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6TH INTERNATIONAL SYMPOSIUM ON NONLINEAR MECHANICS – NONLINEAR SCIENCES AND APPLICATIONS

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The *6th International Symposium On Nonlinear Mechanics – Nonlinear Sciences And Applications* was held from 24th to 29th August, 2003 in Niš and was organized by the University of Niš, Faculty of Mechanical Engineering in co-operation with the Mathematical Institute of the Serbian Academy of Sciences and Arts SANU, Belgrade.

This symposium is a sequel to the previous symposia on *Nonlinear Mechanics* in Serbia. Nonlinear Mechanics is a subject of great importance in the development of science and technology. The aim of the Symposium is to provide a forum to exhibit the progress in this field during the past three years and a place to promote the interaction of modern mathematics and modern mechanics, as well as modern engineering sciences.

Professor *W. Schihlen* from the University of Stuttgart, vice president of IUTAM, wrote: *"So what is new in Nonlinear Dynamics and Mechanics today?"* The initial scope of applications in solid mechanics has broadened to cover material processing, inelasticity and fracture mechanics. In rigid body dynamics, more complex systems such as vehicles, robotics and controlled machines have come into the purview (field) of nonlinear dynamics. On the mathematical side of nonlinear dynamics, it is now recognized that spatio-temporal problems, hysteretic and time delay problems are the new frontiers in this field. Also the term "complexity" has been added to the lexicon of the chaos theory to describe the dynamics of many interacting sub-systems which can exhibit self-organization and evolution. Complexity analysis has gained a foothold in biological and some social sciences as well as in fluid and chemical physics. It remains to be seen what impact it will have on applied mechanics and engineering.

The authors from abroad (Italia, Germany, Poland, Japan, USA, Romania, Russia, China, India, ...) and Serbia & Montenegro (Belgrade, Niš, Novi Sad, Kragujevac, Vranje, ...) have submitted nearly hundred papers printed in the Booklet of abstracts.

All papers were classified into three subjects: *memorial lectures* (3 papers), *invited plenary lectures* (more than 20 papers) and *contributed lectures* (more than 70 papers)

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and were communicated within the memory sessions, key plenary sessions and plenary sessions, respectively.

We believe that, among all the papers communicated during the Symposium, the following ones deserve the special attention of the readers from the Military Technical Institute.

Memorial lectures

– *Milutin Milanković (1879-1958)* (V. Đorđević, the Serbian Academy of Sciences and Arts SANU, Belgrade)

Milutin Milanković ranks among those great scientists of the world who have marked the 20th century. The chief idea underlying his longstanding work was that climatic variations on the Earth result from regular changes in Celestial Mechanics, which in turn cause cyclic changes in the intensity of insolation.

– *Mihailo Petrović Alas (1868-1943)* (K. (Stevanović) Hedrih, Faculty of Mechanical Engineering, Niš)

In essence this symposium is organized with the wish to unite quite disparate sciences in a single place, on the basis of the *Mathematical Phenomenology* of M. Petrović, with the aim of integrating the knowledge of the participants. *Phenomenological Mapping* by M. Petrović and his *Mathematical Phenomenology* and *Mathematical Analogy* can be considered as a continuation of the ideas of Poincare's mapping and M. Petrović as one of the researchers in the row leading to modern researchers who contributed to different kinds of mapping in the research of non-linear dynamics and dynamical systems.

– *Akitsugu Kawaguchi (1902-1984), Tatomir Anđelić (1903-1993) and Danilo Rašković (1910-1985)* (K. (Ste-vanovic) Hedrih, Faculty of Mechanical Engineering, Niš)

This lecture is dedicated to three Professors whom Professor K. Hedrih met along her way of *Tensor Calculus* applications in Mechanics. Professor A. Kawaguchi was the founder and the first president of the Japanese (today international) scientific *Tensor Society* (since 1938). Academician T. Anđelić introduced Tensor Calculus into the studies of Mathematics and Mechanics at the Faculty of Natural Sciences and Mathematics, University of Belgrade (1946); the successes of Analytical Mechanics and Continuum Mechanics of "Belgrade school of Mechanics" are primarily based on its solid mathematical foundation, in majority on Functional and Tensor Analysis and Differential Geometry. Professor D. Raškovic introduced Tensor Calculus into the studies of Mechanics and Engineering at the Technical Sciences High Schools in Serbia; he brought the high mathematical level of Tensor Calculus closer to students of technical sciences and mechanical engineers.

Invited plenary lectures

– *The State of the art in modelling, analysis, design and engineering applications of smart structures* (U. Gabbert, Institute of Mechanics, Otto-von-Guericke University of Magdeburg, Germany)

A brief introduction into the main ideas and concepts of smart structures is given. An overview about recent research activities in this field is presented. Some of the research results of the author's group are discussed in more detail, such as the modelling and

numerical analysis of piezoelectric smart structures including control. Finally, a look into the future is ventured as a very important task to adjust research directions.

– *A Generic optimal control of homo/heteroclinic bifurcations and ensuing global dynamics in different mechanical systems* (G. Rega**,** Dipartimento di Ingegneria Strutturale e Geotecnica, Universitŕ di Roma "La Sapienza", S. Lenci, Istituto di Scienza e Tecnica delle Costruzioni, Universitŕ Politecnica, Ancona, Italy)

The control method, proposed in recent years for controlling nonlinear dynamics and chaos, has been applied to various single-d.o.f. systems representing either exact mechanical models or reduced dynamics of continuous systems. These results are now reconsidered in a unitary context with the aim of better understanding the control procedure and highlighting *generic* properties. Trying to find out generic features of the method, attention is focused on the underlying mathematical problem of optimization, which constitutes a method keystone. It is shown that the one-side control and the global control of the considered symmetric oscillators are *system-independent*, thus strongly confirming the generality of the control method.

– *A More detailed view on the dynamics of the impact damper* (F. Peterka, Institute of Thermomechanics, Academy of Sciences, Prague, Czech Republic)

The motion of the dynamical impact damper is studied using numerical simulation. The regions of existence and stability of different regimes of the system response on the harmonic excitation are evaluated. The boundaries of the regions are specified as grazing, period doubling, saddle-node and Hopf bifurcations. Periodic, quasiperiodic and chaotic impact motions are explained by time series, phase trajectories, bifurcation diagrams and Poincaré maps.

– *On modelling problems in mechanics (theoretical and applied aspects)* (Ly.K. Kuzmina, Kazan Aviation Institute, Russia)

The research subject are complex large-scale systems, for which the original mathematical model, an adequate real object, is extremely complex. The principal tasks are to elaborate universal methods of: modelling, constructing correct simplified models, rigorous substantiating of these reduced models in dynamics, estimating errors and admissible parameters domains by using these reduced models. The suggested method is combining the stability theory and the perturbations theory methods based on the postulates of stability and singularity. It allows to work out the effective manners of rigorous analysis with general methodology of constructing simplified models and their analysing, with dividing the original problem to separate particular ones, with decomposing the original model and its dynamic characteristics, with building the shortened models of hierarchy, and with revealing essential variables and freedom degrees.

– *Regular, chaotic and hyperchaotic vibrations of nonlinear systems with self, parametric and external exci-tations* (J. Warminski, Department of Applied Mechanics, Technical University of Lublin, Poland)

Self-, parametrically and externally excited systems are well known and thoroughly investigated in the literature. The analysis of mechanical systems in which self- and parametric excitation takes place at the same time is carried out in some monographs; in such a case, interactions between two different types of vibrations appear. Analytical, numerical and analogue investigations show that near parametric resonances of the synchronization phenomenon occur.

– *A new concept unifying Lyapunov and orbital stabilities* (S.L.-S. Leelamma, State University, New York)

Following the idea of J.L. Massera that the distance between the trajectories can be measured maintaining different time scales or "clocks" with which time is measured along each motion, a new concept of stability that can unify Lyapunov stability and orbital stability is defined. Also, using the idea of two measures (one to measure the changes in initial values and the other to measure the changes in the solutions), one can achieve unification of a large number of stability notions (various refinements) that are already in the literature. This idea of using different "clocks" (to measure time) while studying the stability of perturbed systems relative to a given nonlinear system is well received by applied mathematicians and engineers.

– *The Numerical integration of differential equations for one dynamic system with dry friction coupling* (L. Bereteu, "POLITEHNICA" University of Timişoara, România)

An algorithm for numerical integration of the differential equations of motion (based on a so-called forth-order Runge-Kutta method) for one dynamic system with dry-friction coupling is derived. Some characteristics, which appear in the integration of these equations, are given and the results of dynamic response simulations are presented. In order to prevent a major failure of the wind turbine structure by vibratory effects, a solution consists of a vibration absorber, placed inside the tower structure (the dry friction forces give the main damping).

– *Lyapunov and non-Lyapunov stability theory: linear autonomous and non-autonomous singular systems* (D. Lj. De-beljković, Faculty of Mechanical Engineering, Belgrade)

Singular systems are those in which the dynamics is governed by a combination of algebraic and differential equations. These systems (also known as descriptor, semi-state or generalized systems) arise naturally as linear approximations of linear and non-linear system models in many applications. The complex nature of singular systems causes many difficulties in their analytical and numerical studies, particularly when there is a need for their control. In that sense the question of their stability deserves a great attention. A particular class of these systems operates in free as well as in forced regimes. A brief survey of the results concerning their stability in the sense of Lyapunov and finite and practical stability is presented.

– *The Regular and chaotic behavior exhibited by coupled oscillators with friction* (J. Awrejcewicz, Technical Uni-versity of Lodz, Poland, L. Dzyubak, Kharkov Poly-technic University, Ukraine)

Using a new approach – applicable to any dynamical system governed by ordinary differential equations and especially suitable for the estimation of regular and chaotic motions – the nonlinear behavior of an autonomous two degree-of-freedom mechanical system with friction is investigated. The domains of a chaotic motion are obtained in various sections of a three-dimensional driving parameter space. Chaotic and regular motions are detected and classified as stick-slip or slip-slip ones.

Contributed lectures

– *A Compressible channel flow over a permeable wall* (V. Đorđević, the Serbian Academy of Sciences and Arts, Belgrade)

The problem of 2-D compressible gas flow through a channel with one permeable wall (which makes the part of the contour of a porous body) is treated as a problem of strong interaction between the channel flow and the flow through the porous body. Simplified equations governing both flows are solved. Exact expressions for the frictions coefficient and the relative increase of the mass flow rate are derived, and their agreement with the existing experiments is better than with empirically defined boundary conditions.

– *The Determination of tooth root stress concentration factor at heavy loaded gear drives* (V. Nikolić, Faculty of Mechanical Engineering, Kragujevac)

A calculation procedure of the strain and stress state of a gear tooth is provided by the finite elements method. The basic relations of the finite elements method with a short description of the developed computer program are presented. The three dimensional curved isoparametric finite element is applicated. The formula for the gear tooth root concentracion factor is derived as well.

– *The Calculation of the separation point for the turbulent flow in plane diffusers* (M. Vujičić, University of Serb Sarajevo, C. Crnojević, Faculty of Mechanical Engineering, Belgrade)

The equations of the turbulent boundary layer in the integral form (adjusted for the internal flow) are used for calculation and the turbulent viscosity model (based on the mixing length) is used for closing the system of equations. The velocity profile in each cross-section of the diffuser is approximated by a sixth-order polynomial. The system of governing equations is reduced to three ordinary differential equations and solved numerically. The obtained results show that the performance, position of the separation point and other flow characteristics of diffusers depend on the angle and the Reynolds number.

– *Fascinating nonlinear dynamics of heavy material particles along circles with coupled rotations* (K. (Stevano-vic) Hedrih, Faculty of Mechanical Engineering, of Niš)

Some research results of fascinating nonlinear dynamics of heavy material particles along the circles with coupled rotations with many different properties of nonlinear dynamics are presented. The paper considers the class of nonlinear systems with coupled rotation motions into a system with two degrees of mobility, but with one degree of freedom of motion defined by one generalized coordinate and one degree of mobility defined by a rheonomic coordinate linearly depending on time. The atlas of the phase portraits families and constant energies curves of the equivalent systems with respect to the original rheonomic system with quazi-parameter nonlinear vibrations is presented.

– *The Controller design for a funnel-shaped smart shell structure* (T. Nestorović Trajkov, Faculty of Mechanical Engineering, Niš, U. Gabbert, H. Köppe, Institute for Mechanics, Otto-von-Guericke University of Magdeburg, Germany)

The controller design which enables vibration suppression of a funnel-shaped shell-type structure (which is a part of a complex medical device – magnetic resonance tomograph) is considered. The funnel-shaped structure is modelled using the finite element approach. The control is achieved with piezoelectric actuators attached to the surface of the funnel (the dynamics of the piezoelectric active elements is taken into account in the procedure of the finite element modeling). The set of linearized

constitutive equations of mechanical and electrical fields is used as a starting point in the finite element modeling procedure. The experimental verification of the frequency response of the funnel was performed.

– *Modelling of laminate composites with embedded piezoelectric actuators and sensors* (U. Gabbert, Institute for Mechanics, Otto-von-Guericke University of Magdeburg, Germany, D. Marinković, Faculty of Mechanical Engineering, Niš)

The Behaviour improvement of structures made of laminate composites can be achieved by embedding components made of smart material between layers. Over the last few years the use of piezoelectric materials as actuators and sensors in vibration control has been successfully demonstrated. The aim of this paper is to present a model of a plate structure made of such a material. The equations governing the mechanical behaviour of a plate are in accordance with the first order plate theory. Based on constitutive equations of piezoelectric material and certain assumptions, governing equations of piezoelectric actuating loads and sensor output are given. The problem of the finite element formulation of the piezolaminated plate is pointed out.

– *Discrete Fourier transform in the problem of the wave packet dynamics* (V.A. Zharov, Moscow Institute of Physics and Technology, Russia)

A method of the wave packet dynamic description is suggested for the Tollmien-Schlichting waves in the boundary layer flow of incompressible fluids. It is based on combining the one mode spectral wave components equation with the wave packet envelope equation. First of all, it gives rise to solving the system of equations for a wave packet envelope that contains the integral equation with the singular kernel which transforms into an algebraic function in the wave number space. This approach is applied when the splitting of nonlinear equations into linear and nonlinear parts is used at each time step. The linear part can be solved with the help of the wave packet spectral component equation and then the field is transformed from the wave number space to the physical space. In the physical space the system of ordinary differential equations is solved by the subsequent inverse Fourier transformation into the wave number space.

– *Large dynamic structures in turbulent boundary layer (review of experimental works)* (Yu.I. Khlopkov, V.A. Zharov, S.L. Gorelov, Moscow Institute of Physics and Technology, Russia)

The data describing vorticity generation and the moment transfer in the turbulent boundary layer that has been accumulated for a long time prove convincingly the existence of large scale vortical structures (coherent structures) that can be governed by autonomous dynamical equations. These structures are responsible for many turbulent boundary layer properties. The experimental results allow to give a definition of the structure and describe some of its details. Such results represent a powerful base for theoretical work.

– *The effect of nonlinear excitation of asynchronous electric motors on the work of driving mechanisms of cranes* (Z. Marinković, S. Marković, D. Marinković, Goran Petrović, Faculty of Mechanical Engineering, Niš)

Two laboratory electrically-driven mechanisms for the analysis of the work of driving mechanisms in the period of acceleration are discussed. One case uses a cage, and the other a slide-disc three-phase asynchronous electric motor with non-linear starting

characteristics. On the basis of non-linear dynamic models, the motion of these mechanisms in the period of acceleration has been analytically solved and simulated by the program package MATLAB/Simulink. The results of these simulations are in good agreement with experimental records, primarily due to the non-linear modeling of curves electric motor ignition.

– *Crack propagation in discrete model of material* (D.B. Jovanović, M.B. Jovanović, Faculty of Mechanical Engineering, Niš)

The theory of fracture mechanics has two main approaches to the problem of crack propagation: continuum mechanics and atomic approach. Interactions of different physical phenomena involved in the initiation and propagation of cracks as well as in the process of fracture and damage, have directed the research towards analyzing processes at the atomic (and molecular) level. The atomic approach considers cracks inside a discrete model of material (atomic lattice). Two intrinsic interatomic force functions are used to represent the mechanical interaction between neighboring atoms (discrete masses) in the lattice. The released potential energy, as a result of crack propagation through the lattice by braking interatomic bonds, is presented.

– *A software for visualization and animation in mathematics and physics* (E. Malkowsky, Faculty of Science and Mathematics, Niš)

A short survey of the basic concepts and principles of the owned software for geometry and differential geometry and its extensions is given. Some applications of this software to the visualization and animation of certain topics in mathematics and physics (such as the illustration of geometric principles in the definition of curves, the study of properties of maps, the graphical representation of some minimal surfaces and of potential surfaces and their Gaussian and mean curvature, the growth of crystals, the study of weak topologies by a collection of functions) are presented.

– *Transformations between surfaces with animations* (V. Veličković, Faculty of Science and Mathematics, Niš)

The application of the owned software and its exten-sions, the graphical presentations of surfaces of different classes, the visualization of mappings between them and the animations of transformations of surfaces are given.

MTI presentation

The following three papers were communicated by the authors from the MTI (Military Technical Institute):

– *An Efficient computation method in fatigue life estimation of damaged structural components* (K. Maksimović, MTI, Belgrade, V. Nikolić, Faculty of Mechanical Engineering, Kragujevac, S. Maksimović, MTI, Belgrade)

This paper focuses on developing an efficient computational method in fatigue life estimations of damaged structural components. The aim is to examine the strength behavior of an important constructional element, the lug, when fatigue cracked, and to propose a stress intensity solution considering various lug geometries. To obtain an efficient algorithm in the crack growth analysis an analytic model for the stress intensity factor of the damaged lug is derived, while numerical modeling, based on the crack finite elements, was used to determine the stress intensity factor solution for an aluminum lug with a through-the-thickness crack.

– *The Determination of the critical jet velocity during the penetration into the homogenous steel obstacle* (M. Ugrčić, Military Technical Institute, Belgrade)

The procedure of the experimental determination of the critical jet velocity during the penetration into the homogenous obstacle is given. The procedure is based on the use of the logic analyzer and special captures to record the discrete data of the curve - the penetration length depending on time. A polynomial form of that mathematically fitted functional curve gives the possibility to determine the critical jet velocity. Also, the results of the experimental determination of the critical velocity of the copper shaped charge jet during the penetration into the homogenous steel obstacle are shown.

– *On a procedure of obtaining the equations of motion of the material point over the smooth surface* (Z. Draško-vić, Military Technical Institute, Belgrade)

In the search for a procedure – more simple but in essence a *formal* one – for the derivation of equations of motion of the material point over the smooth surface the presence of a *formal step* in the usual procedures for obtaining these equations was pointed out. This formality needs one more consistent derivation to be performed from the subspace (a non-Euclidean one) point of view.

Special events

During the Symposium a visit to the major industrial plants / firms in the region of Niš ("MIN", "EI", "Ja-strebac") was organized for the participants from abroad.

Also, an unforgettable sightseeing tour was realized – its key-points were: the *Scull Tower* (world's unique monument dating from 1809), *Mediana* (famous for the archaelogical remains dating from the Roman period), *Ravanica* and *Manasija* (famous Serbian monasteries, the second one especially due to the "Resava school" handwritings) and the *Cave of Resava* (the master-piece of nature).

Organization

The organization of the Symposium, as well as of the above mentioned social events, was perfectly realized, mainly due to the permanent care and enormous efforts of Professor Katica (Stevanović) Hedrih and her tireless collaborators from the Faculty of Mechanical Engineering in Niš.

Conclusion

The Symposium provided an extraordinary opportunity for the participants to meet and discuss recent advances in *Nonlinear Mechanics*. The participants represented a wide range of expertise, from pure theoreticians to people primarily oriented towards applications. Significant achievements of the Symposium were very extensive discussions taking place over the whole range from highly theoretical questions to practical engineering applications.

The main conclusion that can be drawn from the lectures presented at the Symposium is that *Nonlinear Mechanics* as a subject has gained in extent as far as both methodology and applicability are concerned.