undulated structural lattices,” *International Journal of Solids and Structures,* 97, pp. 431–444.

[3] S. Mukherjee, S. Adhikari. (2022), “The in-plane mechanics of a family of curved 2d lattices,” *Composite Structures,* 280, 114859.

DESIGN AND ANALYSIS OF BONE TISSUE SCAFFOLDS: A TWO-WAY FLUID STRUCTURE INTERACTION MODEL

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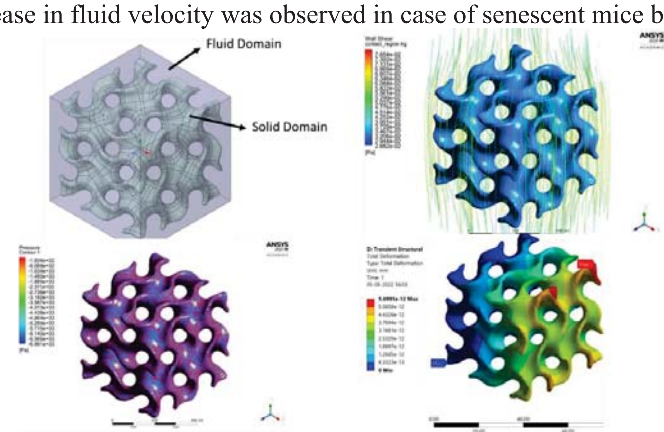
Keywords: FSI, System Coupling, Fluid flow, wall shear stress, Osteogenesis, Osteoporosis

ABSTRACT

Mechanical loading induced canalicular fluid flow inside the lacunar canalicular channel is considered as a stimulus for new bone formation. Canalicular fluid flow induces wall shear stress on the canalicular wall structure, as a result it releases biomechanical signaling molecules responsible for mechanotransduction. However, it remains unclear how the fluid and solid domain of bone tissue interact during the mechanical loading. In the present study, we have developed an idealized model of bone tissue subjected to cantilever loading. We have considered bone tissue as a porous rigid structure having properties in accordance with osteoporotic bone as mentioned in the literature. A two-way fluid-structure interaction module available in ANSYS Multiphysics software is used to mimic the interaction between the solid bone deformation and canalicular fluid motion. Pore pressure, fluid velocity and the deformation of the solid bone tissue is computed. The outcome of present study shows that the porosity and permeability play an important role in the regulation of fluid flow which can be utilized for the development of biomechanical interventions for osteoporotic bone. A substantial decrease in fluid velocity was observed in case of senescent mice bone.



REFERENCES

[1] Kumar, Rakesh, et al. "Estimation of Loading-Driven Fluid-Flow Pattern in Lacunar-Canalicular Space Using Fluid Structure Interaction." Journal of Physics: Conference Series. Vol. 1504. No. 1. IOP Publishing, 2020.

[2] Birmingham, E., et al. "Computational modelling of the mechanics of trabecular bone and marrow using fluid structure interaction techniques." Annals of biomedical engineering 41.4 (2013): 814-826.

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ENSTROPHY IN TURBULENT SWIRLING FLOW IN PIPE

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Keywords: Turbulence, Swirling Flow, Axial Fan, Vorticity, Enstrophy, Time Resolved Particle Image Velocimetry.

ABSTRACT

Turbulent flow is characterized by significant vortex fluctuations, intensive diffusion processes and energy cascade transfer from larger to smaller vortices over a continuous spectrum of wave numbers. The dissipation of the kinetic energy of turbulence occurs in the smallest vortices, because in these areas, both the velocity gradients and the deformation velocities are the largest. Equation for enstrophy ($\underline{\tilde{\omega}}^2/2$) is given in the following form:

$$\frac{D}{Dt}(\underline{\tilde{\omega}}^2/2) = \tilde{\omega}_i\tilde{\omega}_j\tilde{S}_{ij} - \nu(\nabla\times\underline{\tilde{\omega}})^2 + \nu\nabla\bullet[\underline{\tilde{\omega}}\times(\nabla\times\underline{\tilde{\omega}})], \qquad (1)$$

Generation or reduction of enstrophy due to elongation or shortening of the vortex filament is described with first, and its destruction caused by viscosity by the second term on the right side of equation (1). This physically characterizes viscous dissipation of enstrophy. It could be shown that total energy dissipation in time, in arbitrary volume V, is determined by the integral of the distribution of enstrophy in that volume. In accordance with Reynolds' decomposition, the average enstrophy (E_Ω) is defined as follows $E_\Omega = 0.5\underline{\Omega}^2 = 0.5\Omega_i\Omega_i$. It could be, also, shown that the dissipation of the kinetic energy of turbulence is associated with vorticity fluctuations, i.e. with turbulent fluctuating enstrophy [1]. Enstrophy distribution in the turbulent swirling flow, generated by the axial fan in-built in pipe, is presented in figure 1. It is calculated on the basis of the time resolved particle image velocimetry data. Enstrophy is directly related to the kinetic energy, i.e. it corresponds to dissipation effects in this flow. It has maximum in small vortices, i.e. in shear layer, that surrounds vortex core region, where the process of turbulence kinetic energy dissipation occurs.

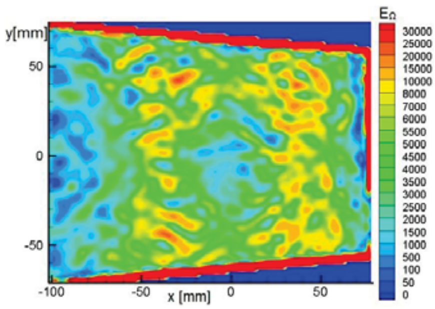

Figure 1. Enstrophy distribution in turbulent swirling flow [1]

REFERENCES

[1] Čantrak, Đ.S. (2012), "Analysis of the Vortex Core and Turbulence Structure behind Axial Fans in a Straight Pipe using PIV, LDA and HWA Methods," *PhD thesis,* University of Belgrade, Belgrade, Serbia.

ON SOME FEATURES OF THE LOSS OF STABILITY OF FLEXIBLE CYLINDRICAL NANOPANELS ON A RECTANGULAR PLAN

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Keywords: cylindrical nanopanels, modified couple stress theory of elasticity.

ABSTRACT

A mathematical model of stability loss of flexible cylindrical nanopanels on a rectangular plan is built in the work. The basis of the obtained mathematical model from the Hamilton principle is the following hypotheses: the panel material is elastic and isotropic, the geometric nonlinearity is introduced according to T. von Karman, the conditions for the flatness of the panels are according to the Vlasov V.Z. criterion. Nonlinear partial differential equations with boundary (articulated support) and initial conditions are solved for static and dynamic problems by the Bubnov-Galerkin method in higher approximations. We study its convergence depending on the number of terms of the series in the expansion of the main functions; it is required that not only the main functions, but also their derivatives up to the second order, coincide. The effectiveness of the Bubnov-Galerkin method for plate nanostructures is considered in the work [1].

The small scale parameter, which are taken into account according to the modified couple stress theory of elasticity, and the curvature parameter significantly affect the solution of the problem and the convergence of the solution. The small scale parameter, which appears at the higher-order moment, is an additional independent material length parameter associated with the symmetric rotation gradient tensor. With an increase in the curvature parameter, the loss of stability occurs with the formation of new forms of equilibrium and edges.

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REFERENCES

[1] Awrejcewicz, J., Krysko-Jr., V.A., Kalutsky, L.A. et al., Review of the Methods of Transition from Partial to Ordinary Differential Equations: From Macro- to Nano-structural Dynamics, *Arch Computat Methods Eng* 28, 4781–4813 (2021). https://doi.org/10.1007/s11831-021-09550-5

INFLUENCE OF STING PLUNGING OSCILLATIONS ON MEASUREMENT OF PITCH-DAMPING DERIVATIVES

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Keywords: Oscillations, Pitch-damping derivatives, Wind tunnel.

ABSTRACT

In the T-38 wind tunnel dynamic stability derivatives are obtained using the forced oscillation technique. In the wind tunnel test section a model is forced to oscillate at constant amplitude and frequency within a single degree of freedom. Aerodynamic damping is obtained by subtracting data from the wind-on run and wind-off run. Wind-off run enables determination of the mechanical damping, while wind-on run enables determination of total damping. A large aerodynamic loads cause translational motion of the model support (sting). The sting translation motion can lead to the occurrence of errors in pitch-damping derivatives determination if the effects of sting plunging oscillations are not accounted. The effects of sting plunging oscillations can be presented as follows: reactions from which pitch-damping derivatives are obtained contain translational component and position of the model oscillation axis should be determined taking account the sting plunge amplitude [1]. In order to determine sting plunging oscillations, three-component strain gauge transducer is realized at the sting root of the T-38 pitch/yaw apparatus, [2]. The strain gauges are connected in a form of a four-active-arm measuring bridges that enable measurements of sting oscillations in pitch, yaw and roll. The contributions of the sting plunging to the direct damping derivative in pitch, measured in the T-38 wind tunnel forced oscillation tests, are shown in equation:

$$M_q + M_{\dot{\alpha}} = \left(\frac{|M_P| \sin\phi}{|\theta|\omega} \right)_0 - \frac{|M_P| \sin\phi}{|\theta|\omega} + \frac{\Delta z}{|\theta|} \frac{M_\alpha}{V \cos\bar{\alpha}} \cos\phi_S$$

where $M_q + M_{\dot{\alpha}}$ is direct damping derivative in pitch, M_α is pitching moment due to angle of attack, $|M_P|$ is amplitude of the excitation moment, $|\theta|$ is amplitude of the model oscillations, ω is model angular velocity, ϕ is phase shift between model oscillatory motion and excitation moment, ϕ_S is phase shift between model oscillatory motion and sting plunging, Δz is amplitude of the sting plunging, V is free stream velocity, $\bar{\alpha}$ is mean value of the angle of attack. Values with index (0) are measured in wind-off run.

REFERENCES

[1] Beyers, M.E. (1986), “Direct derivative measurements in the presence of sting plunging”, *J. Aircraft,* Vol.23.No.3, pp.179-185.

[2] Samardžić, M., et al. (2013), “Apparatus for measurement of pitch and yaw damping derivatives in high Reynolds number blowdown wind tunnel”, *Measurement,* Vol. 46, pp. 2457-2466.

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APPLICATION OF MARINE PREDATORS ALGORITHM IN DESIGN OF RAILWAY VEHICLES SUSPENSION MADE OF COIL SPRINGS

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Keywords: Marine Predators Algorithm, MPA algorithm, Optimization, Railway vehicles suspension, Coil springs.

ABSTRACT

The design and calculation of suspension system is one of the most important tasks in the development of railway vehicles. One of the most common concepts of suspension of railway vehicles, especially freight wagons, is based on a set of coil springs of different lengths, which are placed one inside the other. When the vehicle is empty, only the external spring is active, and when the vehicle is loaded above a certain limit, both springs are active. Thus, the suspension of such railway vehicles has a bilinear characteristic of stiffness. The design of such suspension systems is usually based on a conventional approach whose main goal is to design coil springs that will meet the all required conditions. These conditions can be satisfied by different combinations of parameters and dimensions of the external and internal spring. However, not enough attention is paid to achieving the optimal solution that could provide materials saving.

This was a motivation for the authors to explore the possibilities of applying biologically inspired algorithms in the design of suspension systems of railway vehicles. Accordingly, this paper presents the application of the Marine Predators Algorithm (MPA) in the design of suspension system of railway vehicles based on the coil springs. The main goal of optimization is to minimize the total mass of the set of coil springs, with simultaneously satisfaction all the required conditions related to the behavior of the suspension system of the considered railway vehicle. MPA is very successfully applied in solution of wide spectra of engineering problems. A key inspiration of this algorithm is the widespread food search strategy of ocean predators based on the Lévy and Brownian movements including the optimal encounter rate policy in biological interaction among predators and prey.

After considering the theoretical postulates of the suspension system of railway vehicles based on coil springs, a unique optimization model is developed. It consists of 6 parameters to be optimized (diameters of springs, diameters of wires and numbers of active threads of external and internal spring), target function and 14 constraints (7 for each coil spring). The established optimization model is applied in two specific examples of designing a suspension system of 4-axled freight wagons based on a sets of coil springs, the first for an axle-load of 200 kN and the second for an axle-load of 225 kN. In both cases, the application of the proposed optimization model and the MPA provided a significant reduction in the mass of the set of coil springs. Compared to the conventional design approach, the mass reduction in the first example is 18.2% and in the second example 12.8%. More precisely, the total mass of 16 sets of coil springs of one 4-axled freight wagon in the first example is reduced by about 70 kg, while the mass reduction in the second example is about 50 kg. Considering the fact that commercial freight wagons are usually produced in large series of several thousand pieces and that their

coil springs are made of special and expensive steel, it is obvious that the obtained results of this research have great practical significance and potential impact on improving profitability in the industry of railway vehicles.

REFERENCES

[1] Andersson, E., Berg, M., Stichel, S., (2007), Rail Vehicle Dynamics, Railway Group KTH, Stockholm.
[2] Iwnicki, S.D., (2006), Handbook of railway vehicle dynamics. Taylor & Francis.
[3] Versinskiy, S., Danilov, V., Celnokov, I., (1978), Dinamika vagona. Izdateljstvo Transport, Moskva.
[4] Petrović, D., Rakanović, R., (2006), Železnička vozila - Praktikum, Mašinski fakultet Kraljevo, in Serbian.
[5] Bižić, M., Marković, G., Bulatović, R., Petrović, D., Dedić, M., (2020), Grey wolf optimiser in design of leaf springs of railway vehicles, International Journal of Vehicle Design, Vol. 80, No. 2/3/4, pp.103-120, doi: 10.1504/IJVD.2019.109855.
[6] Faramarzi, A., Heidarinejad, M., Mirjalili, S., Gandomi, A.H., (2020), Marine Predators Algorithm: A nature-inspired metaheuristic, Expert Systems with Applications, Volume 152, 113377, doi.org/10.1016/j.eswa.2020.113377.
[7] Chang-Jian Sun, Fang Gao, (2021), A Tent Marine Predators Algorithm with Estimation Distribution Algorithm and Gaussian Random Walk for Continuous Optimization Problems, Computational Intelligence and Neuroscience, vol. 2021, ID 7695596, 17 pages, doi.org/10.1155/2021/7695596
[8] Abdel-Basset, M., Mohamed, R., Mirjalili, S., Chakrabortty, R.K., Ryan, M., (2021), An Efficient Marine Predators Algorithm for Solving Multi-Objective Optimization Problems: Analysis and Validations, IEEE Access, vol. 9, pp. 42817-42844, doi:10.1109/ACCESS.2021.3066323.
[9] Keyu Zhong, Qifang Luo, Yongquan Zhou, Ming Jiang, (2021), TLMPA: Teaching-learning-based Marine Predators algorithm, AIMS Mathematics, Volume 6, Issue 2: 1395-1442. doi:10.3934/math.2021087
[10] Mohammad Zohrul Islam, Mohammad Lutfi Othman, Noor Izzri Abdul Wahab, Veerapandiyan Veerasamy, Saifur Rahman Opu, Abinaya Inbamani, Vishalakshi Annamalai, (2021), Marine predators algorithm for solving single-objective optimal power flow, PLoS ONE 16(8): e0256050. doi.org/10.1371/journal.pone.0256050.
[11] Shaheen, A.M., Elsayed, A.M., Ginidi, A.R., EL-Sehiemy, R.A., Alharthi, M.M., Ghoneim Sherif, S.M., (2022), A novel improved marine predators algorithm for combined heat and power economic dispatch problem, Alexandria Engineering Journal, Volume 61, Issue 3, 2022, Pages 1834-1851, doi.org/10.1016/j.aej.2021.07.001.

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ON EULERIAN-BASED APPROACH TO EVALUATE BLOOD MIXEDNESS IN THE PATIENT-SPECIFIC FONTAN CIRCULATION

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Keywords: biomedical engineering, blood flow, Computational Fluid Dynamics (CFD)

ABSTRACT

The human cardiovascular system is immensely altered by the occurrence of a univentricular heart condition (occurs in 3 per 10000 live births), resulting in increased blood flow resistance, and in mixing of the pulmonary and systemic circulation, [1, 2, 3]. Without rapid surgery, infants with such condition will not survive. The Fontan surgical procedure (based on the making the total cavopulmonary connection (TCPC)) has been proposed and improved over the years in clinical practice. Unfortunately, the Fontan procedure can also lead to the increased blood flow resistance, and development of the pulmonary malformations (PAVMs), followed by an increased risk of thrombosis formation, [1, 2, 3]. In the present work, we developed a novel combined Magnetic Resonance Imaging (MRI) and Computational Fluid Dynamics (CFD) approach that can be applied to further optimization and significant improvements of the current surgical procedure. The mathematical model for the prediction of the blood flow patterns and resulting mixedness is based on solving a set of non-linear PDEs: (i) conservation of mass, (ii) conservation of momentum (Navier-Stokes), (iii) conservation of species (i.e. mixture fraction of the blood originating from the liver and superior vena cava, respectively). The latter is solved by the originally developed Eulerian approach, i.e. by solving the convection/diffusion/reaction type of the PDE and corresponding mixture fractions. The considered geometry of the solution domain and inlet conditions are extracted from the 3T MRI 4D-Flow scans, making the numerical simulations patient-specific. The discretized form of the transport equations (i-ii-iii) is solved by the final volume (FV) approach, which is the second-order accurate in time and space utilizing the polyhedral numerical mesh, [4]. To properly capture gradients of the local velocity and concentration of species in the proximity of the blood vessel wall, the numerical mesh is refined in these regions. A typical numerical mesh contained approximately 3.5×10^6 polyhedral control volumes, which corresponds to 14×10^6 tetrahedral elements. We performed detailed analysis for six patient-specific geometries with already performed Fontan procedure with various conduit sizes. The level of blood mixing at the caudal (starting) and cranial conduit (ending) planes are calculated and compared with the ideal mixing assumption. Next, the hepatic flow distribution and corresponding power losses are calculated. Based on simulation results, we demonstrated that here developed Eulerian approach in predicting the local level of the blood mixedness was numerically much more efficient, more accurate, and easier for the postprocessing than the corresponding Lagrangian

methods. The final presentation will also address the patientspecific conduit-size optimization and thrombosis risk estimation - both based on the newly developed Eulerian-based model and a virtual surgery approach.

REFERENCES

[1] D. A. de Zelicourt, A. Marsden, M. A. Fogel, A. P. Yoganathan (2010), ”Imaging and patient-specific simulations for the Fontan surgery: current methodologies and clinical applications”, Prog. Pediatr. Cardiol. 30 (1-2), pp.31-44.

[2] S. F. van der Woude, F. M. Rijnberg, M. G. Hazekamp, M. R. M. Jongbloed, S. Kenjeres, H. J. Lamb, J. J. Westenberg, A. A. W. Roest, J. J. Wentzel (2021), ”The Influence of Respiration on Blood Flow in the Fontan Circulation: Insights for Imaging-Based Clinical Evaluation of the Total Cavopulmonary Connection”, Front. Cardiovasc. Med. 8 683849, pp.1-12.

[3] F. M. Rijnberg, S. F. van der Woude, H. C. van Assen, J. J. Juffermans, M. G. Hazekamp, M. R. M. Jongbloed, S. Kenjeres, H. J. Lamb, J. J. Westenberg, J. J. Wentzel, A. A. W. Roest (2021), ”Non-uniform mixing of hepatic venous flow and inferior vena cava flow in the Fontan conduit”, Journal of the Royal Society Interface 18 20201027, pp.1-8.

[4] S. Kenjeres (2016), ”On Recent Progress in Modelling and Simulations of Multi-scaleˇ Transfer of Mass, Momentum and Particles in Bio-medical Applications”, Flow, Turbulence and Combustion 96, pp.837-860.

ESTIMATION OF EXTREME LOADS ON A WIND TURBINE BLADE AT LARGE ANGLE-OF-ATTACK AND HIGH VELOCITY

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Keywords: Wind, Blade, CFD, AoA.

ABSTRACT

Angle-of-attack (AoA) of wings, blades and other geometric shapes has a dominant role in the generation of aerodynamic forces and turbine power since it changes the flow behavior. The development of software and computers has enabled simplified numerical testing, which reduces time while saving resources compared to experimental testing. Computational fluid dynamics (CFD) is a strong numerical tool that is being increasingly utilized to simulate a wide range of flow processes across many industries and is much employed in engineering design. One of the most common approaches is to use Reynolds-averaged Navier-Stokes (RANS) family of turbulence models where all effects of turbulence are modeled. For near-wall treatment, in aeronautics, the k-ω shear stress transport (SST) model is widely employed. In this paper, small horizontal axis wind turbine (model DE-AW01) blade at different AoAs has been numerically investigated. A detailed description of the blade geometry is also given. Numerical simulations of full three-dimensional flow fields using the k-ω SST turbulence model for the closure of the governing flow equations have been performed. The tests were performed at a high wind speed of 35 m/s (126 km/h) at AoAs of 85, 90 and 95 degrees which corresponds to extreme weather conditions. It has been confirmed that numerical simulations can provide sufficiently accurate estimates of the axial force and power. Furthermore, the obtained results were compared, primarily lift and drag, as the two most dominant components of aerodynamic forces, and the most convenient flow case, that minimizes blade loading, has been determined.

REFERENCES

[1] V. P. Cambanis, H. Stapountzis (2001), “An experimental study and simulation with fluent of the horizontal–axis wind turbine (HAWT) blade–tower dynamic interaction” *2nd Southeastern Europe FLUENT User Group Meeting*, Greece

[2] A. Kumar, R.P. Saini (2017), "Performance analysis of a Savonius hydrokinetic turbine having twisted blades" *Renewable Energy* 108 (2017) 502-522

[3] M. M. M. Saad, S. B. Mohd, M. F. Zulkafli (2018), "Power generator of small wind turbine: Under high-speed operation" *Sustainable Energy Technologies and Assessments* 26 (2018) 1-5

[4] M. K. Uddin, M. Z. Islam, M. Rokunuzzaman, R. I. Rubel (2015), "Experimental and Numerical Measurement of Lift and Drag Force of NACA 0015 Airfoil Blade" *International Conference on Mechanical, Industrial and Materials Engineering 2015*, Bangladesh

OPTIMIZATION OF SUPPLIER SELECTION USING ANALYTICAL HIERARCHY PROCESS IN FUZZY ENVIRONMENT

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Keywords: Optimization, AHP, supplier selection, fuzzy, decision variables.

ABSTRACT

Decision making to choose the best or optimal supplier among an extensive set of suppliers is a critical and important issue in production study at local and global level. The right decision for suppliers can give high quality product at lesser cost with satisfaction of customers at different tiers of supply chain system. Optimizing means finding the maximum or minimum value of a certain function, defined on some domain. Analytical AHP is a well-known multi-criterion decision making technique. It is a useful, simple, and systematic approach. In this paper, problem has been considering to select global suppliers using analytical Hierarchy Process as a tool in fuzzy environment. Parameters under consideration as selection criteria are cost, services, quality, past performance, level of risk, and application of IT and its adaptability. Ranking criteria has been used in this work based on triangular fuzzy number. AHP helps to final ranking for selection of suppliers. For the validity of the propose combine algorithm and optimal solution a numerical problem is solved with 4 level of hierarchy, 6 main criteria and 22 sub-criteria having 4 suppliers. Further, the proposed method can be extended in other field of decision making.

REFERENCES

[1] Adi, S, Neva., S., Effendi, M. (2021), “Supplier Selection Using The Analytical Hierarchy Process Method”, *Malaysian Journal of Consumer and Family Economics,* Vol. 27 (S1).
[2] Attri R., Grover S., Dev N. and Kumar D. (2012), “An ISM approach for modelling the enablers in the implementation of Total Productive Maintenance (TPM)”, *International Journal System Assurance Engineering and Management*.
[3] Atul, B., Satish, V., (2010), “Study of Vendor Managed Inventory Practices in Indiana Industries”, *Journal of Manufacturing Technology Management*, 21 (8), 2010, 1013-1038.
[4] Hosseinzadeh, B., et.al (2018), “Application of data envelopment analysis approach for optimization of energy use and reduction of greenhouse gas emission in peanut production of Iran”, *Journal of Cleaner Production*, 172, 1327-1335.
[5] Paradi, J. C., Sherman, H. D., & Tam, F. K. (2018), “Bank branch productivity applications: Strategic branch management issues addressed with DEA data envelopment analysis in the financial services industry”, *Springer*, 129-143.

[6] Mobasshira, Z, (2020), "Supplier Selection Using AHP-VIKOR and AHP-TOPSIS Method: a Case Study for Bangladeshi Jute Mill of Khulna Region" *SSRG International Journal of Industrial Engineering,* 7.1, 1-11.

[7] Natarja, N. R and Johnson, A. J. (2011), "Guidelines for Using Variable Selection Technique in Data Envelopment Analysis", *European Journal of Operation Research*, 215, 662-669.

[8] Sahay, B.S. (2003), "Supply chain collaboration: the key to value creation‖", *Work Study*, Vol. 52, No. 2, 76-83.

[9] Singh, M.D. & Kant, R. (2008), "Knowledge management barriers: An interpretive structural modelling approach", *International Journal of Management Science and Engineering Management*, Vol. 3, No. 2, pp. 141-150.

EFFECT OF MEASUREMENT NOISE ON MPC FOR DRAG REDUCTION

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Keywords: Model Predictive Control, Sparse Identification of Nonlinear Dynamics, Nonlinear AutoRegressive eXogenous model, robustness, flow control, drag reduction.

ABSTRACT

Model-based techniques, such as model predictive control (MPC), have recently gained significant interest for control of the dynamics of complex systems. A desirable feature of MPC is its excellent applicability to highly non-linear systems subject to constraints, operating conditions that are difficult to handle with traditional linear control systems. MPC has taken advantage of progress in data-driven modeling techniques for system identification, such as sparse identification of nonlinear dynamics (SINDY, Brunton et al., 2016), autoregressive models (e.g. Nonlinear AutoRegressive eXogenous model NARX, see Menezes and Barreto, 2008), and machine learningbased techniques, such as neural networks and deep reinforcement learning. The goal of this work is to test the robustness of data-driven MPC in presence of model uncertainties and measurement noise, in view of future application in experiments.

MPC aims at controlling dynamical systems by solving under constraints an optimal control problem over a receding horizon (Kaiser et al., 2017). Assuming that the temporal dynamics of the system can be properly discretized with a time step ΔT_{sys}, the control action to be applied in a time window ΔT_{ctrl} (normally larger than ΔT_{sys}) is determined by identification of the optimal sequence u on a control horizon $T_c = m_c \Delta T_{sys}$, being m_c the length of the control window. The optimal sequence is the one which minimizes an appropriate cost functional (1) on a prediction horizon $T_p = m_p \Delta T_{sys}$, with m_p being the length of the prediction window.

MPC relies on identification of a model of the dynamical system to obtain accurate predictions of its behaviour under a range of control actions. The robustness of MPC is challenged by the presence of noise in the measurements, which contaminates the training and the prediction process. In this work, we aim to explore the robustness of MPC for drag reduction purposes in presence of measurement noise in the sensors both in training and in the state vector employed in the online optimization process. Specifically, the experiment considered here is the control of the wake of a fluidic pinball (Deng et al., 2020), a configuration of three cylinders with common diameter D, placed at the vertices of an equilateral triangle of side $3D/2$. The control action consists of the rotation of the two rear cylinders in counter-rotating mode. The simulation is run at a Reynolds number (Re) of 150, which is sufficiently large to guarantee a chaotic behaviour (Deng et al., 2020).

MPC parameters have been assigned based on the characteristic shedding times of the fluidic pinball. The model time-step is assumed to be $\Delta T_{sys} = 0.1$ convective units, (c.u.; i.e., time required for the undisturbed flow to cover a distance equal to D); the control time-step is $\Delta T_{ctrl} = 5\Delta T_{sys}$; the control and the prediction windows are assumed to be 1.0 c.u. wide. The state vector is composed by drag (C_d) and lift (C_l) coefficients of the three cylinders, $\mathbf{x} = (C_d, C_l)'$, where $\mathbf{A}'$ denotes the transpose of the matrix $\mathbf{A}$. The cost function is set as:

$$J(\mathbf{x}_j, u_j) = \sum_{k=0}^{m_p} \|\hat{\mathbf{x}}_{j+k} - \mathbf{x}_k^*\|_{\mathbf{Q}}^2 + \sum_{k=1}^{m_c-1} (\hat{u}_{j+k}^2 R_u + \Delta\hat{u}_{j+k}^2 R_{\Delta u}), \quad (1)$$

where $\mathbf{x}_j$ is the state vector at time-step t_j and $\|\xi\|_{\mathbf{Q}} = \xi'\mathbf{Q}\xi$, being $\mathbf{Q}$ a positive definite diagonal weight matrix. R_u and $R_{\Delta u}$ are scalars establishing the relative importance between the terms in the cost function. The optimal problem penalises the error of the predictions of the state $\hat{\mathbf{x}}$ in the prediction window $t_{j+k}, k = 1,...,m_p$, with respect to the reference state $\mathbf{x}^* = (0,0)'$, the action cost u_k and its variability $\Delta u_k = u_k - u_{k-1}$, $u_k \in [-2,2]$, in the control window $t_{j+k}, k = 1,...,m_c$. The control performance is investigated both under ideal measurement conditions $\mathbf{Y} = \mathbf{X}$ and in presence of measurement noise $\mathbf{Y} = \mathbf{X} + \eta\mathbf{Z}$. In this case, $\mathbf{X}$ is a $n \times 2$ matrix (where n is the number of time instants over which the state is evaluated) with i-th row equal to $\mathbf{x}'_i$, $\mathbf{Z}$ is a matrix of independent identically distributed Gaussian entries with zero mean, and η is the noise magnitude. The noise level is chosen to be up to 3% of full-scale of the free state vector (i.e., $\eta = (0.15,0.03)'$). The plant to model the dynamics of the system is obtained using SINDy (based on a sparsity-enforcing regression on a space of functions of the dynamics equations) and NARX methods (founded upon a neural network predicting the future values of the state vector on the basis on the previous values of both state vector and control actions). The prediction models are trained offline under different control actions.

Figure 1 shows the results of the application of MPC control in the presence and absence of measurement noise and using the two different predictive methods mentioned above. In presence of noise, NARX-MPC seems to converge to a control with higher intensity oscillations in C_l, and slightly superior drag reduction performances. SINDY-MPC is characterised by narrower C_l oscillations (compared with NARX-MPC) at the expense of a lower performance in terms of drag reduction. For SINDY-MPC, the effect of noise perturbation on the control appears negligible. Even in the presence of measurement noise, the stability of the control is still guaranteed and the control shows remarkably good robustness.

ACKNOWLEDGEMENTS

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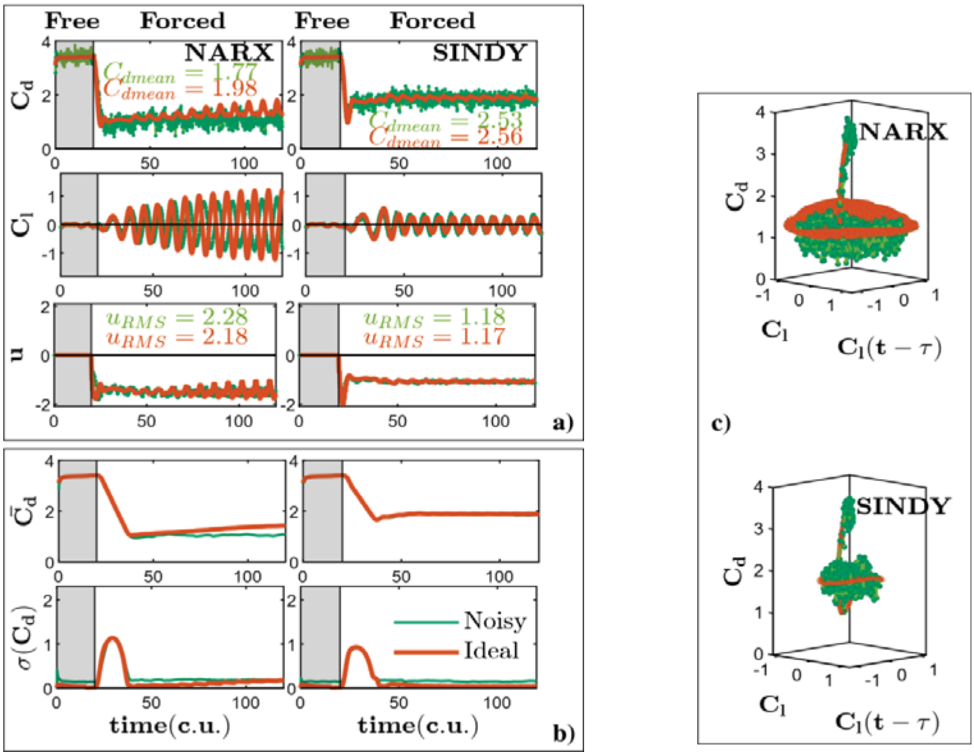

Figure 1: Control performance for the fluidic pinball at *Re* = 150 for ideal (orange curve) and noisy (green curve) measurement using NARX and SINDy methods. Plots a) show time series of the states and input at free and forced stages. Plots b) present the performance of the control in terms of moving average and moving standard deviation of the C_d over the last 15 c.u.. Plots c) are aerodynamic force diagrams: C_l, $C_l(t-\tau)$ (being τ one quarter of the shedding period), and C_d.

REFERENCES

[1] Brunton, S. L., Proctor, J. L., and Kutz, J. N. (2016). Discovering governing equations from data by sparse identification of nonlinear dynamical systems. *Proceedings of the National Academy of Sciences*, 113(15):3932–3937.

[2] Deng, N., Noack, B. R., Morzynski, M., and Pastur, L. R. (2020). Low-order model for successive´ bifurcations of the fluidic pinball. *Journal of fluid mechanics*, 884.

[3] Kaiser, E., Kutz, J., and Brunton, S. (2017). Sparse identification of nonlinear dynamics for model predictive control in the low-data limit. *Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science*, 474.

[4] Menezes, J. M. P. and Barreto, G. A. (2008). Long-term time series prediction with the narx network: An empirical evaluation. *Neurocomputing*, 71(16):3335–3343.

ON USING LMP LIMITERS IN SIMULATION OF GAS FLOW IN CONVERGING-DIVERGING NOZZLE BY RKDG METHOD

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Keywords: Discontinuous Galerkin Method, Euler equations, LMP, converging-diverging nozzle.

ABSTRACT

Simulation of strong shocks by Runge — Kutta Discontinuous Galerkin (RKDG) method [1] necessarily includes an additional limiting procedure which helps to suppress non-physical oscillations of solution. One of the popular approaches for limitation is Local Maximum Principle (LMP) [2] due to the simplicity of implementation and the speed of algorithm. These algorithms are based on the calculation of special correction function α, $\alpha \in [0,1]$. The condition $\alpha < 1$ in the cell shows that solution has too big slopes in the cell, and slopes should be multiplied to α for correction.

The LMP-based limitation for the system of hyperbolic equation [2] is written in the vector form. It could be understood as the independent computation of correction function for every component of solution. When this approach is applied to the Euler equations, the convergingdiverging nozzle test shows strong distortion of solution, while many standard verification tests show a good agreement with a reference solution.

To rectify the situation, we should look at the physical meaning of solution of Euler equations – density, momentum and energy: $(\rho,\rho u,\rho v,\rho w,\rho e)$. Density is involved implicitly to all conservative variables. When the correction function changes all slopes independently (or, for example, we try to choose the minimal α among all variables), the physical agreement between conservative variables is violated, which affect the value of the sound speed. The affection becomes visible for cases when a speed of sound is large. Therefore, calculation of α value only for density and using it for all variables helps to keep the solution physical (fig. 1).

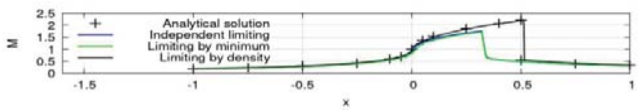

Figure 1: Comparison of analytical and numerical Mach number for gas flow in the nozzle

REFERENCES

[1] Cockburn, B., Shu, C.-W. (1989) ”TVB Runge-Kutta Local Projection Discontinuous Galerkin Finite Element Method for Conservation Laws II: General Framework”, Mathematics of Computation, vol. 52, no. 186, p. 411.

[2] Michalak K., Ollivier-Gooch C. Limiters for unstructured higher-order accurate solutions of the Euler equations // 46th AIAA Aerospace Sciences Meeting and Exhibit, 2008. Art. 2008776. 14 p. doi.org/10.2514/6.2008-776.

CFD ANALYSIS OF PRESSURE DROP FROM THE AIR SIDE IN AUTOMOTIVE HEAT EXCHANGER USING POROUSMEDIA APPROACH

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Keywords: Automotive heat exchanger modelling, Porous media, Numerical simulations.

ABSTRACT

Air-to-liquid heat exchangers which are used in the automotive industry are of fin and tube type. In conjunction with the heat exchanger, axial fans are used, for two main reasons: to compensate the pressure drop of air and to enhance the cooling efficiency. In design process of heat exchanger, it is necessary to choose the appropriate axial fan which will meet the demands. One of the main data set in that sense is the relationship between the air volumetric flow rate and pressure drop in the heat exchanger. In this paper, air flow through the fin and tube type heat exchanger is analyzed using steady-state numerical simulations. Since it is practically impossible to generate the numerical grid for the real, physical fins, they are modelled using the porous media approach [1], with Darcy-Forchheimer model, applied in defined cell zone which corresponds to fins. By this, additional sink/source term is added in momentum equation. From series of numerical computations, where the inlet flow rate is varied, the relationship between pressure drop in porous zone and flow rate is established. Flow of the air is treated as incompressible and isothermal. OpenFOAM [2], free and open-source software for computational fluid dynamics (CFD) is used for aforementioned computations. The control volume is modelled to match the experimental airflow test rig set up, while for the boundary conditions velocity inlet and pressure outlet are used. Symmetry boundary condition is applied along the longitudinal plane of the model, in order to reduce the mesh count. Values of coefficients in Darcy-Forchheimer model are estimated from the geometrical characteristics of the heat exchanger and available experimental data. It is concluded that porous media approach implemented in OpenFOAM software can be used as toolkit in prediction of pressure of drop from the air side in automotive heat exchanger.

REFERENCES

[1] Li Z., Ding Y., Liao Q., Cheng M., Zhu X. (2021), "An approach based on the porous media model for numerical simulation of 3D finned-tubes heat exchanger," International Journal of Heat and Mass Transfer, Volume 173, 121226, ISSN 0017-9310, *https://doi.org/10.1016/j.ijheatmasstransfer.2021.121226.*

[2] The OpenFOAM Foundation, OpenFOAM v9: http://www.openfoam.org

CONCEPTUAL DESIGN OF SOLAR-POWERED HIGH-ALTITUDE LONG ENDURANCE AIRCRAFT

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Keywords: HALE/ HAPS, conceptual design, solar-powered aircraft, aerodynamic analysis, structural analysis

ABSTRACT

The design of high-altitude unmanned aerial vehicles is one of the most current research topics today in the field of aviation. The possible purposes of such flying platforms are numerous, from communication hubs, terrain observations, performing various measurements in the upper layers of the atmosphere, to various military uses. However, these are complex systems that involve many unresolved scientific and research challenges such as: the necessity of extremely low airframe weight, low air pressure and density cruising at high altitudes where air pressure and density are much lower than in the Earth's vicinity, sub-zero temperatures, exposure to increased radiation, low Re implying accentuated viscosity effects and decreased aerodynamic characteristics, assuring complete flight autonomy, need to generate the required energy for flight solely from solar energy, adequate sizing and control of rechargeable batteries, etc.

At the beginning, the initial mission requirements, mission profile, assessment of daily power consumption and battery mass as well as methodologies for the initial estimation of aircraft structural mass and wing loads are discussed. Then a novel high-lift airfoil specially designed for low-Re high-altitude flight through multi- objective optimization was designed by using genetic algorithm. Subsequently, aerodynamic analysis of the wing carried out by the methods of computational fluid mechanics, specifically by solving Navier-Stokes equations averaged by Reynolds statistics and closed by a 4-equation turbulent model is shown. Finally, static analyses of the behavior of wing structures under the combined action of calculated aerodynamic and gravitational loads were performed, as well as dynamic, modal analyses (important for knowing the response of the structure in non-stationary operating conditions) using the finite element method.

REFERENCES

[1] Hasan, M.S. (2022), "Analysis, modeling and optimization of solar-powered high-altitude platform-station (HAPS)," *Doctoral Dissertation,* Belgrade, Serbia, April, 2022.

[2] Hasan, M. S., Svorcan, J. M., Simonović, A. M., Mirkov, N. S., & Kostić, O. P. (2021). Optimal airfoil design and wing analysis for solar-powered high-altitude platform station. Thermal Science, (00), 241-241.

[3] Noth, A., Siegwart, R., and Engel W., "Design of Solar Powered Airplanes for Continuous Flight," Environmental Research, no. 18010, p. 18, 2007, doi: DISS. ETH NO. 18010.

PROSPECTS OF DRAFT GEAR MODELLING FOR TRAINS IN EUROPE

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Keywords: Railway, Draw gear, Modelling, Nonlinear

ABSTRACT

The railway vehicles coupling system and draft gear on European trains carry traction forces between vehicles. Most of the freight and some passenger trains in Europe are equipped with a divided coupling system and draft gears, e.g. screw couplings with draw gear and buffers. Screw couplings failure leads to train breaks since they are designed as a safety device, in particular coupling links and screw as main safety components pre-planned to break. Mathematical modelling of friction draw gear and buffers as nonlinear elements have hysteresis and significant influence in longitudinal train dynamics (LTD) models. The different approaches were applied to solve this discontinuity based on velocity-dependent, intermediate slope, and others during the development of mathematical models.

The Digital Automatic Coupler (DAC) testing, that has been launched in 2022., indicates the transition from the current system and enables faster, automated shunting processes which will increase the capacity of railway transport. Testing under real operational conditions involves prototyp of automatic coupler: CAF (SA3-Typ), Dellner (Scharfenberg-Typ), Wabtec (Schwab-Typ) and Voith (Scharfenberg-Typ). Mathematical modelling of this automatic coupler will be based on previous automatic coupler models developed for passengers and non-European freight trains.

REFERENCES

[1] Wu, Q., Cole C., Lou S., Spiryagin M. (2014), "A review of dynamics modelling of friction draft gear", Vehicle System Dynamics, April 2014.
[2] Spiryagin, M., Cole, C., Sun, Y.Q., McClanachan, M., Spiryagin, V., McSweeney, T. (2014), "Design and Simulation of Rail Vehicles", CRC Press, UK, 2014, pp. 337.
[3] Crciun, C. I., Cruceanu, C. (2018), "Longitudinal dynamic force distribution for different hysteretic buffer characteristics", The 8th International Conference on Advanced Concepts in Mechanical Engineering IOP Publishing IOP Conf. Series: Materials Science and Engineering 444 (2018) 042003 doi:10.1088/1757-899X/444/4/042003
[4] Massa, A., Stronati, L., Aboubakr, A. K., Shabana, A. A., Bosso, N. (2012), "Numerical study of the noninertial systems: application to train coupler systems", Nonlinear Dynamics, Vol. 68, No. 1-2, pp. 215–233.
[5] Wu, Q., Spiryagin, M., Cole, C., et al. (2018), "International benchmarking of longitudinal train dynamics simulators: results", Vehicle system dynamics, 2018, Vol. 56, No. 3, pp. 343–365.
[6] www.dac4.eu

LAYERED MODEL OF RED BLOOD CELL MEMBRANES AS VISCOELASTIC SHELLS

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Keywords: Red blood cells, Membrane, Viscoelastic solid, Deformability.

ABSTRACT

Red blood cells (RBC) fulfil important functions of delivering oxygen, carbon dioxide and nutrition's from the lungs to tissue and back. RBC membranes are composed by the phospholipid bilayer (b), internal cytoskeleton (c), and outer shell of the glycocalyx (g). RBC membranes can also be loaded by absorbed cholesterol, metabolic products, tissue decay components and some other molecules and particles. As a result, the mechanical and electric properties of RBC of young healthy donors and patients with cancer and stroke are different [1]. High thickness and rigidity of such RBC decrease their ability to pass through the capillaries with diameters ~5μm. Besides, novel technologies based on loading of the RBC by nanoparticles and nanotubes for the diagnoses and treatment purposes also needs detailed models of the RBC deformability in the capillaries or microtubes of different bioengineered devices.

In this study a review of the mathematical models of RBC membranes as layered shells is presented. A novel model composed by three well-studied layers (b), (c), (g), and additional layers of nanodiamonds, ND (d) and hydration layer (h) of bound water molecules. Each layer was modeled as viscoelastic Kelvin-Voigt body. Numerical computations for the 3D biconcave shape were carried out by the molecular dynamics simulations. Validation of the numerical results was conducted on the corresponding semi-analytical solution for the spherical model [1]. The results have been used for estimation the thickness of the layer of ND on the RBC of experimental rats before and after the X-ray treatment of the transplanted cancer [2] and the thickness of the (h) layers in healthy volunteers and patients [3]. High accuracy of the model has been confirmed.

REFERENCES

[1] Batyuk L., Kizilova N. (2018), "Modeling of dielectric permittivity of the erythrocytes membrane as a three-layer model," *Development trends in medical science and practice: the experience of countries of Eastern Europe and prospects of Ukraine*, Riga, "Baltija Publishing," pp. 18-37.
[2] Batyuk L., Kizilova N., Berest V. (2017), "Investigation of antiradiation and anticancer efficiency of nanodiamonds on rat erythrocytes," *IEEE 7th Intern. Conf. "Nanomaterials: Application & Properties",* Odessa, Ukraine, 04NB23.

EFFICIENT FLOW-FIELD DESIGN FOR PROTON EXCHANGE MEMBRANE FUEL CELLS

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Keywords: Power engineering, Fuel cell, Flow-field, Uniform flow distribution, Optimization.

ABSTRACT

Proton exchange membrane fuel cells (PEM FC) represent green carbon-free renewable energy sources based on direct conversion of the chemical energy into electrical one ($H_2+O_2 \rightarrow H_2O$ + energy). The PEM needs uniform distribution of the fuel gases over the membrane. Different designs of the flow-field plates as the systems of channels for hydrogen/air delivery to the anode/cathode side of the PEM have been elaborated, optimized, manufactured and tested [1]. Nevertheless, the problem of the best design providing uniform gas delivery at low pressure drop, low hydraulic resistivity of the flow field, and low electric losses is still widely discussed in literature [2]. In this study a T-type fractal system with n generations of rectangle channels with constant depth $h_j = 1\,mm,\ j = 1,2,...,n$ and scaled gradually decreased widths $w_j = \lambda w_{j-1},\ \lambda < 1$ is proposed.

CFD modeling has been conducted with AnSys Fluent 2021 R3 software (academic version). The size of the FC is 5x5 cm; the inlet mass flow rate $\dot{M}$ has been taken from the experiments [2]. The constant temperature at the wall due to chemical reaction and electric current has been set. The total entropy production ($\dot{S}$) due to viscous and thermal dissipation and Joule heat and the flow uniformity parameter ($\zeta = k^{-1}\sum_{j=1}^{k}\left|\dot{m}_j - \dot{m}_{mean}\right|$, where $\dot{m}_j$ is the mass flow rate in the j-th outlet, $\dot{m}_{mean} = \dot{M} / k$) have been used for selection of the best design $\left\{w_j\right\}_{j=1}^{2k-1}$ for each n=3-6. In comparison to other fractal systems [1,2], the new design has different widths w_n of the outlet channels that provides constant hydraulic resistivity of each way along the fractal flow field from the inlet to any of $k=2^{n-1}$ outlets and more uniform fuel delivery to PEM.

REFERENCES

[1] Sauermoser M., Kizilova N., Pollet B.G., Kjelstrup S. (2020), "Flow field patterns for proton exchange membrane fuel cells,"*Front. Energy Res*.vol.8, 13.

[2] Sauermoser M., Pollet B.G., Kizilova N., Kjelstrup S. (2020), "Scaling factors for channel width variations in tree-like flow field patterns. An experimental study," *Intern. J. Hydrogen Energy*, vol. 46, pp. 19554–19568.

OPTIMIZATION OF COMPACT FRACTAL-TYPE HEATERS/COOLERS FOR AEROSPACE ENGINEERING

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Keywords: Fluid flow, Heater, Cooler, Optimization, Aerospace engineering.

ABSTRACT

Elaboration of compact heaters and coolers with high efficiency is of great interest for aerospace applications including the nanoavionics, microprocessors and microengines. Very efficient structures can be found in nasal ducts of polar animals [1]. In the reindeers the cold air passes through the spiral-type structures [2]. As a result, the ambient air of T~-(30-60)ºC can be heated to the body temperature (T~38-39º C) after passing a relatively short area of the length L~8-20 cm (from new-born to mature animals). The ramified fractal-type structures are proper to polar bears, wolves and foxes [1]. In this study the fluid flow through a rectangle channel with fractal fins of n=2-4 generations of T- or Y-type junctions is considered. The heater is located inside the channel along its axis.

The dimensions of the fractal have been taken from the measured data [2]. Exact solution of the optimization problem ($Y_h \to \max$, $L_{th} \to \min$, where Y_h is the hydraulic conductivity, L_{th} is the thermal inlet length) has been obtained by decomposition of the complex geometry into a set of flows between the parallel plates and rectangle channels. Their analytical values Y_h are known from the general 2D theory. Numerical computations on the steady 3D laminar and turbulent fluid flow with heat transfer along the rectangle duct with fractal heater have been carried out in the ANSYS Fluent 2022R1 software (academic version). The mean temperature <T>(x), pressure <p>(x) and velocity <v>(x) distributions have been computed for each geometry. The most efficient design has been chosen using the Pareto frontiers (Y_h, L_{th}). For each value n=2-4 at least 2-3 designs with reasonably low length L_{th} and high conductivity Y_h have been found and proposed for aerospace and microfluidic applications.

REFERENCES

[1] Ulu G., Semerciöz A.S., Özilgen M. (2021),"Energy storage and reuse in biological systems: Case studies,"*Energy Storage*, vol. 3, e253.

[2] Solberg S.B.B., Kjelstrup S., Magnanelli E., Kizilova N., Barroso I.L.C., Acquarone M., Folkow L. (2020),"Energy-efficiency of respiration in mature and new-born reindeer,"*J. Comparative Physiol. Ser. B*, vol.190, pp.509-520.

WATER-DRIVEN POLUTIONS TRANSFER AND ACCUMULATION AT THE FLUID-SOLID INTERFACES

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Keywords: Environmental engineering, Water flows, Pollutions, Sustainable development.

ABSTRACT

During the last decades global climate changes lead to gradual warming of the air, appearance of the fast 'heat waves', storms and tornado [1]. As a result, salinity of the river waters increased that lead to worth conditions of the river plants and animals. In this study the results of monitoring of the air temperature T_a, concentration of the industrial pollutions C_j in the air and in the river water B_j over the territory of Kharkiv city and rivers Kharkiv, Lopan and Udy during 2018-2020 years are presented. The non-linear regression dependencies between the measured value have been computed and analysed.

A mathematical model based on the non-linear systems of ordinary differential equations for the ground waters (GW), surface waters (SW) and concentrations of the pollutions in the air (C_j), GW (D_j), SW (B_j) and soils (S_j) has been formulated accounting for the water precipitation, evaporation, runoff and storage for the drinking water (DW), technical water (TW) and waste water (WW) treatment, and pollution transfer and accumulation at the fluid-solid interfaces. Two steady states of the system have been computed; one corresponds to the healthy ecology of the city when all the pollutions are accumulated in the WW and cleaned, while another solution correspond to high pollutions without any possibility of the ecosystem for self-restoration. The model has been validated based on the computed regression dependencies and the results obtained on different mathematical model on the same urban territory [2]. A good correspondence between theoretical and measured data has been shown. Several scenarios of drinking water availability depending on the population growth and industrial development are computed based on the mathematical model with determined parameters. It is shown, due to non-linearity of the model, chaotic dynamics in the system is possible. Some strategies of stabilization of the system and control over the DW availability are proposed and discussed.

REFERENCES

[1] Stewart I., Mills G. (2021) *The Urban Heat Island*, Esevier.

[2] Kizilova N., Rychak N. (2021), "*Optimal strategies for water management and self-restoration of the ecosystems: nonlinear dynamics, stability and controllability*," 16th Intern. Conf. "Dynamical Systems: Theory and Applications", Lodz, pp. 520-521.

INVESTIGATION OF SHAPE MEMORY ALLOYS CONSTITUTIVE MODELING

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Keywords: shape memory alloys, modeling, finite element method, finite strains.

ABSTRACT

Shape Memory Alloys are often used as super-smart materials that can follow specific devices' behavior demands by their specific properties [1]. The possibility of memorizing the basic shape or exhibiting large deformations and rotations that can be recovered at a specific temperature inspired researchers to investigate SMA experimentally and simulate the SMA structures response by Finite Element Method (FEM) software. Two main topics which improved the accurate FEM simulation recently are:

- Thermo-mechanical coupling [2] and
- Extension of small strain stress integration algorithm to large strain problems [3].

These provided the possibility to model various specific behaviors such as:

- Response of the SMA structures loaded by various loading rates controlled by force or displacement [2],
- Stress relaxation and creep behavior [4],
- Large deformation and rotations in real SMA structures [3].

In this work, the author will present an overview of the SMA structures' behavior simulation with specific details [2-5] related to further investigation activities.

REFERENCES

[1] Dunić, V., Slavković, R. and Pieczyska, E. (2018), "Properties and Behavior of Shape Memory Alloys in the Scope of Biomedical and Engineering Applications" in *Biomaterials in Clinical Practice*, Springer

[2] Dunić, V., Pieczyska, E., Tobushi, H., Staszczak, M., Slavković, R. (2014), "Experimental and numerical thermo-mechanical analysis of shape memory alloy subjected to tension with various stress and strain rates", *Smart Materials and Structures*, 23, 5, 055026 (11pp)

[3] Dunić, V., Slavković, R., (2020), "Implicit stress integration procedure for large strains of the reformulated Shape Memory Alloys material model", *Continuum Mechanics and Thermodynamics*, 32, 5, 1287-1309

[4] Dunić, V., Pieczyska, E., Kowalewski, Z., Matsui, R., Slavković, R. (2019), "Experimental and Numerical Investigation of Mechanical and Thermal Effects in TiNi SMA during Transformation-Induced Creep Phenomena", *Materials*, 12, 6, 883

[5] Pieczyska, E., Staszczak, M., Dunić, V., Slavković, R., Tobushi, H., Takeda, K. (2014) "Development of stress-induced martensitic transformation in TiNi Shape Memory Alloy", *Journal of Materials Engineering and Performance*, 23, 7, 2505-2514

PHYSIOLOGICAL LOADING AND ITS EFFECT ON STREAMING POTENTIAL GENERATED BY INTERSTITIAL FLUID FLOW IN DISORDERED BONE'S CANALICULI

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Keywords: streaming potential, fluid flow, physiological loading, poroelastic modeling, Osteogenesis imperfecta.

ABSTRACT

Bone streaming potentials (SPs) and streaming currents (SCs) may be employed to investigate bone pore structure and fluid flows, as well as to send remodeling signals to cells. This study was undertaken to address two related problems. First, will the physiological loading generated from gait cycle of Osteogenesis imperfecta patient affect the magnitude of SP? Second, does the physiological loading have any effect on the pore pressure and fluid flow of OI affected osteon? A mathematical model of an osteon has been used to relate the effects of loading on SPs and SCs developed in a canaliculi and to investigate the effect of strain loading on interstitial fluid flow.

The transversely isotropic poroelastic model osteon model was developed to find the fluid pressures at the inner and the outer surfaces of the osteon wall. Two types of impermeable boundary cases for the osteon outer wall are considered: elastic restrained (Case I) and displacement confined (Case II). Also, a canaliculus model was developed to correlate the fluid pressure gradient to the electrical double layer effect of the canaliculi. Finally, Ohm's law was employed to determine the SP.

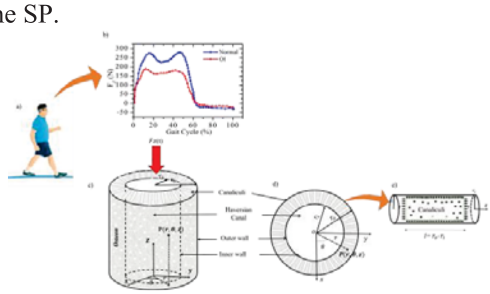

Figure 1. Representation of methodology: a) Representation of physical exercise b)Gait pattern of normal and OI person c) cylindrical osteon d) cross-section of osteon with canaliculi e)strain induced canaliculi

Loading was done in accordance with the gait cycles reported for OI and healthy bones. The theoretical model was developed to find the distribution patterns of interstitial fluid patterns for OI affected osteon at various time points during the stance phase of the gait cycle. There was a significant decline in fluid flow when the osteon for OI gait loading. At higher strain rate there is linear increase in streaming potential amplitude (SPA), which is off course less compared to normal gait loading. The results suggested that improved physical exercises or activities can be developed to increase the level of canalicular fluid flow, thereby initiating possible osteogenic activities and the bone.

REFERENCES

[1] Cowin, S.C., Weinbaum, S., Zeng, Y. (1995), "A case for the *bone canaliculi as the anatomical site of strain generated potentials," Journal of Biomechanics 28, 1281–1297.*

[2] Wu, X. G., Yu, W. L., Cen, H. P., Wang, Y. Q., Guo, Y., & Chen, W. Y. (2015)."*Hierarchical model for strain generalized streaming potential induced by the canalicular fluid flow of an osteon*." *Acta Mechanica Sinica* 31.1, 112-121.

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NUMERICAL SIMULATION OF COLUMN BASE PLATE BEHAVIOR

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Keywords: column base plates, finite element analysis, rotational stiffness, moment capacity, steel structures.

ABSTRACT

Base plates are the structural components responsible for transferring loads from the structure to the foundation [1]. They have a significant influence on the stability and stiffness of steel structures. This kind of connection has a complex nature due to the different behaviors of the components, including the base plate, grout, anchor bolts, and foundation. The main goal of this work is to investigate the rotational behavior [2] of column base plate connections. First, a nonlinear three-dimensional finite element model (Figure 1) was created for this connection using the CAST3M software [3]. The model was subjected to a constant axial load, and then a monotonic moment loading was applied. The model response is validated and calibrated with an existing experimental test. Next, this model evaluates the effects of some of the essential components of column base connections, such as anchor bolts, base plates, and stiffeners [4].

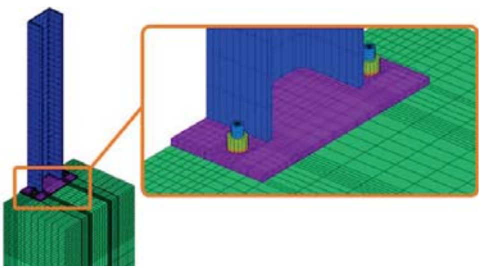

Figure 2 Meshing of column base plates

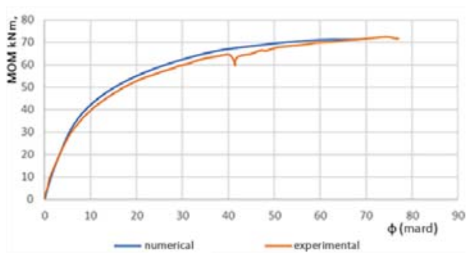

Figure 3 Comparison between the experimental and numerical (FEA) result

REFERENCES

[1] Ebadi, P., Soleimani, M. & Beheshti, M., (2018). Design methodology of base plates with column eccentricity in two directions under bidirectional moment. Civil Engineering Journal.

[2] Latour, M., Piluso, V., Rizzano, G., (2014), "Rotational behaviour of column base plate connections: Experimental analysis and modelling", *Engineering Structures*, 68, pp. 14-23.

[3] http://www-cast3m.cea.fr

[4] Ravari, A. K., Othman, I. B., Ibrahim, Z. B., (2011), "Finite element analysis of bolted column base connection without and with stiffeners", *International Journal of Physical Sciences*, 6(1), pp. 1-7

NUMERICAL INVESTIGATION OF THE INFLUENCE OF GEOMETRY ON THE THERMAL PROPERTIES OF A HEAT PIPE

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Keywords: Heat pipe, Heat transfer, Numerical simulation.

ABSTRACT

The unique property of a very high heat transfer rate in heat pipes, which originates from the phase change of a high latent heat working fluid, has led to their use in a wide range of engineering applications such as electronics cooling, heat exchangers, spacecraft and satellites etc. The zero-power demand, low weight, compactness and reliability further the benefits of their use. A small amount of working fluid inside a sealed pipe is used to transport heat with a slight temperature difference between the evaporation and condensation segments. The recirculation of fluid is realized through a wick structure and driven by capillary forces. In order to investigate the influence of the shape of the heat pipe on the rate of heat transfer, a numerical test was performed on two types of flat geometry heat pipes – square and hexagonal shaped, as well as circular and ellipsoidal shaped. The parameters of interest were pressure and temperature distribution, velocity in condensation direction and thermal conductivity distribution. Results indicate that the difference in geometry causes differences in all observed parameters, and thus significantly affects the thermal properties of the heat pipe.

REFERENCES

[1] Mahjoub S., Mahtabroshan A. (2008), "Numerical Simulation of a Conventional Heat Pipe", *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering* Vol:2, No:3.
[2] Desai K., Lakra G., Rajesh R., Prabu S. (2021), "Investigation on the effect of thermal properties by changing geometry of a heat pipe using simulation", *Materials Today: Proceedings,* Volume 46, Part 17, Pages 8473-8479.
[3] Nemec P., Čaja A., Malcho M. (2011), "Mathematical model for heat transfer limitations of heat pipe", *Mathematical and Computer Modelling,* Volume 57, Issues 1-2, Pages 126-136.
[4] Mahdavi M., Tiari S., De Schampheleire S. (2018), Qiu S., "Experimental study of the thermal characteristics of a heat pipe", *Experimental Thermal and Fluid Science,* Vol. 93, Pages 292-304
[5] Suman B., Kumar P. (2005), "An analytical model for fluid flow and heat transfer in a micro-heat pipe of polygonal shape", *Int. J. Heat Mass Transf.*, 48 (21-22), p.4498–4509.
[6] Chan C.W., Siqueiros E., Ling-Chin J. (2015), Royapoor M., Roskilly A.P., " Heat utilisation technologies: A critical review of heat pipes", *Renewable and Sustainable Energy Reviews* 50, p.615–627
[7] Faghri A.(2018), "Review and Advances in Heat Pipe Science and Technology", *Journal of Heat Transfer,* Vol 134
[8] Lenhard R., Malcho M., Jandačka J. (2019),"Modelling of heat transfer in the evaporator and condenser of the working fluid in the heat pipe", *Heat Transfer Eng.* 40 (3-4) 215–226.

AN OVERVIEW OF FORWARD DYNAMICS ALGORITHMS AND THEIR USE IN OPEN-SOURCE DYNAMICS ENGINES

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Keywords: Forward dynamics, Robotics, Dynamics engine, Open-source, Simulator.

ABSTRACT

Simulation of real-world dynamics is of major importance in testing and verifying developed industrial concepts and solutions, developing and verifying potential control paradigms, scientific research, learning and training tools, or the entertainment industry as a basis for a game engine. The module of the 3D virtual simulator that achieves simulation of the real-world behaviour such as rigid and elastic body dynamics, particle dynamics, fluid dynamics, electrodynamics, magnetism, etc., is often referred to as a dynamics engine or physics engine. The core of the rigid body dynamics (physics) engine is the solution to the forward dynamics problem, which is defined as finding a rigid body's path, velocity, and acceleration for a given input actuating torque and external forces. The past few decades saw a considerable amount of research in robot dynamics modelling, and there are many methods for robot dynamic model development available in the literature. The most commonly used algorithms for solving robot forward dynamics problem are the Composite-Rigid-Body Algorithm (CRBA) [1] and the Articulated-Body Algorithm (ABA) [2]. CRBA and ABA are reduced coordinate methods where known constraints, such as joints, are embedded in the formulation of the equations of motion. Besides reduced coordinate methods, there are maximal coordinate methods using Lagrange multipliers [3-4] to enforce constraints using constraint reaction forces.

This paper presents a comprehensive overview of forward dynamics algorithms and their usage in dynamics engines. Special reference is given to the most commonly used algorithms and methods and their advantages and disadvantages depending on the application. Most important software intended for virtual simulation of robots is presented, emphasising free, open-source use.

Firstly, brief history and introduction of CRBA, ABA and Lagrange multipliers methods is given, as they are the most commonly used methods employed by dynamics engines. Next, general phases of the simulation process are described. An integral segment in creating a simulation is the definition of the world - a description of the environment and robot models that are to be simulated. Application of the actuation and external forces and torques to the model, detection of collisions between the bodies, constraint solving, forward dynamics computation and integration to obtain velocity and position of the bodies are performed. Each of these aspects is described with special attention to constraint solving and computation of forward dynamics using the algorithms mentioned above. There is a myriad of free and open-source dynamics engines available, and the focus herein is on the most commonly used engines for simulating robots: Open Dynamics Engine (ODE) [5], DART (Dynamic Animation and Robotics Toolkit) [6], Bullet [7], and Simbody [8] as they are present in the two most popular free, open-source robotics simulators Cyberbotics Webots [9] and OpenRobotics Gazebo [10]

(Ignition is the successor of Gazebo).

It can be concluded that the most used reduced coordinate method in simulators is ABA, while Lagrange multipliers are the most popular maximal coordinate method. ABA is mainly used for simulating open-loop multi-body systems (robot manipulators) where joint constraints are known upfront. In contrast, Lagrange multiplier methods are used where modularity of the simulated model during simulation run-time is crucial. In reality, most dynamic engines have access to both of these methods to ensure the diversity of the simulation processes that can be executed.

Presented conclusions are useful for the appropriate selection of available simulation methods depending on the application, as well as within further advancement and development of simulation and verification frameworks for robotic manipulators and rigid body systems.

REFERENCES

[1] Walker M. W., Orin D. E. (1982), "Efficient Dynamic Computer Simulation of Robotic Mechanisms," *J. Dyn. Sys., Meas., Control.*, vol. 104, no. 3, pp. 205-211, Sept., doi: 10.1115/1.3139699.

[2] Featherstone R. (2008), "Forward Dynamics - Propagation Methods," *in Rigid Body Dynamics Algorithms*, Boston, MA, U.S.: Springer, ch. 7, pp. 119-140.

[3] Baraff D. (1996), "Linear-Time Dynamics using Lagrange Multipliers," *SIGGRAPH*, New Orleans, Louisiana, U.S, pp. 137-146.

[4] Hernandez F., Garre C., Casillas R., Otaduy M. A. (2011), "Linear-Time Dynamics of Characters with Stiff Joints", *Proc. of V Ibero-American Symposium in Computers Graphics - SIACG*, pp. 163-168.

[5] Open Dynamics Engine. (2001-2004), Russell L. Smith. [Online]. Available: https://www.ode.org/

[6] DART (Dynamic Animation and Robotics Toolkit). (2021), Georgia Tech and Carnegie Mellon University. [Online]. Available: https://dartsim.github.io/index.html

[7] Bullet. (3.24). [Online]. Available: https://pybullet.org/wordpress/

[8] Simbody: Multibody dynamics API. (3.7), SimTK. [Online]. Available: https://simtk.org/projects/simbody/

[9] Webots. (2022), Cyberbotics. [Online]. Available: https://cyberbotics.com/

[10] Gazebo. (2022), Open Robotics. [Online]. Available: https://gazebosim.org/home

STATICS OF THE FLEXIBLE MESHED CYLINDRICAL NANOSHELL IN THE TEMPERATURE FIELD

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Keywords: Mathematical modeling, Meshed cylindrical nanoshell, Temperature field, Steady solution method .

ABSTRACT

In this work, a mathematical model of the flexible meshed cylindrical nanoshell behavior under static loading and temperature effects is constructed. The Kirchhoff-Love kinematic model was adopted. Geometric nonlinearity is taken into account according to the Theodor von Karman model. We consider the shell material to be a homogeneous isotropic Cosserat pseudocontinuum. Along with force stresses, moment stresses are considered, while it is assumed that the fields of displacements and rotations are not independent. The dependence of the higher-order symmetric moment tensor components on the bending-torsion tensor components is taken in the form proposed by Yang [1]. The Duhamel-Neumann's hypothesis is taken into account; it is believed that thermal deformations are superposition of elastic deformations and thermal expansions.

The motion equations of a continuous micropolar cylindrical shell taking into account external medium dissipation and thermal effects, the boundary and initial conditions are obtained from the Hamilton's energy principle. To the motion equations of the continuous micropolar cylindrical shell, we add three-dimensional stationary heat equation with first kind boundary conditions. It is assumed that the shell consists of two mutually perpendicular edges families. Each family is characterized by the edges width, distance between the edges, and the angle of edges inclination relative to the positive OX axis direction. According to the G. I. Pshenichnov's continuum theory, the regular system of densely located edges can be replaced by the continuous layer (homogenize). Pshenichnov 's theory allows, on the basis of the flexible continuous cylindrical nanoshell element behavior mathematical model, to obtain the mathematical model of the meshed nanoshell behavior.

The static problem solution was obtained by the steady solution method [2]. In the work, a study of the stationary temperature influence, mesh geometry, and an independent length parameter related to the shell material particles moment interaction on the stress-strain state of the shell was made.

The work was supported by the RSF grant 22-21-00331

REFERENCES

[1] Yang, F., Chong, A. C. M., Lam, D.C. C, Tong, P. Couple stress based strain gradient theory for elasticity. Int. J. Solids Struct. 2002. 39. pp. 2731–2743.

[2] Krysko, V.A., Awrejcewicz, J., Komarov, S.A. Nonlinear deformations of spherical panels subjected to transversal load action. Computer Methods in Applied Mechanics and Engineering.2005. 194 (27-29), pp. 3108–3126

ANALYTICAL MODELING OF HARDNESS IN THE HEAT AFFECTED ZONE DURING WELDING A PLATES MADE OF STEEL P355GH BY GMAW PROCESS

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Keywords: welding, analytical modeling, hardness, heat affected zone.

ABSTRACT

The quality of the welded structure is often assessed on the basis of the value of hardness in the heat affected zone (HAZ). These property of quality and reliability is very important to be determined as accurately as possible using analytical methods. Main purpose of investigations performed here is to gain insight into the accuracy and applicability of available analytical models which are significantly faster and simpler than numerical ones. The prediction of hardness value in HAZ at some distance from the surface of plate, based on the different analytical models of temperature filed, was carried out. One of the most important parameters that affect the value of hardness - time $\Delta t_{8/5}$, was determined based on above mentioned 3D analytical models of temperature field. The hardness values distribution was determined experimentally after the plates made of steel P355GH are welded by GMAW process. Comparisons between analytical and experimental results were carried out and conclusions have been drawn.

A REVIEW ON GROUND SOURCE HEAT PUMP

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Keywords: energy; geothermal; renewable; heat pump; ground loop system; diffusivity; temperature.

ABSTRACT

A Ground Source Heat Pump (GSHP) is a type of heating system that transfers heat to or from the ground, taking advantage of the earth's relatively constant ground temperatures throughout the seasons. The earth can be considered as a semi-infinite medium whose temperature is determined by a variety of factors and the surface temperature of which acts as a boundary condition that effects the internal field. Due to poor thermal diffusivity of rocks, any temperature change at the border is slowly transported downward and recorded, but attenuated and diffused at depth below the surface [1]. Ground-source heat pumps use renewable energy stored in the ground to provide one of the most energy-efficient methods of heating. The use of free energy from the environment reduces consumption costs while also reducing reliance on fossil fuels. They also can reduce GHG emissions by 66% or more compared with conventional heating systems that run on fossil fuels [2].

The method used in working of a GSHP is based on the fact that the earth's core temperature is largely consistent, warmer than the air in winter and colder than the air in summer. During the winter, a geothermal heat pump may move heat stored in the earth into a structure, and during the summer, it can transfer heat out of the building. In this paper, we will look at the history of geothermal energy and GSHP as one of its applications, and the numerous configurations that it can be built in, which includes the four basic type of ground loop systems. We will also look at the advantages and disadvantages of the GSHP, its uses, and the new technology being made using the GSHP.

REFERENCES

[1] V. Cermak, "Underground temperature and inferred climatic temperature of the past millenium," *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, vol. 10, no. 1, pp. 1–19, 1971, doi: 10.1016/0031-0182(71)90043-5.

[2] A. Mustafa Omer, "Ground-source heat pumps systems and applications," *Renew. Sustain. Energy Rev.*, vol. 12, no. 2, pp. 344–371, 2008, doi: 10.1016/j.rser.2006.10.003.

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ROUV HEADING BY A FRACTIONAL-ORDER PI CONTROLLER

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Keywords: Mathematical model of ROUV motion, Stabilization, Underwater robots, Fractional-order PI controller, ROS, Gazebo.

ABSTRACT

To control a remotely operated underwater vehicle (ROUV) of the observation ROUVs class, the interactions among mechanical, electronic and information processing elements call for an integrated approach at all design and development stages. Different methodologies must be combined in a multi-formalism modelling approach supported by a suitable simulation and prototyping environment. The proposed approach involves the development of a virtual ROUV prototype in the ROS Gazebo environment, to assess performance in the successive developing steps reliably, and a ROUV controller board (stm32F407, Quad-core Cortex-A7) with a digital camera and an inertial measurement unit (3D accelerometer, 3D gyroscope, compass), to implement and run the control algorithms in real-time. A mathematical model of the system is derived to design a fractional-order PI controller of the ROUV yaw angle in the horizontal plane.

The considered system is "MUVIC-Light", which was developed by the first author to perform inspections at a depth of up to 200 meters (Fig. 1). The characteristic features of such system are a significant elongation (the length of the hull is several times greater than its diameter) and the use of rudders or ailerons to control movement. The Gazebo simulator allows to describe the objects and environment, to define the robot dynamics, and the TCP/IP protocol to transmit video and sensor data to/from the controller board.

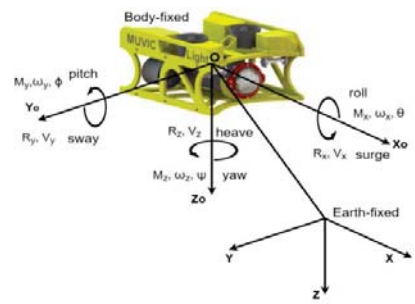

Figure 1. The ROUV coordinate system.

To tune the controller, a nonlinear 6-DOF mathematical model of the ROUV dynamics is derived based on the Euler-Lagrangian formulation. Then, by linearization, a transfer function is obtained, relating the yaw angle and the voltage applied to the motors driving the ROUV. The controller is tuned as in [1]. ROS and Gazebo allow simulation of control system, computer vision, 3D positioning, robot path planning in a realistic environment that can be considered as a digital twin. Namely, the developed codes can be directly used in a real scenario.

REFERENCES

[1] Lino, P., Königsmarková J., Maione, G., Lazarević, M.P. (2021), "Independent-joint control of 5DOF robotic manipulators by fractional-order PI^{ν} controllers," *29th Mediterranean Conference on Control and Automation (MED)*, Bari, Italy, June 22–25, pp. 403-408.

APPLICATION OF BIOLOGICAIIY INSPIRED ALGORITHMS FOR OPTIMIZATION IN MACHINING PROCESS

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Keywords: Energy efficiency, Cutting parameters, BES algorithm.

ABSTRACT

One of the most important goals of the metal processing industry is the production of high quality machine parts and achieving the highest possible productivity. Great efforts are made in reducing the energy consumption of machine tools when performing cutting operations, that significantly affect the time and cost of making parts. By choosing the optimal cutting parameters such as cutting depth, revolutions per minutes of the main spindle, feed, feed rate, energy efficiency is achieved in the process of cutting, which is the basic objective function. The total energy required to perform cutting operations depends on the cutting energy and non-cutting energy. The cutting energy depends on the required cutting power and the cutting time, while the non-cutting energy depends on the energy consumed for tool movement and the energy consumed for spindle rotation change. In this work a one-criterion optimization of cutting process parameters is presented using biologically inspired bald eagle algorithm. The obtained optimization results are presented and compared with the results reported in the literature. The results of the comparison show that the development of new biologically inspired algorithm greatly contributes to the achievement of energy efficiency in the process of manufacturing machine parts.

REFERENCES

[1] Hu, L., Tang, R., Cai, W., Feng, Y., & Ma, X. (2019), Optimisation of cutting parameters for improving energy efficiency in machining process, Robotics and Computer-Integrated Manufacturing, Vol. 59, pp. 406-416, doi.org/10.1016/j.rcim.2019.04.015.

[2] Radovanović, M. (2019), Multi-objective optimization of multi-pass turning AISI 1064 steel, The International Journal of Advanced Manufacturing Technology, Vol. 100(1), pp. 87-100, doi.org/10.1007/s00170-018-2689-z.

[3] Miodragović, G. R., Đorđević, V., Bulatović, R. R., & Petrović, A, (2019). Optimization of multi-pass turning and multi-pass face milling using subpopulation firefly algorithm. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, Vol. 233(5), pp. 1520-1540, doi.org/10.1177/0954406218774378.

[4] Gavrus, C., Ivan, N. V., & Oancea, G. (2022), Machining Parameters Optimization Based on Objective Function Linearization. Mathematics, Vol. 10(5), 80, doi.org/10.3390/math10050803.

[5] Chauhan, P., Pant, M., & Deep, K. (2015), Parameter optimization of multi-pass turning using chaotic PSO, International Journal of Machine Learning and Cybernetics, Vol. 6(2), pp. 319-337, doi.org/10.1007/s13042-013-0221-1.

[6] Mellal, M. A., & Williams, E. J. (2015), Cuckoo optimization algorithm for unit production cost in multi-pass turning operations. The International Journal of Advanced Manufacturing Technology, Vol. 76(1), pp. 647-656, doi.org/10.1007/s00170-014-6309-2.

[7] Alsattar, H. A., Zaidan, A. A., & Zaidan, B. B. (2020), Novel meta-heuristic bald eagle search optimisation algorithm. Artificial Intelligence Review, Vol. 53(3), pp. 2237-2264, doi.org/10.1007/s10462-019-09732-5.

NUMERICAL AND ANALYTICAL STUDY OF A BAR DAMPER DEVICE

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Keywords: Bar damper, Numerical elastoplastic analysis, Double-curvature deformation model.

ABSTRACT

Additional damping in the seismically isolated buildings is provided with energy dissipation devices (EDD) [1]. EDD consisting of steel bar elements between two steel plates, named bar damper (BD), is recently proposed (Fig. 1). Due to a large relative displacement of the plates, the bar elements bend and plastic hinges form at the both ends of the bars, providing seismic energy dissipation [2].

Dynamic analysis of isolated structures requires defining mechanical properties of EDD. In this paper, a nonlinear finite element model of BD is developed in Abaqus/Standard. The analysis is conducted with a built-in plasticity material model [3] and with material model in which the logarithmic objective rate is implemented via the user subroutine [4]. Based on the results, a force-displacement relationship, as well as the elastic and post-elastic stiffness and yield force of the BD are obtained.

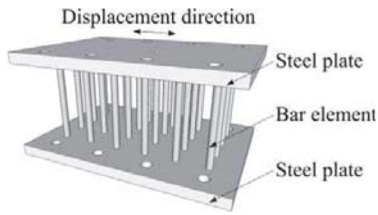

Figure 1. Bar Damper Device

An analytical model of the single bar is also proposed based on the assumption that the bar element is fixed into the steel plates. A double-curvature deformation of the steel bar occurs due to a relative lateral displacement of the plates. The elastoplastic deflection beam theory [5] is used to determine the mechanical properties of such bar element due to a monotonically increasing lateral load. The results of the proposed analytical model are in a good correlation with the numerical results, so the analytical model can be applied for determining mechanical properties of bar damper device.

REFERENCES

[1] Javanmardi, A., Ibrahim, Z., Ghaedi, K., Ghadim, HB., Hanif, MU. (2020), "State-of-the-Art Review of Metallic Dampers: Testing, Development and Implementation," *Archives of Computational Methods in Engineering*, vol. 27, issue 2, pp. 455-478.

[2] Ghaedi, K., Ibrahim, Z., Javanmardi, A., Rupakhety, R. (2021), "Experimental Study of a New Bar Damper Device for Vibration Control of Structures Subjected to Earthquake Loads," *Journal of Earthquake Engineering*, vol. 25, issue 2, pp. 300-318.

[3] ABAQUS Documentation (2013), Dassault Systèmes Simulia Corp., Providence, RI, USA.

[4] Trajković-Milenković, M., Bruhns, OT., Zorić, A. (2021), "On instability of constitutive models for isotropic elastic-perfectly plastic material behaviour at finite deformations," *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, vol. 235, issue 20, pp. 4692-4703.

[5] Gere, JM., Timoshenko, SP. (1997), "Mechanics of Materials," 3th ed., Springer Science+Business Media, Dordrecht, Netherlands.

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STABILITY OF PRESTRETCHED CIRCULAR COMPOSITE PLATES

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Keywords: Circular composite plates, Strain mismatch, Stability.

ABSTRACT

A strain mismatch between flat layers in laminated composites induces out of plane deformation. Depending on the amount of the applied strain mismatch, the transformation involves bending or buckling into one of the available finite number of 3D modes [1].

To study how the concept works, we focus on a circular bi-layer composite plate. First, after one layer of the circular composite is stretched by a prescribed amount, it is fixed onto the second layer which is stress-free. Then the structure is released. A number of distinct forms that emerge in this system, are analyzed using Föppl-von Kármán plate theory and via numerical simulations using finite element method.

From the equilibrium equation

$$\overline{D}\Delta^2 w - \nabla\cdot\left(\widetilde{\nabla}\widetilde{\nabla}\mathcal{F}\;\nabla w\right) = 0,$$

$$\Delta^2\mathcal{F} + \frac{\overline{\alpha}\left(1-\overline{\nu}_A^2\right)}{2}[w,w] = 0,$$

where the second equation comes from the in-plane compatibility condition $\nabla\times(\nabla\times\boldsymbol{\varepsilon}^0)^{\mathrm{T}} = 0$, $\widetilde{\nabla}\widetilde{\nabla}\mathcal{F} \coloneqq \Delta\mathcal{F}\boldsymbol{I} - \nabla\otimes\nabla\mathcal{F} = \boldsymbol{N}$ and $[\ .\ ,\ .\ ]$ is the Monge-Ampere operator, we show three different solutions can be obtained: *i)* for small prestretch, the system bends into an axisymmetric solution, similar to a shallow paraboloid, *ii)* for moderate prestretch the system loses its stability and deforms into a k-fold axisymmetric postbuckling form with circumferential wrinkles, where k depends on the amount of the applied prestrain, and *iii)* for large prestretch, we show that a cylindrical deformation mode is energetically favorable.

It is therefore shown in this contribution, that the amount of prestretch inducing residual stress in plates and shells may change the critical load at which the instability occurs as well as the corresponding modeform. We note that this result is not very common because higher modes usually correspond to higher potential energies.

REFERENCES

[1] L. Stein-Montalvo, P. Costa, M. Pezzulla, D. Holmes (2019), “Buckling of geometrically confined shells”, *Soft Matter*, 15(6), pp. 1215-1222.

CAM PROFILE OPTIMIZATION FOR MINIMAL JERK

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Keywords: Cam Profile Optimization, Marine Predators Algorithm, Snake Optimizer

ABSTRACT

Cam-follower systems are widespread in today's society as one of the most robust systems used in various mechanisms, and sometimes can even replace other elements such as springs or reduce the total number of parts in some system. A cam-follower system consists of a camshaft and a follower where the profile shape of the camshaft, rotating at a constant angular velocity, defines the law of movement of the follower. One of the most common applications of the cam-follower system is found in the internal combustion engine design where the shape of the camshaft determines a sequence in which appropriate valves on the cylinders open. The angular velocity of the camshafts in those applications are high, in order of magnitude of couple of thousands revolutions per second. A properly designed profile of the cam can have significant impact on the systems' performance.

The cam-follower system has a program that distinguishes two main stages: rise and dwell, and the program can consist of multiple rise and dwell sections. During the dwell section, the follower is not changing its position, and it is usually represented as a flat line in the unwrapped cam-follower program. Rise represents the change of altitude of the follower, meaning that during that phase, the follower is being displaced, and it can be modelled with smooth curves. The curve that is used for the rise should be continuous, and at least three times differentiable. The first three derivatives represent velocity, acceleration, and jerk, which are all important factors for the systems performance. The curve is usually modelled with polynomials of at least fifth degree (3-4-5), harmonic curves such as cycloid, Fourier functions etc. The use of computer techniques, numerical, metaheuristic optimization methods, such as MPA algorithm and Snake Optimizer, allows calculating the constants that make up the equations that describe the curves in higher degree than it was possible with analytic tools due to lack of boundary conditions, for different purposes.

Marine Predator Algorithm (MPA) and Snake Optimizer were used in order to determine the optimal curve of the cam profile during the rise stage of the cam-follower program for which the jerk has minimal absolute value, as well as the degree of polynomial after which these methods become unstable, or the gain of considering higher polynomials of higher degree becomes insignificant. Compared to the 3-4-5, using the polynomial of 8^{th} degree instead of 5^{th}, with the use of Snake Optimizer or Marine Predator Algorithm, considering that both give similar results, the jerk is decreased by 12,8%, and compared to the cycloidal motion the jerk is decreased by 0,27%. Increasing the degree of the polynomial up to 16^{th} degree, the jerk can be decreased by an additional 3% using the MPA compared to the 3-4-5 method and 1,7% compared to the cycloidal motion, with the same optimizer settings. When polynomial has a degree higher than 16^{th}, if the maximum number of iterations is 1000 and the size of initial population is 30, the optimizer doesn't give any useful improvement and becomes unstable. By increasing the maximum number of iterations and the population size with the rise of degrees of the polynomials, the MPA gives more stable results even after 16^{th} degree of the polynomial.

Considering that there is a 12,8% improvement through increasing the degree of the polynomial from 5^{th} to 8^{th}, and only a 3% improvement from 8^{th} to 16^{th} degree of the polynomial, increasing the polynomial degree beyond 16 results only in an increase of computational time and adds to the instability of optimization process.

REFERENCES

[1] Angeles, J., López-Cajún, C.S. (1991), "Optimization of Cam Mechanisms", Springer Science + Buisness Media Dordrecht.
[2] Bravo, H.R., Flocker, W.F., (September 7, 2011), "Optimizing Cam Profiles Using the Particle Swarm Technique", Journal of Mechanical Design, Vo;. 133, Issue 9, doi: 10.1115/1.4004587
[3] Lampinen, J. (2002), "Cam shape optimization by genetic algorithm", Computer-Aided Design, Vol. 35, Issue 8, 2003, pp. 727-737, doi: 10.1016/S0010-4485(03)00004-6.
[4] Abderazek, H., Yildiz, A.R., Mirjalili, S. (2020), "Comparison of recent optimization algorithms for design optimization of a cam-follower mechanism", Knowledge-Based Systems, Vol. 191, 2020, 105237, doi: 10.1016/j.knosys.2019.105237.
[5] Suman, B., Sudheer, Y., Reddy, C.R. (2020), "Design and material optimization of camshaft in 150 CC engine", International Scientific Research in Science and Technology, IJSRST, Vol. 7, Issue 1, doi: 10.32628/IJSRST
[6] Hashin, F. A., Hussein, A. G. (2022), "Snake Optimizer: A novel meta-heuristic optimization algorithm", Knowledge-Based Systems, Vol. 242, 2022, doi: 10.1016/j.knosys.2022.108320.
[7] Faramarzi, A., Heidarinejad, M., Mirjalili, S., Gandomi, A.H. (2020): "Marine Predators Algorithm: A nature-inspired metaheuristic", Expert Systems with Applications, Vol 152, 2020, doi: 10.1016/j.eswa.2020.113377.
[8] Norton, R.L. (2009), "Cam Design and Manufacturing Handbook", Second Edition, Industrial Press Inc., New York, NY, 2009
[9] Bižić, M., Bulatović, R., Petrović, D., Gašić, M., Savković, M. (2012), "Modeling profile and kinematic analysis of two circular-arc cams", Engineering with Computers 29, 535-546 (2013), doi: 10.1007/s00366-012-0280-z.

COMPUTED TORQUE CONTROL SIMULATION FOR 6DOF INDUSTRIAL ROBOT

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Keywords: Computed torque, Robot control, Dynamic modelling, Simulation.

ABSTRACT

Dynamics play a fundamental role in control algorithms synthesis, mechanical structure design, and motion simulation of robots. The challenge in robot control arises from the non-stationarity and the nonlinear coupling effects in the dynamic model, and many advanced control strategies have emerged within the robot control problem [1]. Besides the modelling complexity in the case of multiple DoFs, taking the dynamic model into account within the design of robot control systems in practice has drawbacks due to potential difficulties in implementation and errors that stem from structured/unstructured uncertainties. From the perspective of the appropriate selection of control strategy for a particular robot, control system performance simulation based on the robot dynamic model is a useful tool [2].

In this paper, a numerical simulation of the computed torque control (CTC) for the 6DoF industrial robot RL15 is presented. CTC is a feedforward control method used for tracking of robot's time-varying trajectories in the presence of varying loads [3]. The method implemented in this study considers the speed PI controller in the joint space of the robot, with feedforward compensation of the load torque due to the movement of interconnected robot links. Herein, the following is taken into account for realistic simulation of control system performance: 1) resonant properties of the mechanical structure; 2) the effective inertia of the actuator calculated from the inverse dynamic model; 3) motor torque limits. CTC-based control system performance is compared with the traditional speed PI controller using the realistic simulation model.

A dynamic model was developed using the modified recursive Newton-Euler algorithm (mRNEA). Firstly solution to the inverse dynamics problem has been calculated for the desired joint trajectories. Obtained actuators' torques are compared with maximum torques that motors can achieve, and in a case that these maximum levels have been exceeded, unachievable torques/forces are replaced with the maximum/minimum possible, and forward dynamics algorithm has been executed in order to calculate achievable accelerations so that the performed simulation is realistic. Joints' velocities and positions are calculated using numerical integration methods [4] and are used as reference values for control system performance simulation.

The structural flexibility of robotic manipulators may limit the performance and decrease the stability of a rigid model-based design of a control system. Given that the rigid model-based control strategies are adopted in this study, flexibilities of the mechanical structure are considered indirectly through the limitation of controller gains for simulation purposes. CAE software is used for the determination of manipulator dynamic model parameters. For the

developed CAD model of the RL15 robot, the lowest natural frequency of the manipulator is determined in CAE software and compared with simulated control system bandwidths defined by controller gains and the effective inertia obtained from numerical simulations of the dynamic model and inertia of employed motors and its gearboxes.

Control system performance simulation has been performed in Simulink software. Controller gains are selected for the LTI-model with the highest load, i.e. the maximum value of effective inertia. Dynamic saturation that takes into account motor possibilities depending on the current robot motion and load has been applied at the controller output.

Simulation of the designed control techniques is useful within the appropriate choice of the control strategy regarding achieving a compromise between the complexity of the controller development and its implementation on one side and prospective benefits obtained with controller implementation. Practical implementation possibilities are discussed within the paper.

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REFERENCES

[1] Siciliano, B., Khatib, O. (2016), “Springer handbook of robotics”, *Springer*.
[2] Vidaković, J., Kvrgić, V., Lazarević, M., Stepanić, P. (2020), “Computed torque control for a spatial disorientation trainer”, *Facta Universitatis, Series: Mechanical Engineering*, 18(2), pp. 269-280.
[3] Spong, M.W., Vidyasagar, M. (2008), “Robot dynamics and control”, *John Wiley & Sons*.
[3] Kvrgic, V., Vidakovic, J. (2020), “Efficient method for robot forward dynamics computation”, *Mechanism and Machine Theory*, 145, 103680.

MODELING, SIMULATION AND CONTROL OF PROPELLER DRIVEN SEESAW SYSTEM WITH ASYMMETRIC GEOMETRY USING PID CONTROLLER

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Keywords: PID controller, Simulation, UAVs.

ABSTRACT

Various algorithms are used to control modern unmanned aerial systems. However, thanks to the simplicity of application, the most commonly used control algorithm for aircraft but also for other dynamic systems in various industries is the PID (Proportional, Integral, Derivative) controller. For the proper response of the system and fast stabilization during the action of certain disturbances during its operation, it is necessary to precisely adjust the parameters of the PID controller. This paper presents a mathematical model of a seesaw system for which a PID control simulation was performed for different asymmetric geometries. Asymmetric geometry implies different positions of the rotor relative to the axis of system rotation, as well as when the rotor disks do not lie in the same plane, which simulates the influence of inaccuracy in the construction of multi-rotor UAVs. The control simulation shows the possibility of compensating for the mentioned geometric irregularities to ensure the appropriate behavior of the system. The limit values of this influence are also shown, at which the PID control algorithm cannot adequately perform the correction and ensure the correct response of the system. The obtained simulation results would be verified by making an adequate physical model and obtaining experimental results for the same input parameters, which may be the subject of future research work.

REFERENCES

[1] Tengis, T., Uurtsaikh, L., & Batminkh, A. (2020). Balancing a seesaw with reinforcement learning, *International Journal of Advanced Culture Technology*, *8*(4), 51-57.

[2] Idrissi, M., Salami, M., & Annaz, F. (2021). Modelling, simulation and control of a novel structure varying quadrotor. *Aerospace Science and Technology*, *119*, 107093.

[3] Nemati, A., & Kumar, M. (2014, June). Modeling and control of a single axis tilting quadcopter. In *2014 American Control Conference* (pp. 3077-3082). IEEE.

[4] Romero, L. E., Pozo, D. F., & Rosales, J. A. (2014). Quadcopter stabilization by using PID controllers. *Maskana*, *5*, 175-186.

[5] Leal, I. S., Abeykoon, C., & Perera, Y. S. (2021). Design, Simulation, Analysis and Optimization of PID and Fuzzy Based Control Systems for a Quadcopter. *Electronics*, *10*(18), 2218.

[6] Garcia, R. A., Rubio, F. R., & Ortega, M. G. (2012). Robust PID control of the quadrotor helicopter. *IFAC Proceedings Volumes*, *45*(3), 229-234.

[7] Bolandi, H., Rezaei, M., Mohsenipour, R., Nemati, H., & Smailzadeh, S. M. (2013). Attitude control of a quadrotor with optimized PID controller.

UNMANNED AERIAL VEHICLE TRAJECTORY VISUALIZATION AND RECONSTRUCTION USING THE CHANGES IN SIGNIFICANT VARIABLES OVER TIME

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Keywords: Trajectory, UAV, flight measurements

ABSTRACT

Advancements in using technology of unmanned aerial systems have made UAVs easier to operate, more affordable, and capable of performing a broader range of tasks.This has led to a large expansion of UAV applications in society, which has led to a large expansion of their applications. However, the main challenge is still to determine the precise location where the UAV would collect the desired data during an autonomous flight. This type of problem often occurs when the purpose of an unmanned aerial vehicle is to perform tasks that require high precision in measurements and when the UAV is not in optical sight. High-precision Global Navigation Satellite System (GNSS) sensors can be used to solve this problem, but this adds significant cost and operational complexity to the operation of a UAV. Also, these sensors cannot be used in urban areas, industrial zones or indoors because the signals become unreliable. By using RTK (real-time kinematic) GPS, sufficient precision is achieved for the reconstruction of the aircraft trajectory. This network operates on the principle of a base station, whose location is precisely determined, while the UAV is a moving body, so it is possible between these two objects to correct or remove errors that either one of them would observe themselves. The objective of this paper is to produce localization of a moving UAV, and 3D visualization its trajectory, using a telemetry data as well as error estimation.

REFERENCES

[1] He, F., T. Zhou, W. Xiong, S. Hasheminnasab, and A. Habib (2018). "Automated Aerial Triangulation for UAV-Based Mapping". In: Remote Sensing 10.12, p. 1952.
[2] Jebara, T., A. Azarbayejani, and A. Pentland (1999). "3D structure from 2D motion". In: IEEE Signal processing magazine 16.3, pp. 66–84.
[3] Ess, A., K. Schindler, B. Leibe, and L. Van Gool (2010). "Object Detection and Tracking for Autonomous Navigation in Dynamic Environments". In: I. J. Robotic Res. 29, pp. 1707–1725. doi: 10.1177/0278364910365417.
[4] Hartley, R. and A. Zisserman (2003). Multiple view geometry in computer vision. Cambridge university press.

WAVE ATTRACTORS IN LARGE ASPECT RATIO DOMAINS

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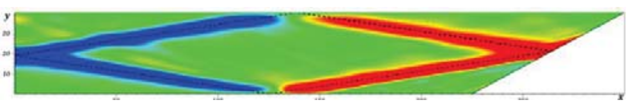
Keywords: Internal waves, Inertial waves, Wave Attractors.

ABSTRACT

Internal and inertial waves play an important role in the ocean dynamics trough energy cascades from global tidal forcing to small-scale internal waves and resulting mixing. Inertial waves in closed domains possess a remarkable property of focusing on the limit cycles called wave attractors. The growth of amplitude at wave attractors results in instabilities in case of viscous fluids. The scenarios of transition to turbulence and description of fully turbulent regimes differ substantially from the cases observed in closed domains in absence of wave attractors. Our previous studies demonstrated the key role of a cascade of triadic resonances as the route to fully developed wave turbulence, either with overturning events or not [1]. In present report we consider a shallow trapezium and the wave attractors with multiple reflections from the horizontal boundaries. The exact ray theory solution for the coordinates of such (n,1) wave attractors was obtained, as well as the expression for the Lyapunov exponents [2]. Next we show that in a shallow domain with small aspect (depth-to-length) ratio, the frequency spectrum of (1,1) wave attractor motion may exhibit significant peaks at integer and half-integer multiples of the forcing frequency. For the aspect ratio of about one tenth the temporal average of total kinetic energy grows monotonically with amplitude and have a bend at a particular amplitude. Below this amplitude the cascade transferring energy to superharmonic components prevails, while above this value the amplitudes of subharmonic and superharmonic waves are comparable. The spatial spectra of waves in the domains of the aspect ratio varying from small values to the values close to unity are compared. It is shown that in the former case (i.e. for shallow domains) the spectrum has two zones at small and high wave numbers characterized by different slopes. The fully turbulent regimes show the trend toward long-term evolution leading to new regimes with complex resonant dynamics of large-scale coherent structures. The figure below represents a snapshot of the vertical velocity in (1,1) case.



REFERENCES

[1] Brouzet, C., Sibgatullin, I. N., Scolan, H., Ermanyuk, E. V., and Dauxois, T. (2016). Internal wave attractors examined using laboratory experiments and 3d numerical simulations. Journal of Fluid Mechanics, 793:109–131.

[2] Sibgatullin, I., Petrov, A., Xu, X., and Maas, L. (2022). On (n,1) wave attractors: Coordinates and saturation time. Symmetry, 14(2):319.

FEM ANALYSIS OF CONTINUOUS TRACKS

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Keywords: Heavy machinery, FEM, Continuous track, DIN Standard, Stress field.

ABSTRACT

Continuous tracks are a type of heavy vehicle propulsion which are commonly found in tanks, excavators, and specialized off-road vehicles. They have an advantage over wheels when it comes to robust vehicle weight distribution over soft terrain, and some disadvantages as well. They can damage paved roads and have complex design so, considering an enormous weight they must carry, their reliability must be determined and verified. Bucket wheel excavators (BWE) are one of the largest (average height 35 m) and heaviest (between 1500 and 2000 tons) machines in the world that are used for large scale mining operation, such is SRs 1200 x 24/4 (400kW) + VR [1], which operates in Kolubara mining pit. This excavator weight 1528 tons and can dig up 4100 cubic meters of material per hour. However, this heavy duty machine can suffer plastic deformations, cracks, fractures, breakages of its key components which require repairs and reconstructions at very high cost [1]. Finite Element Method (FEM) simulations [2] are widely used for solving various problems in the heavy machinery industry because they can determine condition of parts and assemblies without damaging or destroying them [1]. In this paper, we will present a methodology for FEM analysis of continuous tracks according to DIN 22261-2 standards, for various required load cases. The main parts of the assembly are drive wheels, which move the track paddles, and the supporting structure that holds large seesaws (four-wheeled bogies) and small seesaws (two-wheeled bogies). On the upper side of the supporting structure, there are four mounting points for drive wheels. On the lower side of the supporting structure, there are two joints, to which large seesaws are attached. FEM model is created in FEMAP software, and analysis was done using NX Nastran solver. The FEM results show that analyzed continuous track design is valid for all of the load cases and the maximum calculated stress is less than the maximum permissible stress.

REFERENCES

[1] Bošnjak S., Petković Z., Matejić P., Zrnić N., Petrić S., Simonović A., (2005), "Analysis of Stress-Strain State of Bucket Wheel Excavator Revolving Platform Structure – Fundament of Efficient Reconstruction", *Structural Integrity and Life,* Vol. 5, No. 3, pp. 129–142.

[2] Živković M., (2005), *"Nelinearna analiza konstrukcija"*, Mašinski fakultet u Kragujevcu, Kragujevac, Serbia.

DEVELOPMENT OF INTERFACE FOR IMPLEMENTATION AND APPLICATION OF USER CONSTITUTIVE MODELS IN FEM SOFTWARE PAK

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Keywords: user model, FEM software, interface.

ABSTRACT

Researchers and engineers often have problems developing and implementing constitutive models for the simulation of the various materials into a Finite Element Method (FEM) based software. The reasons are complicated procedures and difficulties related to the features of the FEM software. This paper aims to describe the development of an interface for implementing and applying user constitutive models in FEM software PAK [1] for the structural analysis (Figure 1). First, this paper presents an overview of the possibilities of implementing user models in various FEM software [2] and the procedure of implementing constitutive models in 3D finite elements in PAK software. After that, the possibility of creating an interface for easy use of user subroutines for constitutive models intended for other FEM software was analyzed, and guidelines for developing one such interface in PAK software were given. Finally, the developed and implemented interface was tested for the selected constitutive model, and the implementation functionality was verified [3].

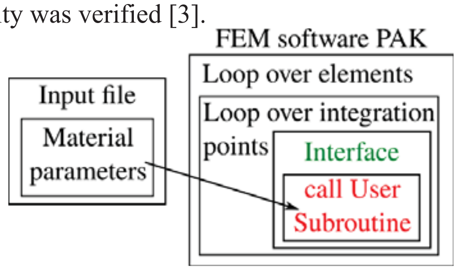

Figure 4 Scheme of the interface implementation into the FEM software PAK

REFERENCES

[1] Kojić, M., Slavković, R., Živković, M., Grujović, N. (1999), “PAK-S, Program for FE structural analysis”, Programmers Manual Kragujevac, Serbia.
[2] Abaqus 6.9-2 User Subroutines Reference Manual
[3] Dunić, V., Slavković, R. (2020) “Implicit stress integration procedure for large strains of the reformulated Shape Memory Alloys material model”, *Continuum Mechanics and Thermodynamics*, 32, 5, 1287-1309

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Modelling in Mechanics and Engineering
Mathematical Institute SANU, 08-10. September, 2022.

APPLICATION OF ITERATIVE LEARNING CONTROL FOR PATH FOLLOWING OF 3DOFS ROBOT ARM

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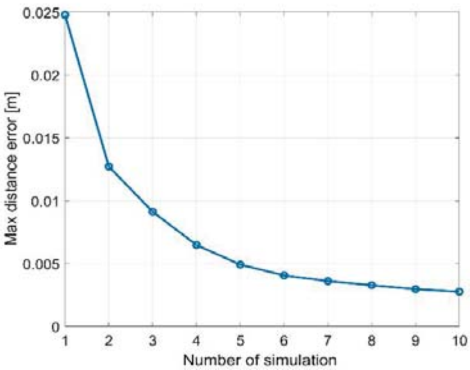
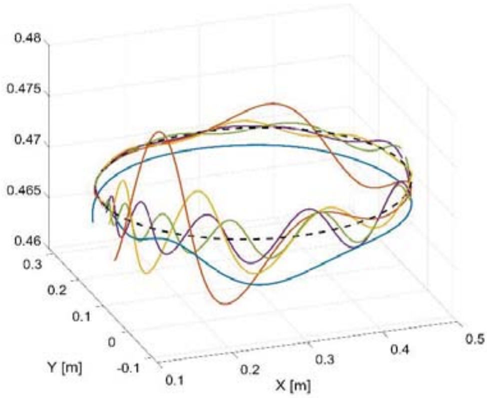
Keywords: Iterative learning control, Robot motion control, PID controller.

ABSTRACT

This paper deals with a topic of robot trajectory control which is very popular in academic and industrial research community. The task is very challenging considering the nonlinear nature of robot manipulators, as well as high demands in tracking performances [1]. To accomplish this, we proposed a combined feedforward-feedback control scheme [2], which outperforms each of these two subroutines when run separately. The first one is based on iterative learning algorithm of proportional-derivative (PD) type, while the second one is classical feedback controller, also of PD type [3]. Parameters of the controller are designed to achieve good performance/robustness trade-off, which is a key element in modern control design. Mathematical model of three degrees of freedom robot arm is derived with included actuator dynamics [4].

One of typical industrial applications of robot manipulators is a task of following a trajectory in space with prescribed velocity law. Processes like arc welding, painting, laser cutting, object inspection etc., are some of which wherein such demands can be met. In this particular case, robot manipulator needs to follow a circular trajectory with constant speed along the path. Numerical solution of inverse kinematics problem needs to be addressed first in order to obtain desired trajectory in joint space. Then, proposed control scheme is employed and some preliminary results are given in figures below. Ten consecutive simulations of robot trying to follow a predetermined path are performed using the iterative learning control algorithm. In each subsequent simulation tracking performances are improving, reducing the maximum distance error by ten times in overall. Furthermore, by increasing the number of simulations, the error can be made arbitrarily small. Also, this control design allows following of different types of trajectories, with various velocity laws.





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REFERENCES

[1] Bristow A. Douglas, Tharayil Marina, Alleyne G. Andrew (2006), Survey of Iterative Learning Control: A Learning Based Method for High Performance Tracking Control, IEEE Control Systems, Vol. 26, Issue 3, pp. 96-114.

[2] Boško P. Cvetković, Mihailo P. Lazarević, Petar D. Mandić, Tomislav B. Šekara, Paolo Lino (2021), Open Closed-Loop *PD PD*□ / Type ILC Control Of Neuroarm Robotic System, 8th International Congress of Serbian Society of Mechanics, Kragujevac, Serbia, June 28-30.

[3] Marko Č. Bošković, Milan R. Rapaić, Tomislav B. Šekara, Petar D. Mandić, Mihailo P. Lazarević (2019), A Novel Method for Design of Complex Compensators in Control Systems, 18th International Symposium INFOTEH JAHORINA, Jahorina, BiH, March 20-22.

[4] Petar D. Mandić, Paolo Lino, Guido Maione, Mihailo P. Lazarević, Tomislav B. Šekara (2019), Design of Fractional Order Lag Network and Fractional Order PI Controller for a Robotic Manipulator, IFAC PapersOnLine, Volume 53, pp. 3669-3674.

CAN FULLY CERAMIC GEARS PROVIDE A FEASIBLE ALTERNATIVE TO THEIR STEEL COUNTERPARTS IN INDUSTRIAL APPLICATIONS

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Keywords: Instructions, Mechanics, Engineering.

ABSTRACT

The most common gear strength calculations performed in accordance with ISO/TC 60/SC 2 include surface durability [1] and bending strength [2] calculations. Typical geared power transmissions are characterized by high Hertzian contact stresses (surface durability) on the flanks – frequently in the order of 10^3 MPa – versus almost half an order magnitude lower first principal stresses on the tooth root (tooth bending strength). Therefore, the use of high strength special steel alloys is almost mandatory, especially in high-end applications, mainly to withstand the high contact stress values. Ceramic materials are typically characterized by high compressive strength versus very low flexural strength that at first glance makes them inefficient for gear transmissions since they are unlikely to withstand the tensile root stresses. Nevertheless, ceramic materials possess a number of advantages that makes them potential candidates for geared transmissions, such as their exceptional thermal properties exceeding those of most steels, their low density (weight), their excellent wear characteristics [3,4] and limited lubrication demands [5, 6]. Full ceramic gears can be mainly found in micro-scale applications [7-9], while the available literature is very limited at meso-scale [10]. Other applications include the use of ceramic-steel composites as shown in the work of Imbaby and Jiang [11]. The present work investigates the main challenges of using high-end ceramic gears and attempts to provide an insight on defining the design envelope of such gears to counter the main disadvantages. The increase of the normal pressure angle beyond the 25-degree limit set by ISO 6336 is investigated, since in minimizes the tensile tooth root stresses, while also increasing the curvature of the contact surfaces without greatly increasing Hertzian stresses. Weber et al. [12] also showed that increasing the pressure angle beyond the 25-degree limit results in increased torque capacity prior to surface damage of the flanks. Also a comparative assessment of the performance of fully ceramic gear designs versus their conventional steel counterparts is performed through FEA simulations to set the basic design requirements for such gears and to promote further investigation of the feasibility of their usage in high power density applications.

REFERENCES

[1] International Organization for Standardization. (2019). Calculation of load capacity of spur and helical gears — Part 2: Calculation of surface durability (pitting)(ISOStandard No. 6336-2:2019). Retrieved from https://www.iso.org/standard/63821.html

[2] International Organization for Standardization. (2019). Calculation of load capacity of spur and helical gears — Part 3: Calculation of tooth bending strength(ISOStandard No. 6336-3:2019). Retrieved from https://www.iso.org/standard/63822.html

[3] Lafon-Placette, S., Delbé, K., Denape, J., & Ferrato, M. (2015). Tribological characterization of silicon carbide and carbon materials. Journal of the European Ceramic Society, 35(4), 1147-1159.

[4] Gong, T., Yao, P., Zuo, X., Zhang, Z., Xiao, Y., Zhao, L., ... & Zhong, A. (2016). Influence of WC carbide particle size on the microstructure and abrasive wear behavior of WC–10Co–4Cr coatings for aircraft landing gear. Wear, 362, 135-145.

[5] Strey, N. F., Ramos, R., & Scandian, C. (2022). Superlubricity and running-in wear maps of water-lubricated dissimilar ceramics. Wear, 498, 204328.

[6] Zhang, W., Yamashita, S., & Kita, H. (2020). Self lubrication of pressureless sintered SiC ceramics. Journal of Materials Research and Technology, 9(6), 12880-12888.

[7] Kyung-Hun, L. E. E., Jung-Min, L. E. E., Joon-Hong, P. A. R. K., & Byung-Min, K. I. M. (2012). Fabrication of miniature helical gears by powder extrusion using gas atomized Zn–22% Al powder. Transactions of Nonferrous Metals Society of China, 22(6), 1313-1321.

[8] Liu, L., Ni, X. L., Yin, H. Q., & Qu, X. H. (2015). Mouldability of various zirconia micro gears in micro powder injection moulding. Journal of the European Ceramic Society, 35(1), 171-177.

[9] Hassanin, H., & Jiang, K. (2010). Optimized process for the fabrication of zirconia micro parts. Microelectronic Engineering, 87(5-8), 1617-1619.

[10] Reiterer, M., Kraft, T., & Riedel, H. (2004). Manufacturing of a gear wheel made from reaction bonded alumina—numerical simulation of the sinterforming process. Journal of the European Ceramic Society, 24(2), 239-246.

[11] Imbaby, M. F., & Jiang, K. (2010). Stainless steel–titania composite micro gear fabricated by soft moulding and dispersing technique. Microelectronic Engineering, 87(5-8), 1650-1654.

[12] Weber, C., Tobie, T., & Stahl, K. (2017). Investigation on the flank surface durability of gears with increased pressure angle. Forschung im Ingenieurwesen, 81(2), 207-213.

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NUMERICAL COMPUTATIONS OF ELASTIC TORSION USING THE FINITE-VOLUME METHOD

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Keywords: Saint-Venant's torsion, Laplace and Poisson PDE, Finite volume method.

ABSTRACT

Analytical and numerical studies of Saint-Venant's torsion for bars of arbitrary cross-section is still a topic of interest for reasearchers and engineers. Numerical studies are mainly based on Finite Element Methods (FEM), or more recently on Boundary Element Methods. In this paper, elastic torsion problems are studied numerically using the Finite Volume Method (FVM), and three general approaches in torsion formulation [1] are analyzed: (a) Laplace partial-differential equation (PDE) with non-homogeneous Neumann boundary conditions (BC) for warping function w (displacement formulation); (b) Poisson PDE with homogeneous Dirichlet BC for Prandtl stress function φ and (c) Laplace PDE with non-homogeneous Dirichlet BC for conjugate function ψ. When computational domain (cross-section of the bar) is simply connected region, all three approaches are feasible in numerical sense, where the (b) is the simplest in terms of implementation. On the other hand, with multiply connected regions there is a big issue for (b) and (c). For arbitrary, multiply connected region, the values of φ and ψ on inner contours are not known in advance. These values are related to compatibility condition of single-valued displacement, which leads to known value of stress circulation around each inner contour. From that condition it is not possible to determine the value or φ or ψ on inner contours, since the stress distribution is obtained after the solution of the equations in (b) and (c). For such cases, approach (a) is the only option.

Finite volume method is predominantly used in computational fluid dynamics (CFD), and it is very rarely used in computational solid mechanics. But essentially, it is just one approach for numerical solution of PDEs (FVM discretises strong conservative form of momentum equation, while FEM uses weak form). OpenFOAM [2], free and open-source CFD software is used as the tool for implementation of numerical solutions of equations (a), (b) and (c). General FVM solver, based on the (a) is implemented using OpenFOAM libraries, together with appropriate Neumann BC. The solver is then tested on many examples, starting from the problems with known analytical solution (excellent agreement is found). Additional post-processing is implemented within the solver, where after determination of shear stress (calculated from the gradient of warping function field), Prandtl stress function is calculated as the stream function of stress vector field. It is shown that boundary-fitted grid which is characteristic for FVM is very suited for considered computations. Finally, analogy between elastic torsion and some classical fluid mechanics problems governed with the same type of the equations is analyzed.

REFERENCES

[1] Martin H. Sadd (2005), "ELASTICITY, Theory, Applications, and Numerics", Elsevier Butterworth-Heinemann.
[2] The OpenFOAM Foundation, OpenFOAM v9: http://www.openfoam.org

ANALYSIS OF CONTACT STIFFNESS IN ROLLING BALL BEARINGS WITH OUTER RING DAMAGE

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Keywords: Mathematical modelling, rolling bearings, contact stiffness, damage, Finite Element Analysis

ABSTRACT

Mathematical explanation and determination of main performances of rolling bearings can't be solved exactly. One of the problems which need to be solved within this subject is the nonlinear contact which occurs during the rolling bearing operation. The contact between rolling elements and the raceways on inner and outer rings has a high nonlinear character, due to nonlinear load distribution, as well as the variable elastic deformations of bearing elements during rotation. For theoretical research of the rolling bearings without damages and deviations, the contact deformations and contact stiffness can be considered as periodically-variable parameters. The consideration of any additional imperfections makes these parameters highly nonlinear. One of the most often imperfections found in practice is damage on bearing raceways.

The mathematical model for calculation of contact deformations and contact stiffnesses at the contact zones of rolling bearings with damages are analyzed and research. The obtained model is presented and verified on one particular type of radial ball bearing with damages on outer raceway. The nonlinear contact of the investigated bearing type is modelled in Finite Element Method. Obtained numerical results are used for verification of developed mathematical model.

REFERENCES

[1] Dougdag, M., Ouali, M., Boucherit, H., Titouche, N.E., Djaoui, M. (2012) "An experimental testing of a simplified model of a ball bearing: stiffness calculation and defect simulation", *Meccanica*, Vol.47, pp. 285-292.

[2] Atanasovska, I., Mitrović, R., Soldat, N., Momčilović, D. (2020) "Finite Element model for stress state analysis of deep groove ball bearings with defects", *Proceedings of the 5rd International Scientific Conference "Conference on Mechanical Engineering Technologies and Applications" – COMETA2020*, November 26-28, 2020, East Sarajevo – Jahorina, B&H, RS, pp. 285-292.

[3] Soldat, N., Atanasovska, I., Mitrović, R. (2021) "Analysis of the load distribution in a rolling bearing – with and without damage", *Proceedings of the Fifth International Symposium on Agricultural Engineering ISAE-2021*, 30st September-2nd October 2021, Belgrade – Zemun, Serbia, pp. I-28 – I-36.

ANALYSIS AND OPTIMIZATION OF REGULAR T-SHAPED FRACTAL SYSTEM

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Keywords: Fractal-type pipelines, Computational Fluid Dynamics, flow uniformity, Pareto frontier technique

ABSTRACT

Fractal-type exists widely in nature (for example, lungs and vascular systems in mammals, river basins, and plants). They have found applications in many manufactured systems such as the worldwide web, road networks, water, and energy transportation systems. These mechanisms Can be applied in the design of energy transport systems and cooling systems of electronic chips due to the increasing miniaturization of chips in microelectronic equipment and the production of redundant heat under nature inspired. The fractal theory was first put forth in 1926 and has since grown in popularity. This paper covers how a T-shaped fractal system affects the properties of the fluid in motion. The study also includes how the flow could be kept uniform throughout and how its efficiency can be maximized. The Pareto frontier technique is utilized to assess systems after optimizing them. It also compares the CFD results between a regular and optimized T-shaped fractal. The results from the analytical solution and CFD analysis indicate the better performance of the optimized T-shaped fractal and prove that if optimized correctly, the system's overall efficiency and flow uniformity increase. The analytical solution showed a 16% improvement in the heat transfer rate when the optimized T-shaped fractal was used, indicating that tree-like structures and fractal geometry knowledge may help create better cooling/heating fluid in the same flow conditions systems.

REFERENCES

[1] D. S. M. Aman Upadhayay, "A review of the fractal geometry in structural elements," *International Journal of Advanced Engineering Research and Science,* vol. 8, no. 7, p. 9, 2021.
[2] N. A. Hassan Diab, "The engineering applications of fractals," *Simulation,* vol. 57, no. 2, p. 9, 1991.
[3] D. L. Turcotte, "Fractals in fluid mechanics," *Annual Review of Fluid Mechanics,* vol. 20, p. 12, 1988.
[4] S. W. W. a. A. B. Lorente, "Tree-shaped flow structures designed by minimizing path lengths," *International Journal of Heat and Mass Transfer,* vol. 45, no. 16, p. 13, 2002.
[5] D. Pence, "Reduced pumping power and wall temperature in microchannel heat sinks with fractal-like branching channel networks," *Microscale Thermophysical Engineering,* vol. 6, no. 4, p. 11, 2003.
[6] P. C. and Y. C., "Heat transfer and pressure drop in fractal tree-like microchannel nets," *International Journal of Heat and Mass Transfer,* vol. 45, no. 13, p. 15, 2002.
[7] Y. Yan, H. Yan, S. Feng and L. Liu, "Thermal-hydraulic performances and synergy effect between heat and flow distribution in a truncated doubled-layered heat sink with Y-shaped fractal network.," *International Journal of Heat and Mass Transfer,* vol. 142, p. 13, 2019.
[8] S. N. Naqvi, "Optimization of Fractal Structures for Efficient Heating/Cooling of the Air/Fluid Flow," The Institute of Aeronautics and Applied Mechanics (FPAE/IAAM), Warsaw, 2021.

RAPID AND ACCURATE OPTIMISATION OF THE PARTICLE-IN-CELL MODELLING OF GRIDDED ION ENGINES

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Keywords: Particle-in-Cell, Computational, Parallelization, Gridded Ion Engines

ABSTRACT

The Particle-in-Cell algorithm is the standard approach to modelling low density plasma within a gridded ion engine. In its purest form, it is generally accurate but code execution times can be very long, even on High Performance Computers. There are multiple different methods to decrease run times by orders of magnitude, but these naturally introduce inaccuracies. Our proposal is to evaluate many different inputs (for example different propellant compositions), in order to optimise performance. To balance short execution times with high accuracy, we will first simulate each input with aggressive numerical acceleration techniques. The inputs' performance will be given a score. The lowest ranked inputs will be discarded. As inaccuracies were introduced from the numerical acceleration, only a small fraction of inputs will be discarded. All remaining inputs will then be revaluated, however with longer, more accurate simulations. Again, a few of the lowest scoring inputs will be discarded and the rest re-simulated. This cycle of simulating, discarding and then improving accuracy for further simulations will repeat. Eventually, only two or three remaining inputs will remain. By this point, the final simulations will have little to no numerical acceleration methods, resulting in a high level of accuracy. The best performing input will then be found, completing the optimisation process. The total simulation run times should be much faster than performing full-fidelity simulations for every input. As only the clear worst performing inputs are discarded after each simulation round, accuracy should still be high. The final round will be as accurate as possible, but with far less inputs needed to be simulated. Artificial Intelligence and Machine Learning Methods will be considered for further improvement of computational time and results.

REFERENCES

[1] Parke Sturrock JI, Jelic Z, Evans, BJ, Davis RJ. "A Novel Approach for the Particle in Cell Modelling of Gridded Ion Engine Plume Neutralisation," *Journal of Technological and Space Plasmas, Vol. 2, Issue 1 (2021,* Gruenwald Laboratories, DE, pp. 109-115. (DOI: 10.31281/jtsp.v2i1.21)

[2] Croes V, et al, "The Effect of Alternative Propellants on the Electron Drift Instability in Hall-Effect Thrusters: Insight from 2D Particle-In-Cell Simulations*", Phys. Plasmas, Volume 25, Issue 6, April 2018*. https://10.1063/1.5033492

[3] Yuan T, Ren J, Zhou J, Zhang Z, Wang Y, Tang H. "The Effects of Numerical Acceleration Techniques on PIC-MCC Simulations of Ion Thrusters", *AIP Adv., Volume 10, Issue 4, April 2020.* https://10.1063/1.5113561

ANALYSIS OF CROSSING AND VEERING PHENOMENA IN PLANAR FRAME STRUCTURES

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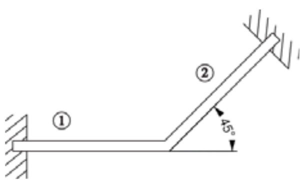
Keywords: Vibrations, Natural frequencies, Sensitivity

ABSTRACT

In this paper, crossing and veering phenomena are discussed for a two-element frame consisted of beams of constant circular cross-sectional area, mass density and modulus elasticity, see Fig. 1. Depending on the mechanical characteristics of frames when two natural frequencies approach one another over the range of the diameter, their loci may cross or repel. Thus, phenomena of crossing and veering are introduced [1]. These phenomena have been thoroughly studied analytically using various discretization methods as in [2] and [3]. While experimental data on these topics are rather scarce, some experimental studies are given in [4]. An analytical solution for the presented problem is proposed in this paper.



$$L_1 = L_2 = 1\text{m}; D_1 = D_2 = D$$
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Figure 1. Frame scheme

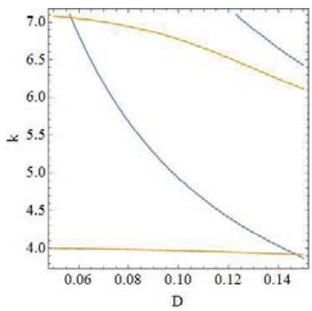

Figure 2. Eigenvalue loci

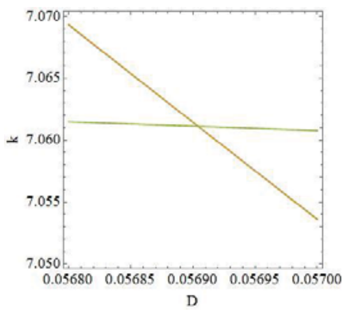

Figure 3. Loci crossing

REFERENCES

[1] Chen, X., Kareem, A. (2003) "Curve Veering of Eigenvalue Loci of Bridges with Aeroelastic Effects," J Eng Mech, pp 146–59.

[2] Tornincasa, S., Bonisol,i E., Kerfriden, P., Brino, M. (2014) "Investigation of crossing and veering phenomena in an isogeometric analysis framework," *Proceedings of the 32nd IMAC*, pp. 361–76.

[3] Liu. X.L. (2002) "Behavior of derivatives of eigenvalues and eigenvectors in curve veering and mode localization and their relation to close eigenvalues," J Sound Vib, pp. 551–64.

[4] Bonisoli, E., Delprete, C., Esposito, M., Mottershead, J.E. (2011) "Structural dynamics with coincident eigenvalues: Modelling and testing," *Conference Proceedings of the Society for Experimental Mechanics Series 6*, pp. 325–337.

NON-RECIPROCAL WAVE PROPAGATION IN PERIODICALLY STRUCTURED TIMOSHENKO BEAMS

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Keywords: Metamaterials, Phononic bandgap, Non-reciprocal wave propagation, Elastic wave, Timoshenko beam theory.

ABSTRACT

In this paper we will investigate non-reciprocal wave propagation in Timoshenko beams, due to space and time modulation of its elastic properties. To that end, an analytical approach is used: the Bloch theorem is applied when choosing the solution form for displacement components and the angle of rotation, which figure in the equations of motion along with the elastic properties. Also, the Fourier expansion is used to express the periodic nature of the modulation. By solving the eigenvalue problem for different modulation parameters, we obtain the band diagrams which can be used to analyze the directionality of wave propagation. These diagrams clearly represent the breakage of symmetry as a consequence of modulation. Thus, a modulated beam behaves as a kind of metamaterial, in which one-way propagation of elastic waves is possible. When shear and rotational effects are neglected, these results converge to the results for the Euler-Bernoulli beam, which are already present in scientific literature.

REFERENCES

[1] Trainiti, G., Ruzzene, M., (2016) "Non-reciprocal elastic wave propagation in spatiotemporal periodic structures", New Journal of Physics, Vol. 18.
[2] Hussein, I. M., Leamy, J. M., Ruzzene, M., (2014), "Dynamics of Phononic Materials and Structures: Historical Origins, Recent Progress, and Future Outlook", Applied Mechanics Reviews, 66(4).
[3] Rao, S. S., (2007), "Vibration of Continuous Systems", John Wiley & Sons, Inc.
[4] Attarzadeh, M. A., Nouh, M., (2018), "Non-reciprocal elastic wave propagation in 2D phononic membranes with spatiotemporally varying material properties", Journal of Sound and Vibration, 422 (p. 264-277).
[5] Riva, E., Marconi, J., Cazzulani, G., Braghin, F., (2019), "Generalized plane wave expansion method for non-reciprocal discretely modulated waveguides", Journal of Sound and Vibration, 449(p. 172-181).
[6] Riva, E., Ronco, M.Di, Elabd, A., Cazzulani, G., Braghin, F., (2020), "Non-reciprocal wave propagation in discretely modulated spatiotemporal plates", Journal of Sound and Vibration, 471.

NONLINEAR PERIODIC CHAINS WITH FRACTIONAL DAMPING

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Keywords: Periodic chain, Cubic nonlinearity, Fractional damping, Dispersion relation.

ABSTRACT

In recent years, there is a growing interest to investigate mechanical metamaterials owing to their unique wave attenuation properties. Periodicity in geometric or material properties is the main mechanism for formation of band gaps in such materials. Alongside with the investigation of linear metamaterials the nonlinear wave propagation problems were studied with the help of perturbation methods for studying this problem. Recently, some researchers investigated low-amplitude travelling waves in a periodic chain having both quadratic and cubic nonlinear terms. Interaction of waves in monoatomic chains having cubic nonlinearity was also studied in the literature [1]. On the other hand, dissipation in phononic crystals and metamaterials can cause significant change in band structure, where consideration of damping is unavoidable from the viewpoint of future practical applications [2]. In this communication, we show the model of nonlinear chains with fractional-order damping included. The model includes point masses connected through cubic nonlinear and linear springs and fractional spring-pot elements, where solution is found by using the multiple scales perturbation and fractional derivative expansion method [3]. Parametric study is conducted to examine the effects of model parameters on dispersion curves. Here, we demonstrate that consideration of nonlinearity and damping can play important role in predicting the wave dispersion behavior of the nonlinear periodic chains and help in future analysis and pre-design procedures of metamaterial based wave filtering and waveguiding .

REFERENCES

[1] Manktelow K., Leamy M. J., Ruzzene M. (2011) Multiple scales analysis of wave–wave interactions in a cubically nonlinear monoatomic chain. Nonlinear Dyn. 63:193-203.
[2] Hussein M. I., Frazier M. J. (2013) Metadamping: An emergent phenomenon in dissipative metamaterials. J. Sound. Vib. 332:4767-4774.
[3] Rossikhin Y. A., Shitikova M. V. (2009) New approach for the analysis of damped vibrations of fractional oscillators. Shock. Vib. 16:365-387.

IMPROVING THE PERFORMANCE OF PIEZOELECTRIC FRACTIONALLY DAMPED DYNAMIC ABSORBERS FOR BRIDGES

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Keywords: Tuned mass dynamic absorber, piezoelectric effect, damping.

ABSTRACT

In this contribution the bridge dynamic absorbers with added piezoelectric elements are presented. The absorbers are c2onnected to the bridge via viscoelastic elements with fractional Kelvin-Voigt viscous damping. To each absorber a bimorph piezoelectric cantilever beam is attached, adding the piezoelectric properties to the absorbers and enabling partial conversion of mechanical energy of vibrations to electrical energy. The governing equations for the system are derived by the use of the Hamilton's variational principle and Gauss's law for electric circuits [1]. This system of equations is solved by introducing the Galerkin method for spatial discretization and the method suggested by Evangelatos and Spanos [2] for approximation of fractional derivatives by the neighbouring integer-order ones. In time domain, the obtained differential equations are integrated numerically, by using the Newmark's procedure.

The absorbers' parameters can be designed for any particular case to improve the absorber performance, and the general algorithm for this procedure will be presented. First, a brief comment will be provided on how the absorber mass and the connecting elements properties can be tuned so as to produce maximal reduction of bridge vibration amplitudes as well as maximal electrical power output near the resonance states. Then, the influence of the absorber positioning on the overall absorber performance will be examined in detail, completing the set of tools necessary for optimizing the absorbers. It will be shown that the absorber performance can be greatly improved by adequate choice of the parameters.

REFERENCES

[1] Alper Erturk, Daniel Inman, Piezoelectric energy harvesting, John Wiley and Sons, 2011.

[2] Georgios Evangelatos, Pol Spanos. An accelerated Newmark scheme for integrating the equation of motion of nonlinear systems comprising restoring elements governed by fractional derivatives. In Recent advances in mechanics, pages 159–177, Springer, 2011.

COMPARATIVE STUDY OF FLUID TRANSPORTATION PROPERTIES OF REGULAR AND IRREGULAR FRACTAL-TYPE PIPELINES-A REVIEW

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Keywords: Fractal-type pipelines, Computational Fluid Dynamics, flow uniformity, Heat exchangers

ABSTRACT

Many scientists and engineers have been inspired by nature to find solutions to issues through observation and mimicry. Heat transfer improvement is one such example. Natural heat and mass transfer events have prompted engineers to look for natural solutions to heat transfer enhancement difficulties. Plant and animal respiratory and circulatory systems, such as blood arteries, human lungs, leaves, coasts, and so on, all exhibit fractal geometries. This inspired the development of fractal heat exchangers, which were found to have an inherent benefit of low flow resistance and high heat transfer capabilities. Fractal heat exchangers and their fractal channels were the focus of the current study, which included a full evaluation of the literature on their thermal and hydraulic performance. Fractal theory, model building, performance comparisons with traditional designs, heat transport and fluid mechanics, and design methodologies are all explored in detail. Fractal theory was first put forth in 1926 and has since grown in popularity. Flow mixing and pressure drop recovery produced by bifurcation are better for fractal channels than standard parallel and serpentine ones, proving their superiority in thermal and hydraulic performance. Traditional scaling rules and a new topology optimization methodology are used in the design process. Finally, the research gaps that need to be filled by future studies are explored. More research is needed on liquid-to-gas heat exchangers, optimal design, and topology optimization. There is a shortage of experimental data [1,2].

REFERENCES

[1] Kizilova, N., Sauermoser, M., Kjelstrup, S., & Pollet, B. G. (2020). Fractal-like flow-fields with minimum entropy production for polymer electrolyte membrane fuel cells. Entropy, 22(2), 176.

[2] Abed Waleed Mohammed, Ahmed Mohammed Abed, 2016," Numerical Study Of Laminar Forced Convection Heat Transfer And Fluid Flow Characteristics In A Corrugated Channel" , Journal Of Engineering And Development , Volume 14 ,Issue 3 ,PP 70-85.

EFFECT OF CENTRAL POINT ON THE ACCURACY OF A FRACTIONAL-ORDER MODEL IDENTIFICATION METHOD BASED ON THE PROCESS REACTION CURVE

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Keywords: process identification, fractional-order systems, fractional first-order plus dead-time model.

ABSTRACT

A general procedure for identifying a fractional first-order plus dead-time (FFOPDT) model has recently been presented in [1]. This procedure is based on fitting three arbitrary points {x_1-x_2-x_3%} on the process reaction curve, where the process information is obtained from a simple open-loop test. In [2] a simplification of the general identification procedure has also been considered, particularizing for the case where only symmetrically located points {x-50-(100–x)%} on the reaction curve are selected. This symmetrical method provides an efficient way to obtain the parameters of the FFOPDT model, by requiring the selection of the optimal location of only one of the points (x), since the other is immediately established by the symmetry requirement.

Analytical expressions of the corresponding FFOPDT model parameters have been obtained for these sets of symmetrical points.

The effectiveness and applicability of this symmetric procedure for the identification of fractional order models has been shown and the influence of the selection of the symmetric point set on the accuracy of the identified model has been determined from several numerical examples. It has also been shown that this identification procedure gives good results compared to other integer and fractional order identification methods.

However, in [2] it has been considered that the central point x_2 is always located in the middle of the output total change (x_2 = 50%). In this paper, the possibility of moving the central point or centroid on the reaction curve is explored, maintaining the symmetry of the extreme points with respect to the selected central point.

The results of this work verify that the accuracy of the identified fractional order model is sensitive to the position of the central point within the set of symmetric points on the reaction curve and it has been discussed how a more accurate identified model can be obtained. New insights have also been offered on this selection of the central point x_2 in the context of the proposed symmetric procedure.

Another aspect to note is that the proposed method is analytical, which facilitates its applicability in terms of less computational effort compared to complicated identification algorithms usually based on optimization. In the industrial context, large process industries usually have hundreds or thousands of control loops. For this reason, simplicity is of primary interest when identifying a process model for control purposes.

In the authors' opinion, this type of identification methods, in which simplicity is emphasized, will encourage their industrial use and help to bridge the gap between theoretical research on fractional models and their practical application in the process industry. This expectation is the main motivation for the present study.

REFERENCES

[1] Gude, Juan J. and García Bringas, P. (2022) “Proposal of a general identification method for fractional-order processes based on the process reaction curve”, submitted to fractal and fractional.

[2] Gude, Juan J. and García Bringas, P. (2022) “Influence of the Selection of Reaction Curve’s Representative Points on the Accuracy of the Identified Fractional-Order Model", *Journal of Mathematics*, vol. 2022, Article ID 7185131, 22 pages, https://doi.org/10.1155/2022/7185131

NONLINEAR VIBRATIONS OF A CYLINDRICAL PIPE EMBEDDED IN A FRACTIONAL DERVATIVE MEDIUM

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Keywords: Fractional derivative expansion method, Cylindrical pipe, Internal resonance.

ABSTRACT

Pipes conveying fluid have important applications in many industrial fields, such as the oil extraction and transmission, offshore infrastructures, heat exchangers and civil engineering. Overview of mechanics of pipes conveying fluids is given in [1], including linear and nonlinear response of pipes made of elastic or viscoelastic materials. It is known that nonlinear vibrations could be accompanied by such a phenomenon as the internal resonance, resulting in strong coupling between the modes of vibrations involved, and hence in the energy exchange between the interacting modes. In recent decades the fractional derivative models have been widely used for solving different dynamic problems of mechanics [2], in so doing a pipe is modelled as a Bernoulli-Euler or Timoshenko beam. However, the more realistic model of the pipe is a cylindrical shell containing fluid. Therefore, in the present paper, the model of the nonlinear cylindrical shell vibrating in a fractionally damped surrounding medium has been generalized for the case of the conveying-fluid pipe embedded in a fractional derivative Kelvin-Voigt medium.

The 1:1 and 1:3 internal resonances in cylindrical pipes conveying fluids have been studied by the fractional derivative expansion method [3]. The internal resonances belong to the resonances of the constructive type, despite of external resonances which could be eliminated by changing the frequency of external loads. Since all of internal resonances depend on the geometrical dimensions of the shell under consideration and its mechanical characteristics, that is why such resonances could not be ignored and eliminated for a particularly designed shell. The results of this study give useful information to avoid the internal resonance and control the resonant responses of the cylindrical pipes conveying fluid.

ACKNOWLEDGEMENT

This research is supported by the Russian Science Foundation, Project No. 21-19-00634.

REFERENCES

[1] Ibrahim, R.A. (2010), “Overview of mechanics of pipes conveying fluids-Part I: Fundamental studies,” *Journal of Pressure Vessels Technology,* Vol. 132(3), PaperID 034001.

[2] Rossikhin, Yu.A., Shitikova, M.V. (2010), “Application of fractional calculus for dynamic problems of solid mechanics: novel trends and recent results,” *Applied Mechanics Reviews*, Vol. 63(1), PaperID 010801.

[3] Shitikova, M.V. (2020), “The fractional derivative expansion method in nonlinear dynamic analysis of structures,” *Nonlinear Dynamics,* Vol. 99(1), pp. 109-122.

NUMERICAL SIMULATION OF THE FRAME STRUCTURE DYNAMIC BEHAVIOR BY THE APPLICATION OF THE NONLOCAL IN TIME DAMPING MODEL

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Keywords: Nonlocal Damping, Composite Materials, Nonlocal Mechanics, Finite Element Analysis, Newmark Method

ABSTRACT

This research is devoted to the numerical description of the dynamic response of composite frame structures considering the internal damping properties of the material. Since the characteristics of such materials can be effectively controlled, composite materials are actively applied in building industry in the recent years. Most of composite materials have complex internal orthotropic or anisotropic structure. Generally, in order to obtain a realistic description of such materials behavior, detailed 3D finite element models are applied. Such an approach requires significant computing resources, thus alternative models are requested, based on the special valid hypothesis, which allows one to achieve the appropriate accuracy level. An entire class of such models is based on principals of nonlocal mechanics [1]. Nonlocality can be considered in space or in time and applied to damping or elastic properties of materials. In this work, the nonlocal in time model of material damping is constructed. It is considered that damping of the structure at the current time moment t is assumed to be dependent not only on instant value of strain rate at this moment $\dot{\varepsilon}(t)$, but also on the values of strain rates $\dot{\varepsilon}(\tau)$ of the previous time history. The longer is the gap between the two time points, the lower is the influence that one of them has on the other. It has been shown in [2] that such a model in 1D statement could be smoothly integrated to the FEA algorithm and effectively used for the approximation of numerical simulation or physical experiment data.

In this work, the equation of motion of a frame structure FE model with the nonlocal in time material damping is solved using implicit scheme. It is shown that such approach allows to create flexible model, that can be effectively applied in case, when 1D models are more preferable then 3D ones, for instance on the initial design stages or for optimization problems solving.

This research was supported by the Russian Science Foundation, Project no. 21-19-00634.

REFERENCES

[1] Banks H. T., Inman D. J. (1991), "On damping mechanisms in beams", *Journal of Applied Mechanics,* 58(3), pp.716–723.

[2] Sidorov V.N., Badina E.S., Detina E.P. (2021) "Nonlocal in time model of material damping in composite structural elements dynamic analysis", International Journal for Computational Civil and Structural Engineering, 17(4), pp.14-21.

SPECIAL SESSION 1

Optimizing Design for Inspection – ODIN

Session Chair: **Nataša Trišović**

Acknowledgment

A part of the research presented in this Special Session is realized within project COST Action CA18203 - Optimizing Design for Inspection (ODIN – www.odin-cost.com) supported by COST (European Cooperation in Science and Technology - www.cost.eu).

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FRACTIONAL ORDER PID CONTROL ON STRUCTURAL RELIABILITY OF STOCHASTIC DYNAMICAL SYSTEMS

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Keywords: FOPID; stochastic dynamical systems; Gaussian white noise

ABSTRACT

In this talk, the reliability of stochastic dynamical systems under Gaussian white noise excitations with fractional order proportional–integral–derivative (FOPID) controller is estimated. First, the FOPID controller is approximated by a set of combination of displacement and velocity based on the generalized van der Pol transformation. Then, the stochastic averaging method of energy envelope is applied to obtain a diffusive differential equation, from which, the Backward Kolmogorov equation, governing the conditional reliability function, and the Generalized Pontryagin equation, governing the statistical moments of first-passage time, are derived from the averaged equation and solved numerically. Finally, in two examples, the critical parameters in the FOPID controller are proved to be capable of improving the reliability of the stochastic dynamical system apparently, and all numerical results are verified to be efficient and correct by the Monte Carlo simulation.

FLIGHT DYNAMICS MODELLING AND FLIGHT SIMULATION

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Keywords: Datcom+pro, FlightGear, JSBSim, flight, model, simulation.

ABSTRACT

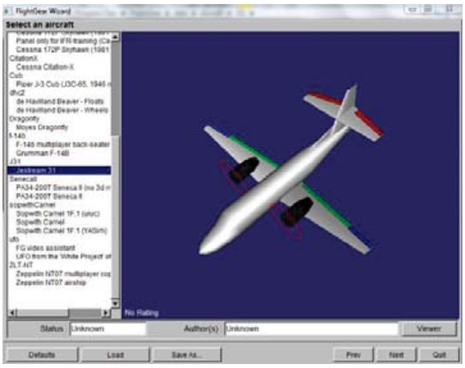

Figure 5 - The Cranfield Jetstream 31 on the list of available models in "Flightgear"

The open source projects "FlightGear" and "JSBSim" along with "Datcom+pro" [low-cost software] combined and used together provided a compact position for building a model and producing a simulation, i.e. modelling and flight model simulation, using low-cost or free software.

Essential configuration files were constructed in "JSBSim" and combined at the end with "FlightGear" in order to model the Cranfield Jetstream J31 aircraft (a small twin-engine aircraft with a pressurised fuselage).

The outcomes of the project were a "JSBSim" flight dynamics files importable in "FlightGear", model developed with the use of "Datcom+pro" and a three-dimensional graphical model for the Cranfield Jetstream 31 aircraft.

Figure 6 - The modelled Cranfield Jetstream 31 in "FlightGear"

REFERENCES

[1] Holy Cows, Inc., Datcom+pro version 3.0, Main program [online], available: http://www.holycows.net/Datcom/ [accessed 18 April 2022]

[2] FlightGear, open-source flight simulator, Current stable release: 2020.3.13, Download main program [online], available: https://www.flightgear.org/ [accessed 18 April 2022]

[3] JSBSim - an open source flight dynamics model (FDM), JSBSim version 1.1.11, [accessed 18 April 2022]

NON-LINEAR DYNAMICS OF A DAMAGED STIFFENED COMPOSITE LAMINATED PANEL

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Keywords: Non-linear vibrations, Debonding, Stiffener, Fiber reinforced laminate.

ABSTRACT

In this communication, vibrations of a stiffened composite laminated plate, Figure 1, with and without damage, are studied. The analysis is carried out in Abaqus finite element software [1]. The stiffened panel is part of a wing representative structure, investigated in the framework of COST action CA18203 [2]. Numerical and experimental analysis indicate that debonding between the composite plate and the stiffener is prone to occur [1, 2]. Therefore, damage of this type is here considered, at critical areas found in static analyses.

Figure 1. *FE model of the stiffened composite panel analysed.*

The structure undergoes harmonic loading and contact restrictions between damaged surfaces are imposed. Time-histories, phase portraits, frequency spectra and Poincaré sections [3] of the healthy and damaged structures are extracted. It is found that damage leads to a non-linear dynamic behavior and that, consequently, non-linear dynamics based tools can be employed to detect debonding in stiffened composite panels.

REFERENCES

[1] Henriques, B. (2021). Static and Dynamic Analysis of an Airplane Wing Representative Structure for Damage Detection. M.Sc. dissertation, Universidade do Porto.
[2] Bisagni, C., A. Raimondo, I. Atanasovska, M. Milic, R. Troian, G. Frulla, A. Polla, Ö. N. Cora, M. L. Bekci, B. Henriques, M. F. S. F. de Moura, F. Almudaihesh and S. Grigg (2022). "Comparison of numerical analyses of a composite wing component subjected to 4-point bending." Composites Part C: Open Access 8.
[3] Nayfeh, A. H. and B. Balachandram (1994). Applied Nonlinear Dynamics: Analytical, Computational, and Experimental Methods. New York, John Wiley and Sons.

BIO-INSPIRED SHAPE OPTIMIZATION FOR STRUCTURAL RESISTANCE

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Keywords: bio-inspired design, shape optimization, IGA.

ABSTRACT

Biological structures usually generate a uniform strain field to avoid over-loading or under-utilising material. This research presents the shape optimization of statically loaded structures. We compare the bio-inspired optimality criteria of a uniform strains distribution with the classical objective function of strains minimization. Associated isogeometry analysis results based on bio-inspired optimization show more uniform the stains distribution and strains of each element decreasing. This research provides new ideas for structural design principles.

Design variables	Bio-inspired criteria		Classical criteria	
	Max von mises stress	Optimal shape	Max von mises stress	Optimal shape
In 1-domain	7.80		22.91	
In 2-domain	7.90		19.91	
In 3-domain	10.74		15.16	

Figure 7: Optimized shapes with bio-inspired criteria and classical method of a maximum strains minimization

REFERENCES

[1] X. Qian, "Full analytical sensitivities in NURBS based isogeometric shape optimization," Computer Methods in Applied Mechanics and Engineering, vol. 199, no. 29-32, pp. 2059–2071, 2010.
[2] V. Agrawal, S S. Gautam. IGA: a simplified introduction and implementation details for finite element users[J]. Journal of The Institution of Engineers (India): Series C, 2019, 100(3): 561-585.
[3] V P. Nguyen, C. Anitescu, S P A. Bordas, et al. Isogeometric analysis: an overview and computer implementation aspects[J]. Mathematics and Computers in Simulation, 2015, 117: 89-116.
[4] C. Mattheck. Design in nature: learning from trees. Springer Science & Business Media, 1998.
[5] U. Müller, W. Gindl, and G. Jeronimidis. Biomechanics of a branch-stem junction in softwood. Trees 2006; 20, 643 – 648.
[6] B. Wilson,B and R. Archer. Tree design - some biological solutions to mechanical problems. Bioscience 1979; 29, 293 – 298.
[7] T. Dean, S. Roberts, D. Gilmore, D. Maguire, J. Long, K. O'Hara, and R. Seymour. An evaluation of the uniform stress hypothesis based on stem geometry in selected North American conifers. Trees; 2002; 16, 559-568.
[8] K.Deb, A. Pratap, S. Agarwal, et al. A fast and elitist multiobjective genetic algorithm: NSGA-II[J]. IEEE transactions on evolutionary computation, 2002, 6(2): 182-197.

STOCHASTIC DYNAMICS OF A SNAP-THROUGH TRUSS OSCILLATOR

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Keywords: Non-smooth dynamics, Stochastic bifurcations, Stochastic Differential Equations, Nonlinearity.

ABSTRACT

An archetypal smooth- discontinuous (SD) oscillator has nonlinearity which can be smooth or discontinuous depending on the value of the smoothness parameter [1]. Physically this oscillator depicts the behavior of a snap-through truss system. The uniqueness of this nonlinear dynamical system lies in the fact that it possesses properties of both a smooth dynamical system and a discontinuous one (at the limit). Furthermore, it exhibits complex co-existence of periodic attractors, hysteresis and also strange chaotic attractors, making it an ideal candidate for study of nonlinear dynamical phenomena.

Furthermore, every dynamical system is inherently affected by the presence of noisy fluctuations, additionally complicating the dynamics. The connotation of an attractor, a bifurcation, a basin of attraction, periodicity and isochronicity is completely different from the deterministic description of these entities [2]. Thus, it is important to carry out a separate study of such systems. The present work discusses the numerous methods of solving smooth and non-smooth dynamical systems in the presence of stochastic forcing, as well as discusses the various phenomenological behavior occurring as a result of the interplay between non-smoothness and noise.

REFERENCES

[1] Cao, Q., Wiercigroch, M., Pavlovskaia, E.E., Grebogi, C. and Thompson, J.M.T., 2008. The limit case response of the archetypal oscillator for smooth and discontinuous dynamics. *International Journal of Non-Linear Mechanics*, *43*(6), pp.462-473.

[2] Arnold, L., 1995. Random dynamical systems. *Dynamical systems*, pp.1-43.

THEORETICAL SOLUTIONS OF THE MULTI-STABLE ENERGY HARVESTERS

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Keywords: Energy harvesters, Frequency response, Stochastic excitation.

ABSTRACT

In this talk, theoretical analysis methods and response regimes of multi-stable energy harvesters will be introduced. Firstly, the amplitude-frequency response equations and the stability analysis of multi-stable energy harvesters with high-order stiffness terms will be presented. Complex multi-valued characteristics are observed in the amplitude of the response displacement. Then, resonance mechanism of nonlinear vibrational multistable energy harvesters under narrow-band stochastic parametric excitations will be discussed. The largest Lyapunov exponent which determines the stability of the trivial steady-state solutions is derived. The nontrivial steady-state moments of multistable energy harvesters are considered. The stochastic bifurcation phenomenon is discussed. Finally, response analysis of the nonlinear vibration energy harvester with an uncertain parameter, the Chebyshev polynomial approximation is firstly utilized to analyze the dynamical characteristics of the nonlinear vibration energy harvester with an uncertain parameter. The ensemble mean response of the stochastic energy harvester is introduced to discuss the stochastic response. The bifurcation property of the displacement and voltage is analyzed.

REFERENCES

[1] Dongmei Huang, Shengxi Zhou, Zhichun Yang, Resonance mechanism of nonlinear vibrational multi-stable energy harvesters under narrow-band stochastic parametric excitations, Complexity, 2019, 1050143.

[2] Dongmei Huang, Shengxi Zhou, Qun Han, Grzegorz Litak, Response analysis of the nonlinear vibration energy harvester with the uncertain parameter, Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multibody Dynamics, 2020, 234(2) 393-407

[3] Dongmei Huang, Shengxi Zhou, Grzegorz Litak, Theoretical analysis of multi-stable energy harvesters with high-order stiffness terms, Communications in Nonlinear Science and Numerical Simulation, 2019, 69, 270-286.

DYNAMIC ANALYSIS OF A THREE-DEGREE-OF-FREEDOM VIBRATION-IMPACT SYSTEM WITH RANDOM PARAMETERS

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Keywords: Multi-degree-of-freedom impact vibration system, bifurcation, Chebyshev polynomial, chaos.

ABSTRACT

This paper establishes a three-degree-of-freedom vibration-impact system with random parameters and unilateral rigid constraint, and studies its bifurcation phenomenon under harmonic excitation. By using Chebyshev orthogonal polynomial approximation method of stochastic smooth dynamical system, the stochastic system is transformed into equivalent deterministic system. At the same time, the abundant period doubling bifurcation phenomena of stochastic system and equivalent deterministic system are explored by using numerical simulation method, and the path to chaos of periodic motion of this kind of non-smooth system is explained. By studying the Poincaré map of bifurcation parameters, the influence of stochastic parameters on bifurcation of non-smooth dynamic system is analyzed. The damage of random factors to the stability of the system will make the dynamic behavior of the system mutate. The results show that the Chebyshev orthogonal polynomial approximation is an effective method to study the stochastic multi-freedom vibration-impact system.

REFERENCES

[1] Zhilong Huang, Zhonghua Liu, Weiqiu Zhu, Stationary response of multi-degree-of-freedom vibro-impact systems under white noise excitations, Journal of Sound & Vibration, 2004, 275(1-2):223-240.

[2] Sanshan Du, Dynamic Response of Vibro-impact System Damping by Stochastic Disturbance, Journal of Lanzhou Jiaotong University, 2020, 39(01):117-123.

[3] Wei Xu, Liang Wang, Jinqian Feng, Investigation of the bifurcation of stochastic van der Pol system, Acta Physica Sinica, 2008, 57(04): 1000-3290.

DESIGN FOR INSPECTION AND SAFETY – NOVEL CONCEPT OF CABLING MACHINE

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Keywords: Cabling machine, Cables, Design.

ABSTRACT

Cabling machine is the usual term used in the cable industry for a machine meant to braid strands of steel wire into cables. A fundamental part of the machine are the input spools from which the wire is unwound, the output spool which gathers the finished cable, and the matrix between them where the braiding is done – cabling. The braiding process hinges on the rotation of one of these assemblies – either the input spools, or the matrix and output spool.

Although there are different designs in use, the most common type of this machine is the horizontal cradle cabling machine, which has a rotating input assembly shaped like a rotor with the input spools around the edges.

It has been noticed in exploitation scenarios that this common design has a major flaw. Due to the very high rotational speed of the rotor – around 100 rpm, the distance between the input spool and the axis of the rotor (around 0.5 m) and the mass of the input spool (around 150 kg), the occurring centrifugal force is quite large (around 4 tons). This force is very taxing for the elements holding the spool, which can easily lead to them being damaged. If this happens, this design of the machine allows the spool to fly off. There are documented cases of the spool flying off, going straight through the roof of the factory and landing in the yard, which makes this design a major safety hazard for the factory staff. To circumvent this issue, a new design of the rotor is proposed, where the input spool would be placed inside the disks of the rotor, rather than between them.

While the aforementioned problem could be mitigated by placing safety elements on the rotor or around the machine, this would greatly increase the mass and complicate the design, inspections and exploitation, so this is generally avoided in existing designs. The proposed design represents the best possible solution for this problem.

Additional analysis has shown that, apart from increasing the diameter of the disk, this new solution doesn't have any drawbacks, and even improves certain other factors, making this solution a notable advancement in the design of machines of this type. Analysis has also shown that this new machine design requires that special attention be paid to certain specific problems, making it a new and exciting challenge for the designer.

REFERENCES

[1] Čavić M., Penčić M., Rackov M., Kostić M. (2018), "Structural Design of the Working Mechanism of the Plastic Cup Stacking Machine", *IOP Conference Series: Materials Science and Engineering*, Vol.393, No.1, pp.1-8.

[2] Rackov M., Kuzmanović S., Knežević I., Čavić M., Penčić M., Stefanović D., Starzhinsky V.E., Shil'ko S.V., Algin V.B. (2019), "The Influence of the Bearing Lifetime on the Performance of Universal Gear Drives with High Gear Ratio Values", *MATEC Web of Conferences*, Vol.287, No.1, pp.10221-10224.

[3] Algin V.B., Ishin M., Paddubka S., Starzhinsky V.E., Shil'ko S.V., Rackov M., Čavić M. (2010), "Development of information model of power transmissions in the light of Industry 4.0", *International Scientific Journal Mathematical Modeling*, Vol.4, No.2, pp.54-63.

[4] Čavić M., Penčić M., Rackov M., Kostić M. (2018), "Structural Synthesis of the Plastic Cup Stacking Machine Mechanism – Application of the Intermittent Motion Mechanisms", *Proceedings of the Symposium International Conference Mechanical Engineering in XXI Century – MASING,* Niš, Serbia, pp. 247-252.

[5] Rackov M., Knežević I., Kuzmanović S., Miltenović V., Mićić D., Čavić M., Penčić M., Temunović J. (2018), "Comparation of Shaft Calculation Methods of Output Shafts in Universal Gear Units", *Proceedings of the International Conference Mechanical Engineering in XXI Century – MASING,* Niš, Serbia, pp. 155-160.

MODELLING OPTIMIZATION FOR A COMPOSITE WING COMPONENT

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Keywords: Finite Element Analysis, Composites, Wing structure, Modal analysis.

ABSTRACT

The paper presents development of optimal finite element model for a representative wing component, which is a part of a large research in the framework of COST action CA18203 [1]. Few different finite element models based on the variation of mesh density, boundary conditions and composite structures are developed. The static nonlinear Finite Element Analysis (FEA), as well as a FEA modal analysis are performed for all of the developed models. A commercial software ANSYS Mechanical APDL 2019 R3 is used for these purposes.

The comparative analysis of the obtained results is performed. The conclusions about the influence of the varied parameters of the developed finite element models on the obtained stress-strain results are discussed. The special attention is paid to the discussion of the modal analysis results obtained for different boundary conditions, as well as for variable composite structures.

Acknowledgment

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REFERENCES

[1] Bisagni C., Raimondo A., Atanasovska I., Milic M., Troian R., Frulla G., Polla A., Cora¨O.N., Bekci M.L., Henriques B., de Moura M.F.S.F., Almudaihesh F., Grigg S.: Comparison of numerical analyses of a composite wing component subjected to 4-point bending, *Composites Part C: Open Access,* doi:10.1016/j.jcomc.2022.100264, Volume 8, August 2022, 100264.

SPECIAL SESSION 2

Experimental Mechanics

Session Chair: **Dejan Momčilović**

Special Session 2 – Experimental Mechanics			
Session Chair: **Dejan Momčilović**, Assistant Research Professor, Institute for Testing of Materials IMS, Belgrade			
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2.	Dragoljub Ilić, **Dragan Milošević**, Dejan B. Momčilović	NEURAL NETWORK MODEL FOR THE CONDITION ASSESSMENT OF HYDRO TURBINES	
3.	Milorad Gavrilovski, **Alen Delić**, Vaso Manojlović	OPTIMIZATION OF ALUMINOTHERMIC RAIL WELDING BY MODELING AND SIMULATION OF BASIC PARAMETERS OF THERMITE STEEL CASTING (online)	
4.	Milica Milić, Ivana Atanasovska, **Ognjen Ristić**, Dejan B. Momčilović	FAILURE ANALYSIS OF BEAM OF UNMANNED AERIAL VEHICLE	
5.	Aleksandar Žurkić	EXPERIMENTAL MECHANICS – VISION OF EXCELLENCE IN SCIENCE BY SHIMADZU	

EXAMINATION OF THE PHYSICAL-CHEMICAL AND MECHANICAL PROPERTIES OF HELICAL CYLINDRICAL COMPRESSION SPRINGS PRESERVED IN THE LEGACY IN THE NIKOLA TESLA MUSEUM

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Keywords: Nikola Tesla Museum, Tesla's legacy, Mechanical engineering, Springs.

ABSTRACT

The results of the scientific research work and creativity of Nikola Tesla (Smiljan, 1856 - New York, 1943), a Serbian-American scientist, engineer and inventor, represent the foundation of new technical and technological breakthroughs that began at the end of the 19th century, and without which our everyday life would be unthinkable.
The legacy of Nikola Tesla is located in his museum in Belgrade and present unique collection composed from archive documents, different items (personal and technical items) and library (monographies, periodical publications and newspaper clips).
The number of original technical items from Tesla's legacy (295 in total) is finite and unchangeable. The collection of items from the field of mechanical engineering consists of 122 different museum artifacts from the following areas: turbo machines, tribology, speed measurement, length measurement, temperature measurement, measuring tools, accessories for technical drawing and writing, machine assemblies and elements, etc. The most numerous groups of objects consist of springs (coil-cylindrical, spiral strip), a total of 30 exhibits. Models of spiral cylindrical springs, depending on how they are loaded, are compression (8 pcs.) or tension type (14 pcs.). The aim of this paper is to present preserved models and to examine the physical-chemical and mechanical properties and contribute with additional knowledge to the Nikola Tesla legacy.

REFERENCES

[1] Svetislav Markovic, Tatjana Lazovic, Ljubica Milović, Bratislav Stojiljkovic, The First Hydroelectric Power Plant in the Balkans Built on the Basis of Tesla's Principles, Conference: HMM '12At: Amsterdam, Netherlands May 2012, DOI: 10.1007/978-94-007-4132-4_27

NEURAL NETWORK MODEL FOR THE CONDITION ASSESSMENT OF HYDRO TURBINES

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Keywords: Hydroturbines, Shafts, Neural Network model, Diagnostics.

ABSTRACT

During regular operation, hydro turbine elements have complex operating conditions. In order to prevent major failures, among other common preventive measures, it is necessary to make a useful model of hydro turbine. Development of this model was focused on real elements and data set of real operating history. To solve this, an integral diagnostic approach is used. Based on the real diagnostics data of the condition and data history of the hydro turbine shaft and the designed life expectancy, a multi-layer perceptron (MLP) based artificial neural network (ANN) is built. The idea with this model was to enable to life assessment of the turbine shaft in any particular moment during regular operation.

This paper describes a model for estimating the condition of the shafts of turbines of the current generator in Hydropower plant Đerdap 2. The significance of this approach is that real experimental data support development of ML ANN (number of neurons and layers) topology, which is optimal for this model, training and testing. Results obtained from this model are used for decision-making about the planning time schedule of maintenance actions, as well as reducing overhaul time and direct losses.

REFERENCES

[1] Chun Cheng, Wenyi Liu, Weiping Wang, Michael Pecht, A novel deep neural network based on an unsupervised feature learning method for rotating machinery fault diagnosis, Measurement Science and Technology, Volume 32, Number 9, 2021

OPTIMIZATION OF ALUMINOTHERMIC RAIL WELDING BY MODELING AND SIMULATION OF BASIC PARAMETERS OF THERMITE STEEL CASTING

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Keywords: Rails, Aluminothermic welding, Casting, Model.

ABSTRACT

The most common and at the same time the oldest method of welding railway tracks in the world is aluminothermic, both in the construction of new ones and in the regular maintenance of tracks. This procedure is the most widely used, both because of its flexibility and low implementation costs. However, this procedure is also characterized by certain disadvantages, which primarily relate to the variability of the quality of the welded joints, due to the inherent limitations of the methods used and their dependence on the operator. Requirements regarding the operational characteristics of welded joints should be seen as its ability to withstand the loads prescribed by the standards without fatigue or breakage. In order to optimize the requirements for the quality of the welded joint, the paper presents the results of the simulation of pouring thermite steel into the mold cavity using the presented model.

This model is a powerful tool for the simulation of mold filling, hardening and cooling of thermite steel, as well as for predicting the locations of internal defects, especially microporosity, as well as microcracks. This visualization enables the optimization of the design of the design of the inlet system and the degassing system, which can avoid common errors in AT welded joints, such as inclusions formed due to large turbulence, cold joints, metal shrinkage, porosity and others. It is also possible to evaluate residual stresses and deformations. In this way, expensive experimentation to optimize the sand mold design for all types and qualities of railway rails is avoided, as shown in the paper in the case of rail E49-260.

REFERENCES

[1] Alen Delic, Vaso Manojlović, Miroslav Sokić, Milorad Gavrilovski, Optimization of mold design for aluminothermic welding of railway tracks by software simulation, Tehnika 2022, vol. 77, br. 3, str. 311-317

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FAILURE ANALYSIS OF BEAM OF UNMANNED AERIAL VEHICLE

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Keywords: Fracture, Composite materials, Failure criteria, UVA, Redesign, Finite Element Analysis.

ABSTRACT

The high level of worthiness of unmanned aerial vehicles (UAV), particularly in everyday life, is something that will be common thing in close future. The design solutions for UAV us subject of constant innovation, focused on the improving structure performances and weight reducing. The use of new materials. like various composites, is necessary during this process to fulfill such demanding structural design requirements. Despite the fact that such kind of composite made UAV structures are subjected to the detailed calculation procedures and experimental verifications in the design phase, the fracture and failure can occur during testing in real operation conditions. The redesign procedure is required in order to overcome the noted issues.

This paper describes failure analysis, as well as structural redesign procedure for a beam element of an unconventional UAV. The fracture analysis is based on the numerical calculations of the deformation and stress state of the element, as well as experimental investigation of material characteristics. The developed redesign solution contains modifications in material of the element, as well as the changes in the structure design of the failure zone. The Finite Element Analysis is performed and discussed for both of the element structures: original design and redesign based on the fracture analysis. The conclusions obtained by the comparison of these Finite Element Analyses show the significant structure improvements in the stress concentration zone, achieved by the proposed redesign.

REFERENCES

[1] Inik T, Karakus S, Yetmez S, Failure analysis of a double edge cracked curved composite beam, April 2022Materialwissenschaft und Werkstofftechnik 53(4):388-393, DOI: 10.1002/mawe.202100328

EXPERIMENTAL MECHANICS – VISION OF EXCELLENCE IN SCIENCE BY SHIMADZU

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Keywords: experimental mechanics, testing machines, measurement, precision

ABSTRACT

Shimadzu Corporation is a Japanese public stock company, manufacturing precision instruments, measuring instruments and medical equipment, based in Kyoto, Japan. It was established in 1875. X-ray devices, the spectrum camera, the electron microscope, and the gas chromatograph were developed and commercialized in advance of other Japanese companies. Shimadzu's corporate philosophy "Contributing to Society through Science and Technology".

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In this paper, the complete portfolio of company will be presented with the highlight on mechanical testing machines.

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