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CONTEMPORARY TRENDS IN ESTONIAN MECHANICS

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Abstract. A short review of contemporary trends in mechanics, based on the Estonian Programme for Mechanics 1995–1997, is presented. New problems and results in solid mechanics, gas and fluid mechanics, biomechanics and marine research as well as practical applications are considered.

Key words: solid mechanics, fluid mechanics, biomechanics.

1. ESTONIAN PROGRAMME FOR MECHANICS

Research in mechanics in Estonia has a solid background. Competent research groups have grown up in the institutes of the Estonian Academy of Sciences and in the universities of Tartu and Tallinn beginning with the sixties. To sustain this scientific potential in the changed conditions of management and funding of science after regaining the independence, the Estonian Committee for Mechanics has formulated the Estonian Programme for Mechanics that started in January 1995.

The orientation of the programme was to enhance basic and applied research and education. The basic objectives were directed to the coordination of the research, to the promotion of interdisciplinary research, to the evaluation of current research and improvement and modernization of teaching mechanics at Tallinn Technical University and Tartu University. The attention was also focused on the need for concentrating efforts for solving acute industrial problems.

The programme was joined by the Institute of Cybernetics (now at Tallinn Technical University), departments of mechanics, instrument engineering, and structural design of Tallinn Technical University, department of theoretical mechanics of Tartu University, departments of mechanics and machinery design and timber technology of Estonian Agricultural University, Estonian Marine Institute and Estonian Energy Research Institute.

The aim of the programme was not to create a new bureaucratic structure but an instrument for coordination of activities. The participants formulated 13 subprogrammes and the heads of subprogrammes formed a Council of the programme. On the annual meetings of the Council the results and plans have been discussed.

All the 13 subprogrammes were relatively autonomous and performed usually by one or two teams. As a rule, each subprogramme contained parts related to basic research as well as to practical applications. However, some of them were more oriented to the theoretical studies while the others were mainly directed to practical needs of modelling of physical or ecological processes and to design tasks. The list of subprogrammes is presented in the Appendix.

2. PROBLEMS AND RESULTS

Summarizing the activities of the programme, many new results were obtained. The studies included nonlinear dynamics (mainly nonlinear wave theory), nondestructive testing, biomechanics, theoretical problems of fluid-solid interactions, and processes in dispersed flows and in water ecosystems in the Baltic Proper. Practical applications were connected with agricultural machine design and development of the equipment for automated measurements in integrated photoelasticity. In the following a very brief (and certainly subjective) review is presented.

2.1. Solid mechanics

In the field of solid mechanics the general nonlinear wave theory is summed up in the recent monograph [1]. Using pseudospectral methods for numerical integration of the classical Korteweg–de Vries equation and some of its modifications and the idea of spectral analysis, additional information on the energy spectra of wave structures beside their spatio-temporal profiles has been obtained [2]. Main attention has been paid to the soliton formation and propagation mechanism in solids with microstructure [3,4]. The concept of virtual solitons (short-living solitons) has been defined and their existence demonstrated. Using the formalism of internal variables, a mathematical model for wave propagation in micro-structured and thermoelastic media has been derived [5].

A theory of nonlinear nondestructive testing of materials has been developed. The possibility of nondestructive evaluation of inhomogeneous predeformed state and variable physical properties of materials has been theoretically proved [6]. The efficiency of acoustodiagnostics has been enhanced by using the wave profile evolution data in addition to the wave velocity measurements. As a result, relatively simple tests allow to evaluate the inhomogeneous properties of the material in many cases.

The continuous-valued cellular automata have been used for simulation of thermomechanical processes. The research included the elaboration of continuous cellular automata algorithms and their applications [7]. From the latter let us mention linear elastic and thermoelastic wave propagation in homogeneous and layered solids in the one-dimensional case, nonlinear one-dimensional heat conduction in regions of phase transitions in water, unsteady heat conduction in a rectangular domain with a cutout under pointwise heating at a boundary, and the two-dimensional convection-diffusion process in a liquid.

New results in design and optimization of non-elastic structural elements have been obtained. Thin-walled beams, plates and shells made of elastic, elastic-plastic and ideal rigid-plastic materials have been studied [8–11].

Determination of the contact areas and pressures in pairs journal–bush in the case of inclined axis gave a possibility to study the elastohydrodynamic lubricating process and to elaborate methods for bearing design [12].

Finite element method for the simulation of the wear processes was used to estimate the relative reliability of various structures [13,14].

In integrated photoelasticity, a hybrid mechanics method for residual stress measurement in axisymmetric glass articles has been elaborated. The method is based on the generalized sum rule which relates axial, radial and circumferential stress, and contains also an integral of the gradient of the shear stress. Hybrid mechanics relationships have been derived for two cases: 1) axisymmetric problem of thermoelasticity, 2) viscous flow in closed conduits. In the first case the main result is the generalized sum rule in two approximations. In the second case a solution is obtained which is free of assumptions used earlier [15].

In magnetooptical tomography it has been shown that using two stress functions the inverse problem may be presented in the form of a Poisson equation and a boundary value problem [16].

The process of string excitation by striking it with a hammer is an important problem in sound formation by musical instruments, especially by pianos. An analytical model of the nonlinear hysteretic hammer, which takes into account all the important dynamic features of the hammer–string interaction, has been developed [17]. According to this model, the felt material of the real and commonly used piano hammer possesses history-dependent properties. This model predicts the sound spectra in a good agreement with experimental data for various types of piano hammers and for arbitrary hammer velocity.

2.2. Solid-fluid interaction, fluid and gas mechanics

Problems of interaction of fluids and elements of solid structures are interesting from many practical aspects. By investigating the dispersion curves of a fluid-loaded cylindrical shell it has been shown that the fluid loading has a qualitative influence on the behaviour of dispersion curves. Main part of the energy is transported by the flexural wave which, depending on the frequency, is either an antisymmetric Lamb wave or a Stoneley wave. The transitions from one propagation type into another take place in the frequency region where strong interaction between all the modes occurs. If one increases the radius of curvature, tending from the shell to the plate, mutual transitions of the wave types take place in the strong interaction frequency region [18,19].

Influence of the singularities on the wave propagation has been investigated. The construction considered was a thin cylindrical shell with an internal stringer or an axial wall. The analysis of the numerical results has shown that in a thin-walled structure an internal wall can provide an additional source of noise, and radiation of the vibration energy into the surrounding medium takes place. The mutual transformations of the waves from one propagation type to another also occur in the internal wall. Calculated echo signals allow to identify different wave propagation types in the shell as well as their radiation into fluid. The influence of the axial discontinuity strongly depends on its position relative to the incident wave [20–22].

Theoretical basis for the investigation of dispersed flows (gas with solid particles) has been developed taking into consideration several additional effects such as collision processes between particles and between particles and boundary surfaces, influence of the particles on the turbulent gas flow, and migration of the particles. Using theoretical and experimental results, new numerical models for mathematical description of dispersed flows in channels, pipes, and boundary layers have been developed [23–27].

Modelling and experimental studies in the Estonian Marine Institute have been focused on the exchange processes controlling the state of the environment and trends in Estonian marine areas. It has been shown that: a) water exchange of the Gulf of Riga is composed of the persistent flow component, determined by the frontal dynamics in the connecting straits, and of the fluctuating component, dominated in the Irbe Strait by the 24 h period oscillations [28,29]; b) plankton blooms are effectively controlled by mesoscale hydrodynamic processes like fronts and eddies as shown by studies in the Gulf of Finland [30,31]; c) deep water renewal in the Baltic Proper is modified by variable channel flow of saline water from the upstream basins, mesoscale circulation within the basins and complex mixing processes.

New estimates of the water exchange have been obtained by combining the hydrographic data and a diagnostic model [32]. A statistical model has been elaborated for reconstruction of the 3D hydrographic fields on the basis of monitoring data [33]. Theoretical studies have been devoted to nonlinear Rossby waves [34] and turbulence [35]. Development of the models and applications includes a 3D circulation model [36], a thermocline model [37] and applied research in Tallinn and Muuga Bay.

A coupled 3D circulation and water ecosystem model FINEST has been developed. In this model the concept of a size-dependent plankton food-web is used. This concept gave the possibility to reduce the number of needed coefficients from five to six times and therefore the correct mathematical statement of the problem was possible. The FINEST model was used for simulations of seasonal and long-term variations in the Gulf of Riga, in the Baltic Proper and, as a result of the international cooperation, in the Egyptian part of the Mediterranean Sea [38–42].

2.3. Biomechanics

In recent years interdisciplinary problems are of greatest interest. There are several problems in biology which can be considered in the frame of mechanics. Indeed, a better understanding of underlying mechanisms of these processes can be achieved by using the methods of contemporary mechanics.

One of such processes is the mechanism of the heart rhythm and underlying activation processes. For analysing this mechanism, the methods of nonlinear dynamics proved useful. In the Institute of Cybernetics the cardiac arrhythmias have been studied by using a simplified model of the His–Purkinje system. The existence of coexisting attractors for this model has been shown. The propagation of electrical activation from the Purkinje fibre to the myocardium has been studied. The fractal properties of blood-vessel systems has been determined [43–46].

The theory of the elastohydrodynamic lubrication process can serve as a good methodological basis for studying biotribosystems, such as various joints [47,48].

2.4. Experimental mechanics

The study of mechanical problems are very often connected with experiments. In the frame of Estonian Programme for Mechanics several test beds for various problems have been designed.

In Estonian Energy Research Institute the test bed for investigation of dispersed flows, equipped with a laser-optical measurement system, gave an opportunity to explain several physical effects (influence of particles on the turbulent gas flow, abnormal concentration distribution in the boundary layer on the surface of a plate). In the Hydraulics Laboratory of the Tallinn Technical University the experimental studies of breaking waves have been carried out. New data for estimating hydrodynamic forces caused by breaking waves in the coastal structures as wharves and piers have been obtained. A surf model with the wave generator has been constructed in a glass walled flume. To study the hydraulic characteristics of breaking waves, a 2D laser doppler velocimeter has been used together with a specially constructed system for data collection and analysis. During the studies, new data on the turbulent characteristics at different phases of the breaking waves have been found which have significant influence on the sediment transport in the surf zone [49–52].

In the Laboratory of Photoelasticity of the Institute of Cybernetics an equipment for automated measurements in integrated photoelasticity has been elaborated which enables one to use tomographic methods for stress analysis in axisymmetric specimens and the scattered light method for stress measurement in thick plates [53].

2.5. Practical applications

Several manual and automated polariscopes for stress measurement in glass products and software package BOTTLE for stress calculation in axisymmetric glass articles are in use in a number of glass companies.

The behaviour of girder- or cable-stiffened suspended structures and complex shell and spatial structures under various work conditions have been studied both theoretically and experimentally [54,55].

Studying the grinding process by colliding, results based on the fracture mechanics of particles in various types of grinding have been used by the design of disintegrators. An adaptive control device for the control of the imbalance of disintegrators has been elaborated and tested [56–58].

The studies in the field of mechanics in Estonian Agricultural University have been mostly directed to solving practical problems. The finite element method has been widely used for calculating the forces in the structures of agricultural machinery and for optimal design of them, e.g. spinharrow circular link, seedbed cultivator, cylindrical shell under local loading and compressors with radial blades [59–61].

Layer growing/removing method for the determination of residual stresses has been elaborated [62,63].

An analysis, based on statistics, and a theoretical study of the classification of the timber strength has been made. The results have been recommended for inclusion in the new Estonian standard of timber and timber structures [64].

2.6. Education

One of the objectives of the programme has been enhancing of the level of teaching mechanics in Estonian universities. This problem was under discussion during the annual meeting of the Council of the programme in 1997. The Council found that programmes for teaching mechanics at Tallinn Technical University and Tartu University do not meet contemporary demands.

The participants of the programme have contributed to teaching by delivering special courses. Special courses read at Tallinn Technical University and Tartu University for students and postgraduates are nonlinear dynamics, nonlinear dynamics and chaos, nonlinear differential equations, biomechanics, mathematical modelling, solitons, experimental mechanics, continuum mechanics, mechanics of viscous and inhomogeneous media, etc.

3. SUMMARY

During the period of 1995–1997, Estonian scientists have been successful in several fields of mechanics. International cooperation with many universities and research centres in Europe has grown very fast. These results encouraged formulation of new tasks for the period 1998–2002. On the 10th Estonian Days of Mechanics on September 11–13, 1998, in Aegviidu, the main problems of the new programme were fixed. These problems involve nonlinear dynamic processes in complicated media (microstructured media, biological tissues, biological systems), several hydrodynamic and ecological processes in the region of the Baltic Sea, etc. Attention will be paid to practical applications of theoretical results in experimental mechanics.

APPENDIX

SUBPROGRAMMES OF THE ESTONIAN PROGRAMME FOR MECHANICS 1995–1997

1. Nonlinear dynamics (Prof. Jüri Engelbrecht, Institute of Cybernetics, Tallinn Technical University).

2. Solid-fluid interaction (Prof. Jaan Metsaveer, Department of Mechanics, Tallinn Technical University).

3. Tribomechanics (Prof. Maido Ajaots, Department of Instrument Engineering, Tallinn Technical University).

4. Non-elastic structures (Prof. Jaan Lellep, Department of Theoretical Mechanics, Tartu University).

5. Experimental mechanics (Dr. Hillar Aben, Institute of Cybernetics, Tallinn Technical University; Prof. Jakub Kõo, Estonian Agricultural University).

6. Structural mechanics (Prof. Valdek Kulbach and Prof. Ülo Tärno, Department of Structural Design, Tallinn Technical University).

7. Mechanics of timber (Prof. Tõnu Keskküla, Department of Timber Technology, Estonian Agricultural University).

8. Mechanics in agriculture (Prof. Mati Heinloo, Department of Mechanics and Machinery Design, Estonian Agricultural University).

9. Marine hydrodynamics (Prof. Jüri Elken, Estonian Marine Institute).

10. Marine ecosystems (Dr. Rein Tamsalu, Estonian Marine Institute).

11. Surface waves and coastal engineering (Prof. Uno Liiv, Department of Mechanics, Tallinn Technical University).

12. Mechanics of dispersive media (Dr. Ülo Rudi, Estonian Energy Research Institute).

13. Mechanics of grinding (Prof. Boris Tamm, Institute of Cybernetics, Tallinn Technical University).

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NÜÜDISAEGSED SUUNDUMUSED EESTI MEHAANIKAS

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On esitatud lühiülevaade nüüdisaegsetest suundumustest mehaanikas lähtudes Eesti mehaanikaprogrammist aastateks 1995–1997. On vaadeldud püstitatud ülesandeid ja saadud lahendusi tahke keha, gaasi ja vedelike mehaanikas, biomehaanikas ning mereuuringutes. Tutvustatud on ka arendustöid ja praktilisi rakendusi.