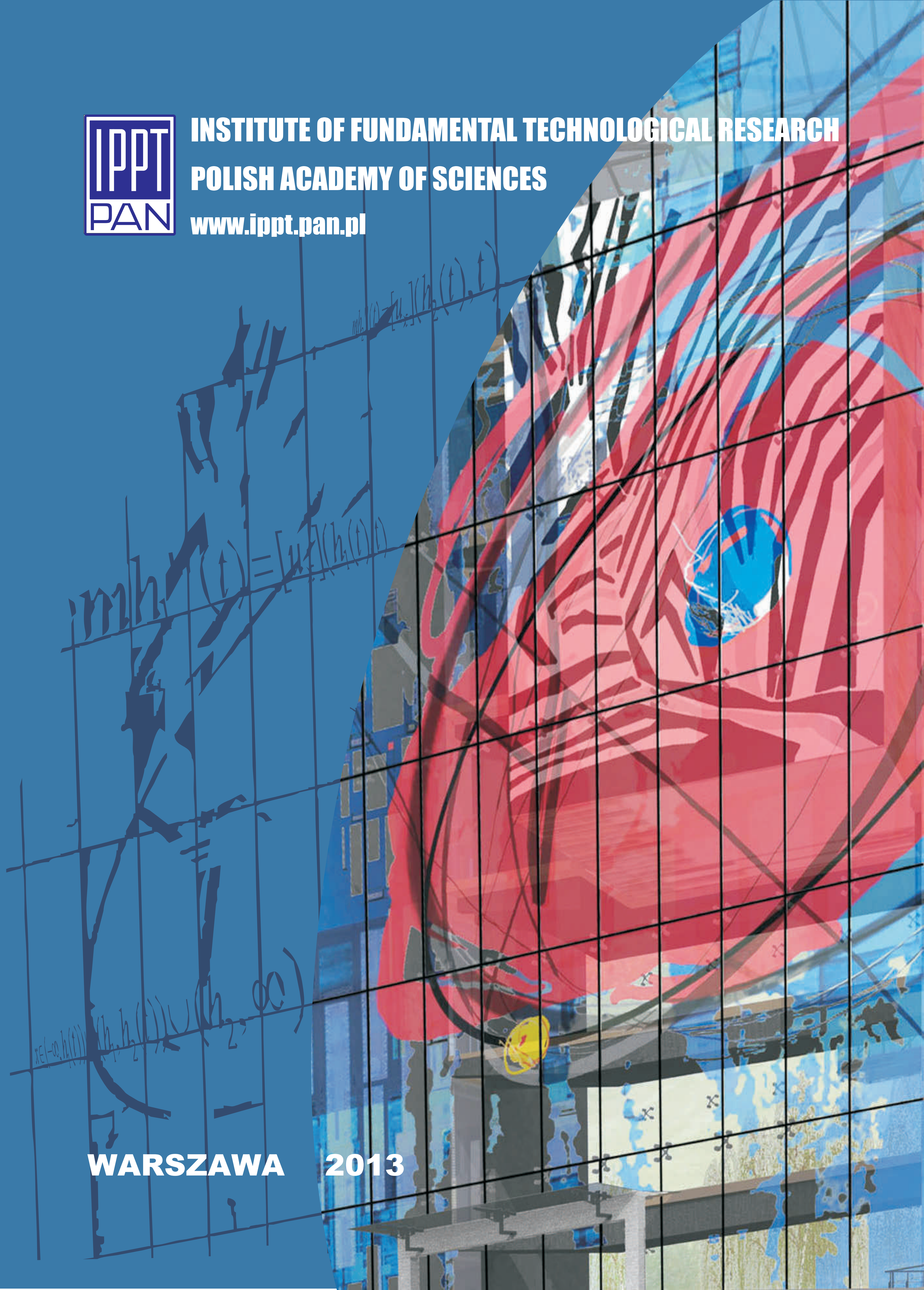

IPPT PAN

INSTITUTE OF FUNDAMENTAL TECHNOLOGICAL RESEARCH

POLISH ACADEMY OF SCIENCES

www.ippt.pan.pl

WARSZAWA 2013

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Message from the Director

The Institute of Fundamental Technological Research (IPPT) has been founded in 1953 on the basis of a few divisions from the Department IV of Technical Sciences of the Polish Academy of Sciences. The development of the Institute was closely related to a few outstanding scientists who created it and later accomplished universally recognized results.

The following names should be mentioned: Witold Nowacki (elasticity and thermoelasticity), Wacław Olszak (plasticity), Janusz Groszkowski (electronics), Aleksander Krupkowski (metallurgy), Władysław Fiszdon (mechanics of fluids), Stefan Ziemba (mechanical systems), Antoni Sawczuk (structural mechanics), Ignacy Malecki (physical acoustics), Leszek Filipczyński (ultrasound in medicine), Wojciech Szczepiński (plasticity, experimental mechanics, Zbigniew Wasiutyński (mechanics of structures and materials). Many other eminent scientists have spent tens of years at the Institute where an atmosphere of stability and tolerance was combined with high level of research and innovative attitude.

The history and tradition of the Institute formed the base for the present. Purpose-oriented research projects, high efficiency and openness to new ideas are always highly appreciated. Cooperation with the industry, joint programs with the research centers in Europe, United States and Japan and involvement in high education programs are the main directions of the present activity in which basic research is supported by and combined with application.

The long and rich tradition of the Institute, its widely recognized excellence in research as well as the current policy towards transforming it into a truly modern institution combining theoretical and applied engineering research with broad industrial support and substantial teaching involvement make all of us at the Institute approach the "turn-of-the-century" scientific and technological challenges with self-confidence and excitement.

The basic core of the Institute is formed by seven departments conducting research in the following fields: mechanics of continuous media, mechanics of structures and materials, fluid mechanics, medical ultrasounds, mechanical systems, biomechanics.

The Institute has traditionally been very active in operating its own post-graduate school (established in 1968) in the framework of which over 700 Ph.D. degrees have been granted to young Polish and foreign researchers.

The Institute is authorized to confer the doctoral degree and habilitation in mechanics, material engineering, informatics and electronics.

The Institute, with its staff of about 120 highly qualified researchers (of whom 14 are full professors, 26 associate professors and 46 senior researchers with the Ph.D. degree), is one of the biggest research institution within the structure of the Polish Academy of Sciences. The main mission of the Institute is to pursue high quality, up-to-date research activities. As its name suggests, the Institute is, and has always been since its establishing, oriented towards basic theoretical and experimental engineering research. Over the years the Institute has established itself as a leading research institution, making significant contributions to many science and engineering areas, promoting successfully novel research directions and enjoying high reputation both in and out of Poland.

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DEPARTMENT OF MECHANICS AND PHYSICS OF FLUIDS

HEAD: Prof. Eligiusz Wajnryb

Master's Diploma and Doctorate (Ph.D.) degree in physics obtained at the Physics Faculty of the University of Warsaw, habilitation at IPPT PAN. In 2010 he became the head of the Department of Mechanics and Physics of Fluids.

DIVISIONS AND RESEARCH GROUPS

- Modeling in Biology and Medicine — Head: Prof. Tomasz Lipniacki
- Complex Fluids — Head: Prof. Eligiusz Wajnryb

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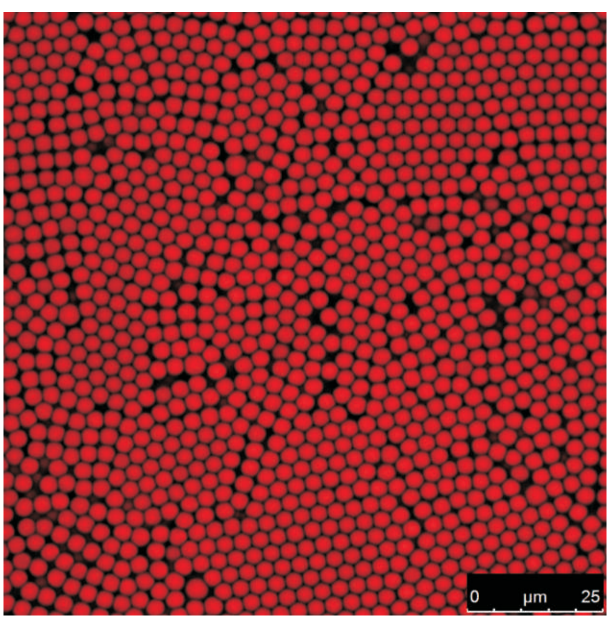
For more than a century the main area of interest of fluid mechanics research concentrated on aerodynamics and turbulence. These subjects complemented by rarified gas dynamics and modeling of blood flow formed the core research of the Department of Liquid and Gas Mechanics (ZMCiG) for over 40 years. In mid 1990's new areas of interest like free surface flow (jets, droplets), thermally driven flows (convection, solidification), development of new experimental methods (PIV & PIT), atmospheric flows (cloud dynamics), modeling complex fluids (suspensions), superfluidity (turbulence), biomedical problems (DNA mechanics, system biology, neurons signaling) began to dominate research area of the department.

Hence, in 1998 it was reconstituted with a new name as Department of Mechanics and Physics of Fluids. Few years later the new trends involving challenging areas of nanofluidics and microfluidics and their applications to biomedical problems completely transformed the department. The new research areas, supported by growing number of young postdoctoral researchers, undergraduate and graduate students, representing diversity of backgrounds from physics and chemical engineering to mathematics and biology, are basically concentrated in two complementary divisions.

In the Division of Complex Fluids (CF) fundamental studies of hydrodynamics of micro- and nano-objects and their concentrated systems are carried out. Self-diffusion, sedimentation and viscosity for dilute and concentrated dispersions of particles with various shapes and a different internal structure (solid, fluid, permeable, core-shell) is analyzed theoretically and determined numerically. The hydrodynamic interactions between non-Brownian particles – destabilization of clusters, periodic orbits, migration of flexible fibers are investigated. Transport in colloidal suspension is studied. The results are important for chemical, biological, medical and industrial applications, such as drug delivery by microgels, motion of active matter, wastewater treatment or conformation of fibrinogen. In the rapidly growing Division of Modeling in Biology and Medicine (MBM) the system biology and nano-medicine dominate the research area. It is mainly focused on single cell analysis of immune responses, carcinogenesis, calcium signaling, and information transmission in neuronal networks. The modeling techniques involve ordinary and partial differential equations, stochastic processes and extensive numerical simulations. The experimental techniques are based on classical biochemistry and confocal microscopy of living cells with fluorescently tagged proteins. Laboratory is active in development of medicine directed electrospinning fibers, designed to drug release and tissue restoration.

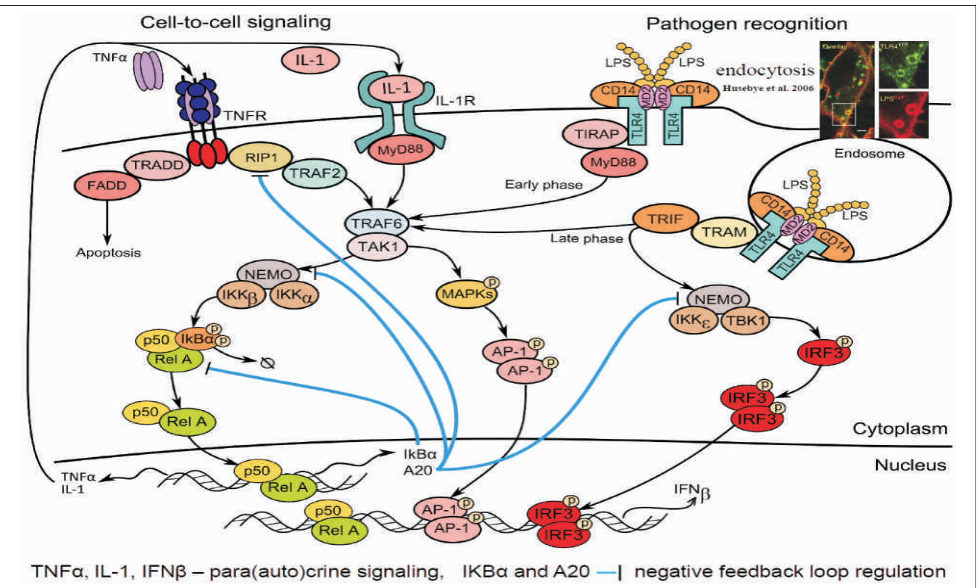


SELECTED RESEARCH ACTIVITIES

MODELING OF INNATE IMMUNE RESPONSES AT SINGLE CELL LEVEL

Innate immunity forms the first line of defense, limiting spreading of infection before the adaptive immune response is activated. In the first phase of the innate immune response, cells detect pathogens or their fragments with their membrane and cytoplasmic receptors. This leads to activation of the regulatory systems of the transcriptional factors NF-κB, IRF3 and AP-1 families, Fig.1. These factors jointly regulate the activity of a several hundred genes responsible for inducing inflammation, antiviral protection, proliferation and apoptosis. In particular, they induce production and secretion of proinflammatory cytokines (among them IL-1, TNFα) as well as interferons α and β. These cytokines are mediators of the second phase of the cellular innate immune response in cells that did not encounter the pathogen.

Fig.1.
Example of pathogen recognition: LPS induced signaling.
LPS (Lipopolysaccharide-outer membrane of Gram-negative bacteria) is recognized by CD14 co-receptor, which transfers it to TLR4 leading to its activation, and binding of adaptor protein Myd88. As a result kinase TAK1 is activated and transmits signal to transcription factors p50-RelA (NF-κB) and AP-1 (early phase ~ 30 min). CD14 induced endocytosis of CD14-TLR4-LPS complexes leads to TRIF mediated activation of IRF3 and p50-RelA (late phase). Activation of transcription factors p50-RelA, IRF3 and AP1 leads to their nuclear translocation and synthesis of cytokines: TNFα, IL-1 and IFNβ that regulate via para (auto)crine signaling the second phase of innate immune responses. Transcriptional activity of p50-RelA and IRF3 is controlled by p50-RelA inducible proteins IkBα and A20 (negative feedbacks).



ANALYSIS OF INFORMATION TRANSMISSION EFFICIENCY IN BRAIN INSPIRED NEURONAL NETWORKS

How the brain transmits the information is one of the major issues that have been recently investigated both through data analysis and theoretical modeling. Recent attempts to quantify information transmission have concentrated on treating neuronal communication process in the spirit of Shannon's information theory. The fundamental concepts of this theory are the entropy and the mutual information which can be handled from a single trajectory (input - output) by application of advanced entropy estimators. One expects to adapt, often amazing, brain effectiveness to design much more efficient computational methods, say supercomputers. There are several important questions at stake, which could lead to this aim, and among them is the analysis of optimal regimes of brain work, especially, taking into account both information and information-energetic criteria. Thus, the important questions are:

- determination of optimal neurons parameters like synaptic failure (biological noise), activation threshold,
- the role of brain-like network architecture ingredients: inhibitory and excitatory neurons, long-range connections size and delay effects,
- optimal adaptation of the brain-network to information source characteristics like its firing rate and strength of correlations.

This research is performed in collaboration with international experimental laboratories.

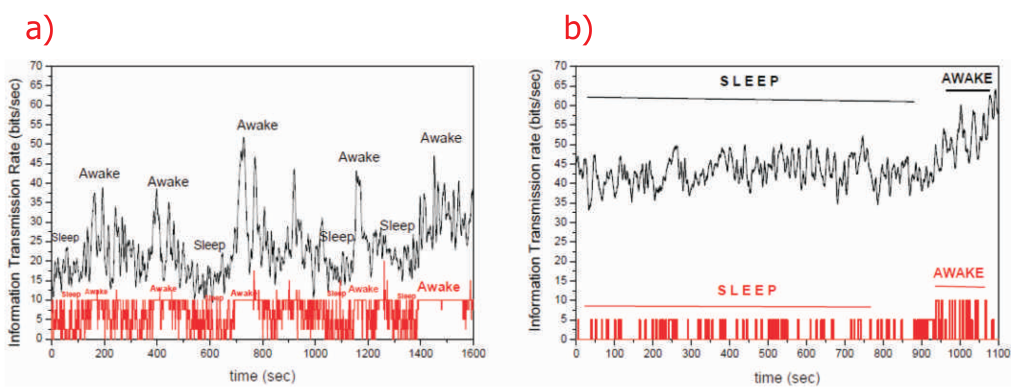


Fig.2.
Typical runs of the information rate for two neurons. The awake-sleep transitions for two typical physiological states as a function of time. In the panel a) the rat alternated several times between the states of sleep and awake. In the panel b) the rat remained in the deep sleep and then suddenly was woken up. The brain states classification by EEG (red line) is also presented. In the plot, the awaken state corresponds to the value of 10.

KINETIC MONTE CARLO SIMULATIONS AND BIOCHEMICAL REACTIONS ON THE PLASMA MEMBRANE

Early events in cellular communication and signaling engage proteins located in the plasma membrane. Slow diffusion therein restricts the number of interacting molecules, enhancing molecular noise, and renders the membrane a spatially organized stochastic reactor. Therefore, exact simulation of signaling on the membrane requires methods which can account for both spatial resolution and stochastic effects, such as the kinetic Monte Carlo on a lattice.

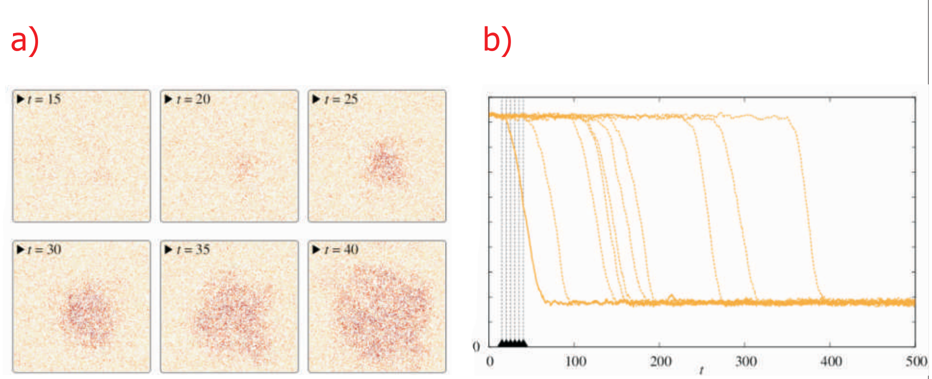


Fig.3.
Spontaneous initiation of activity and propagation of travelling wave:

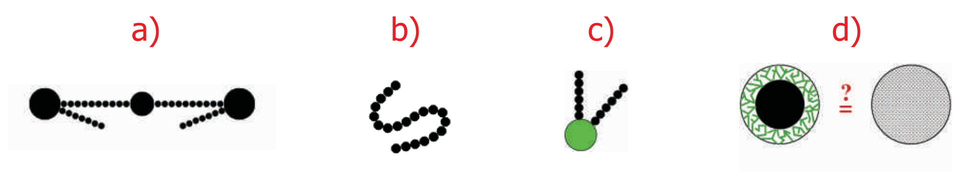
a) bistable kinase auto-phosphorylation system is activated due to a local stochastic fluctuation (orange hexagon – inactive, i.e., unphosphorylated, kinase, red – active, singly phosphorylated kinase, brown – active, doubly phosphorylated, pale green – phosphatase). Then, activity expands as a stochastic travelling wave, eventually filling whole simulated two-dimensional compartment,

b) spontaneous activation in 10 independent simulations with randomized initial conditions.

HOW DO MICRO- AND NANO-PARTICLE SHAPES AND THEIR INTERNAL STRUCTURE INFLUENCE TRANSPORT, SELF-DIFFUSION AND VISCOSITY OF MULTI-PARTICLE SYSTEMS IN FLUIDS?

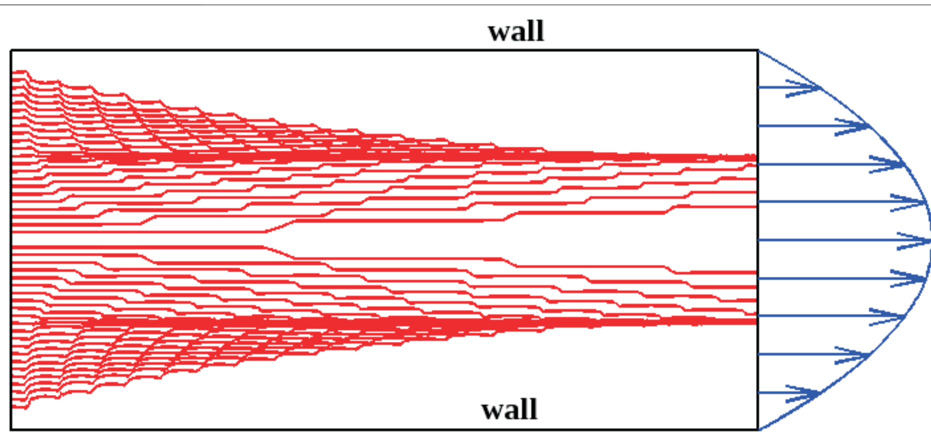
We determine theoretically how motion of particles and forces which they exert on the fluid depend on their shape, flexibility, permeability or slip of the fluid velocity at their surface. Such information is important for many practical applications. For example, measurements of fibrinogen viscosity compared with our numerical results, provide information about conformation of the molecules. Our theoretical description of the permeable particle dynamics in dilute and concentrated systems is useful for the drug and protein delivery by micro-gels.

Fig.4.
a) fibrinogen,
b) flexible microfibers,
c) algae,
d) core-shell permeable micro-gels.



Thin elastic micro-objects of a different length and flexibility entrained by the Poiseuille flow in a microchannel tend to accumulate at different distances from the wall. Theoretical evaluation of this relation is essential for efficient segregation of fibers, vesicles or other types of deformable micro-particles.

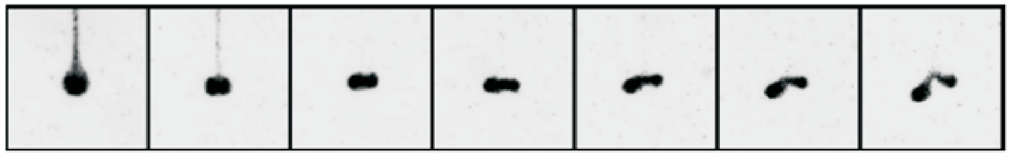
Fig.3.
Trajectories of flexible particles in the Poiseuille flow.



DYNAMICS OF MANY-PARTICLE SYSTEMS SETTLING UNDER GRAVITY IN A VISCOUS FLUID

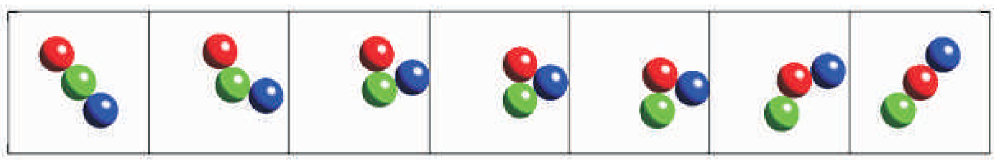
We investigate theoretically, numerically and experimentally systems of close particles which settle gravitationally in a viscous fluid, near by and far from walls. A swarm of randomly distributed non-touching particles forms a suspension drop, which settles as a cohesive entity for a long time, then suddenly destabilizes, splitting into several parts.

Fig.6.
Destabilization of a suspension drop settling under gravity (snapshots from experiments).



Instabilities are also observed for periodic oscillations of particles in regular configurations, both of a small and a large number of particles. We investigate what is the nature of such instabilities, and how important are oscillations for evolution of many-particle systems. Results are useful for such applications as drug delivery in human airways, waste water treatment, and efficient micro-swimming.

Fig.7.
Periodic relative motion of close particles settling under gravity (snapshots from computations).



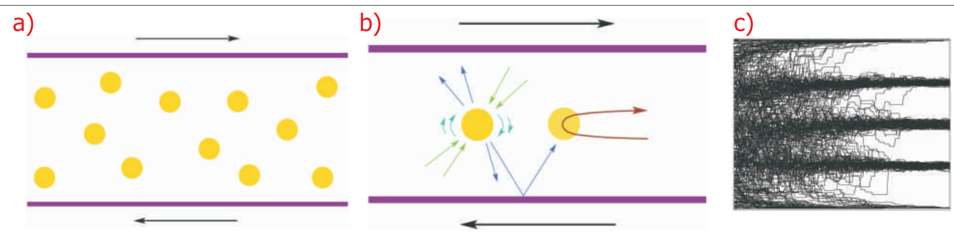
HYDRODYNAMIC INTERACTIONS BETWEEN PARTICLES AND INTERFACES

Our accurate HYDROMULTIPOLE numerical codes, combined with the Cartesian representation, are used for evaluation of many-particle mobility coefficients close to interfaces, in 3D and quasi-2D systems. The interfaces are solid walls, free surfaces or fluid-fluid boundaries, pure or covered with a surfactant. Such computations have important applications in microfabrication, microfluidics and biotechnology. For example, if compared with measurements of test particle mobility, they allow to discriminate between clean and contaminated interfaces.

The effective properties of suspensions, such as effective viscosity and diffusion, in confined geometries are significantly influenced by the presence of walls or fluid-fluid interfaces. Hydrodynamic confinement effects are especially significant in parallel-wall channels or thin films of the width comparable to the particle size. For example, effective viscosity of a fluid containing elongated objects is significantly decreased in a microchannel of a width comparable with a fraction of the particle length. Therefore, a suitable choice of the microchannel width leads to reducing the energy dissipation during the particle transport.

Another example of a significant wall effect is a spontaneous creation of a layered microstructure in a confined Couette flow of non-Brownian dilute suspensions. We explained this effect by the swapping (reversing) of particle trajectories, caused by the presence of a close wall.

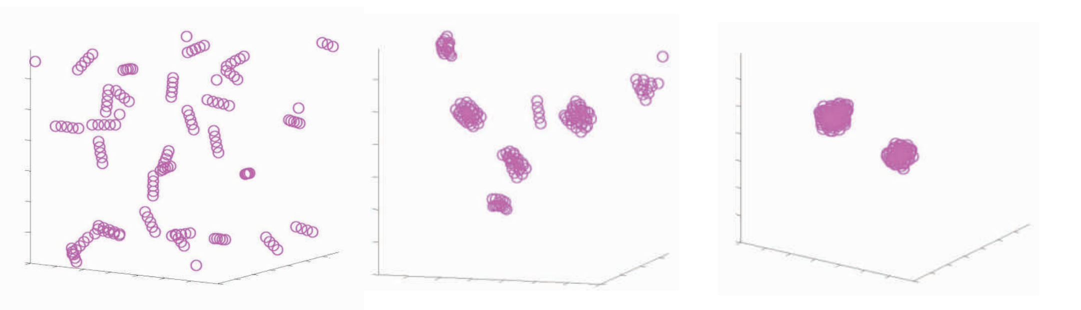
Fig.8.
a) suspension geometry,
b) swapping particle trajectories,
c) time evolution of transverse particle positions in a confined system leads to formation of a layered microstructure.



AGGREGATION OF COLLOIDAL POLYMERS IN EXTERNAL FLOW

This common biological process occurs, for example, in plugging of vascular injuries or development of Alzheimer's and Parkinson's diseases. It is of uttermost importance to establish the dependence of the rate of aggregation on the shear rate of the external flow and the physical properties of the polymer particles to explain vital biological phenomena. To this end, we use combined numerical and theoretical methods: full HYDROMULTIPOLE code as well as a faster code based on the Rotne-Prager approximation, and an asymptotic theory in the limit of a small and a large Peclet number.

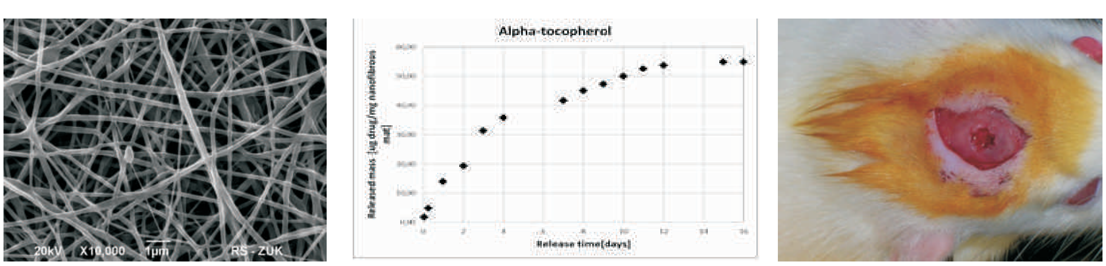
Fig.9.
Snapshots of polymer evolution in shear flow.

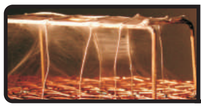


ELECTROSPINNING OF NANOFIBERS FOR BIOMEDICAL APPLICATIONS

The electrospinning is comparatively inexpensive and versatile method of production of micro- and nanofibers. Such nanofibers are of potential use as scaffolds cell cultures and for tissue engineering. Our group investigates both the fundamentals of the electrospinning process as well as the medical applications of the electrospun nanofibers. Currently the materials are being tested for the use in neurosurgery (protective material), urology (ureter and urinary bladder wall implants), plastic surgery (support of implants) and drug delivery systems (DDS). Nanofiber-based DDS are being tested to be used as neuroprotective material for medical treatment of brain injury. We obtained DDS of well-defined release pattern of a model drug – α-tocopherol (vitamin E), Fig. 10.

Fig.10.
a) SEM micrograph of a nanofibrous mat containing 15% of α-tocopherol,
b) the release profile of drug,
c) the operation for tests of mat on an animal model.





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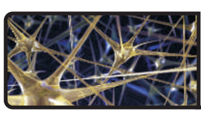

MAJOR PROJECTS

1. Dynamics of micro- and nano- objects suspended in fluids, (NCN). **2.** Application of electrospun nanofibrous mats as active wound dressing for prevention of post-accidental brain damage, (NCBiR). **3.** Particles in turbulence, (ESF). **4.** Inter- and intra-cellular signaling in innate immune response: experimental and mathematical analysis, (NCN). **5.** Mechanistic aspects and spatial organization of cell signaling, (FNP). **6.** Multiphase flows in microchannels, (NCN). **7.** Hydrodynamics of complex fluids, (NCN). **8.** Smart and green interfaces - from single bubbles and drops to industrial, environmental and biomedical applications, (ESF). **9.** Multiparameter and Information Theoretic models of Biochemical Signal Transduction (FNP). **10.** Application of information theory-based computational methods for the analysis of signal transduction efficiency in neuronal networks, (NCN). **11.** Traveling waves in cylindrical domains, (NCN). **12.** Innate Immune Signalling: Optimal Microfluidics Protocols, Prediction and Control, (EC). **13.** Sliding Droplets - Elucidating the Mechanism of Lubrication for Sliding Droplets: Hydrodynamics, Surface Forces, and the Role of Surfactants and Polymers, (EC).

DEPARTMENT OF MECHANICS OF MATERIALS

HEAD: Prof. Henryk Petryk

Graduated at Warsaw University of Technology, doctorate (Ph.D.) and habilitation obtained at IPPT, full professor since 1995. Corresponding member of the Polish Academy of Sciences, Editor of Archives of Mechanics, Chairman of the Scientific Council of IPPT PAN.

DIVISIONS AND RESEARCH GROUPS

- Applied Plasticity — Head: Prof. Ryszard Pęcherski
- Mechanics of Inelastic Materials — Head: Prof. Henryk Petryk
- Surface Layers — Head: Assoc. Prof. Stanisław Kucharski
- Advanced Composite Materials — Head: Assoc. Prof. Michał Basista
- Thermoplasticity — Head: Michał Maj, Ph.D.

STAFF

Prof. Stanisław Stupkiewicz
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Zuzanna Poniżnik, M.Sc.
Urszula Czubacka
Marek Dawidziuk
Leszek Urbański
Stefania Woźniacka

The Department of Mechanics of Materials conducts comprehensive research – experimental, theoretical and computational – on advanced materials such as:

- **Multifunctional and multicomponent materials**
  (shape memory alloys (SMA), metal-ceramic composites, intermetallics, high-strength alloys, etc.);
- **Materials of fine microstructure**
  (composites with nanoparticles, ultrafine grained materials (UFG), after severe plastic deformation (SPD), etc.);
- **Thin layers and coatings**
  (functionally graded materials (FGM), ion implanted layers, thermal barrier coatings (TBC), contact layers, etc.).

Particular emphasis is put on:

- **Micromechanical and multiscale modelling;**
- **Experimental studies from macro- to nano-scales.**

Recent activity of the department includes also processing of composite materials by powder metallurgy. In the strategic plans of the department, constitutive modelling and numerical simulations are coupled with materials processing and experimental characterization of mechanical and physical properties as well as with microstructural analysis. The perspective goal is to develop materials of optimal properties for applications in automotive, aircraft, energy and electronics industries, to which the department will address the research results.

A general scientific scope is to conduct high-quality research that includes novel elements and represents original contribution to the state-of-the-art at international level. Mechanics has been traditionally a strong discipline in the Institute. Nowadays, the research in the Department of Mechanics of Materials is aimed at achieving a deeper insight into physical phenomena at lower dimension scales, establishing closer relations between theory and experiments for a variety of scales and loading conditions, and developing advanced computational methods for quantitative simulations of the phenomena being investigated.

Specific research areas, methods and results that are representative for the activity of particular divisions and research groups of the department are illustrated on the next pages. The respective selected papers referenced below are all published in internationally recognized journals which frequently are leading journals in the relevant fields.

A significant part of the department activity is related to leadership of and participation in a number of research projects which were qualified for founding from European or national sources. Specification of two major projects follows the list of publications below; there are a number of smaller-scale projects which are not listed here but are also helpful in financing the research activity of the department.

SELECTED RESEARCH ACTIVITIES

PROCESSING OF ADVANCED COMPOSITE MATERIALS

Processing and modelling of bulk metal-ceramic composites (MMC, CMC) and functionally graded metal-ceramic materials (FGM) represent recent major activities of the Department. The processing methods currently used are those of powder metallurgy. Main pieces of the processing laboratory are: planetary mill, hot press (HP), cold isostatic press (CIP) and particle size analyzer. At present the materials processed include (i) copper- and chromium-matrix composites strengthened with alumina particles with addition of rhenium, and (ii) nickel-aluminum intermetallics matrix composites with alumina ceramics as the reinforcing phase.

Fig.1.
Processing laboratory of the Advanced Composite Materials Group:
a) hot press (HP; grey) and cold isostatic press (CIP; blue);
b) planetary mill (in the background).

a)


b)


ADVANCED COMPOSITE MATERIALS: MODELLING

Thermal residual stresses which are generated in the composites during the cooling phase of the sintering process in HP can be detrimental to the material microstructure causing microcracking and, thus, leading to the degradation of material properties, e.g. the modulus of elasticity. The cooling induced thermal stresses, the resulting damage and the reduction of Young's modulus are modeled numerically and compared with the experimental measurements done by the cooperating partners. The modelling methodology makes intensive use of the images of real material microstructures obtained by the computed micro-tomography combined with image processing to automatically generate a finite element mesh (Fig.2a,b).

The research group is also developing analytical and numerical models of effective material properties with special attention paid to interpenetrating phase composites. Modelling of fracture of metal-ceramic composites is another activity of the group (Fig.2c), as well as chemomicro-mechanics of cementitious composites.

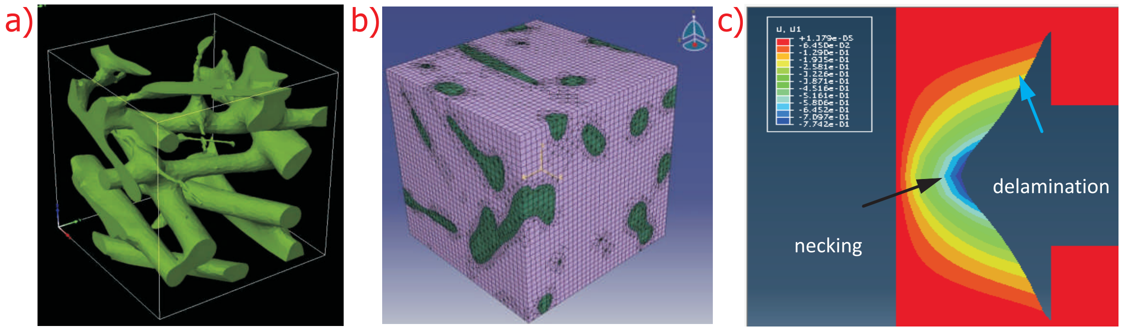


Fig.2.
a) Micro-CT image of interpenetrating phase composite created with SimplewareScanIP/FE software,
b) ABAQUS FEM mesh created with sofware SimplewareScanIP/FE,
c) modelling of crack bridging by metal ligament in IPC: radial displacement distribution.

MICRO-MACRO TRANSITION in HETEROGENEOUS MATERIALS

Development of crystallographic texture during large plastic deformation and mechanical response of polycrystalline materials (see Fig.3a) are modelled including the effects of mechanical twinning which is an important deformation mechanism in many advanced materials such as intermetallics, magnesium alloys, and others. Appropriate scale transition methods, taking into account confinement effects induced by lamellar substructure of grains (see Fig.3b below), have been developed, and improved predictions of crystallographic texture have been obtained. A novel method of scale transition for heterogeneous elastic-viscoplastic materials has been proposed. Instead of incorporating both elastic and viscous properties of the constituents in a single computational step, they are used in the averaging scheme sequentially. Models of fatigue crack growth in thin steel plates containing hydrogen have also been developed.

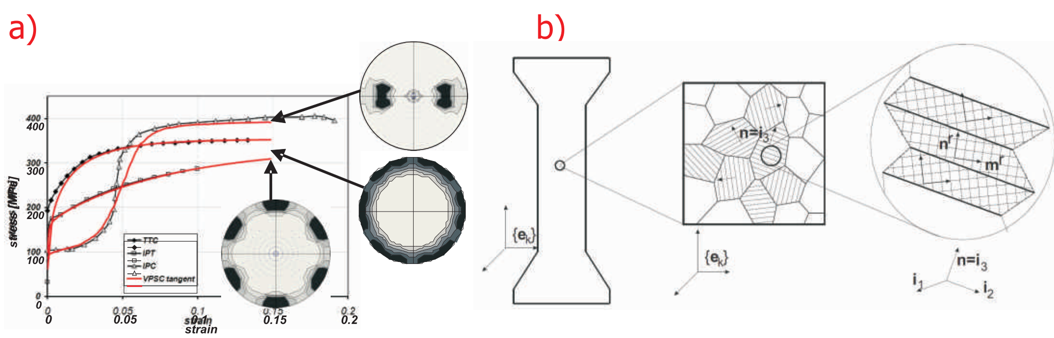


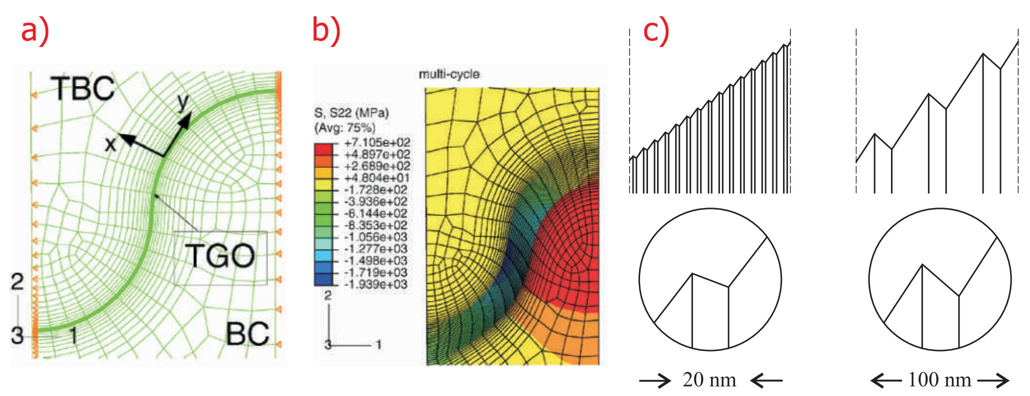
Fig.3.
a) Effect of crystallographic texture on stress-strain response of a polycrystal (plasticity and twinning),
b) three-scale model of a polycrystal of lamellar substructure.

ANALYSIS OF INTERFACE LAYERS

Properties and functional behavior of modern advanced materials are to some extent governed by interfacial phenomena. Modelling of interfaces and interface layers represents thus an important part of mechanics of materials. Results of FEM simulation of thickening of a thermally grown oxide layer (TGO) (Fig.4a) are shown in Fig.4b near the interface between thermal barrier coating (TBC) and bond coat layer on the substrate in a high temperature application of CMSX-4 super-alloy. An energy model of segmentation cracking of thin films has also been developed.

Figure 4c shows another example, namely, of the predicted low-energy morphology of the transition layer at the austenite-twinned martensite interface in NiTi shape memory alloy with size effect. The micromechanical approach developed has provided tools for estimation of the associated interfacial energy of elastic micro-strains which cannot be measured directly in experiments.

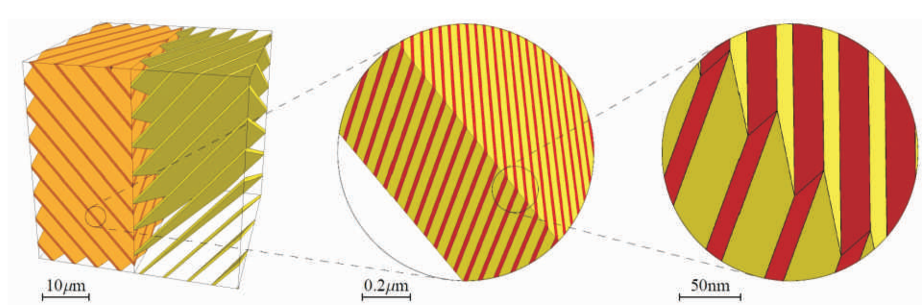
Fig.4.
a) Finite element model,
b) local stress distribution after multi-cycle thermal loading of TBC;
c) FEM prediction of austenite-twinned martensite interface in NiTi shape memory alloy with size effect.



MULTISCALE MODELLING OF SHAPE MEMORY ALLOYS

Shape memory alloys (SMA) belong to the class of multifunctional materials. They exhibit spectacular effects such as pseudoelasticity and shape memory effects which are associated with martensitic phase transformation induced by temperature changing or mechanical loading. Their macroscopic behaviour is governed by formation and evolution of microstructures at several length scales. Multiscale modelling approaches have been developed for this class of materials with the aim to obtain predictive models of macroscopic behaviour starting from the microstructural data and transformation mechanisms at the crystalline lattice level. Current research is focused on the analysis of interfacial energy and size effects in martensitic microstructures; Figure 5a shows the calculated microstructure of an idealized SMA polycrystal with the characteristic dimensions predicted by minimization of incremental energy including interfacial energy contributions. Micromechanically inspired macroscopic models of SMA are developed which are suitable for advanced simulations of SMA devices, like simulation of crimping of a stent-like structure (Fig. 5b).

Fig.5a
Calculated three-level microstructure of martensite in CuAlNi shape memory alloy.



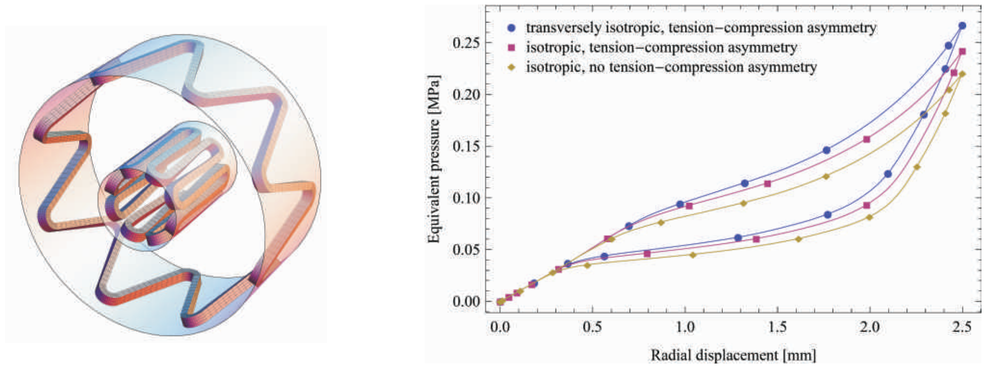


Fig.5b
Simulation of response of a segment of a superelastic stent made of NiTi SMA.

MODELLING OF MICROSTRUCTURE EVOLUTION AND GRAIN SUBDIVISION IN DUCTILE METALS

Macroscopically uniform plastic deformation in metals exhibits inhomogeneity at lower scales including formation of dislocation structures and deformation banding in plastically deforming crystals. To model development of deformation bands in FCC metals, we have used rate-independent crystal plasticity theory combined with the incremental energy minimization. Patterns of deformation bands that are energetically preferable to uniform deformation (Fig.6) are determined for different loading types, for example, to explain the formation of distinct microstructures depending on the crystal orientation in tension. A related direction of our research is the modelling of grain refinement in metals subjected to severe plastic deformations.

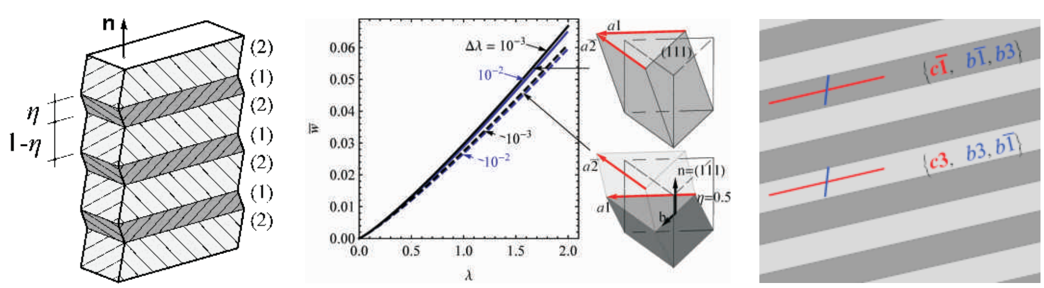


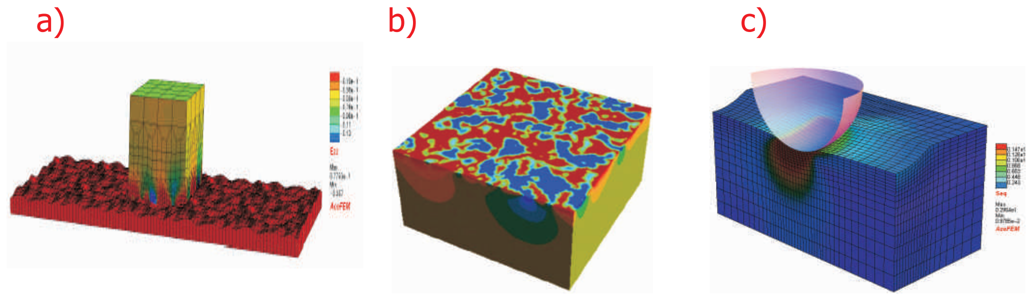
Fig.6.
Deformation band pattern that is energetically preferable to uniform deformation of a ductile single crystal.

MICROMECHANICS OF CONTACT PHENOMENA

Contact phenomena, such as friction, wear, lubrication, heat transfer, etc., are governed by local interactions at the scale of surface asperities. Micromechanics, which provides the link between the macroscopic properties and microscopic interaction mechanisms, is a natural approach to develop refined models of these phenomena. Developed contact homogenization approaches rely on formulating and solving microscopic boundary value problems which are formulated for representative unit cells of rough interfaces with underlying contact layers (Fig.7a). Practical applications include prediction of the effective thermal contact conductance for rough surfaces in contact: Fig.7b shows the fluctuation of temperature at a rough contact interface.

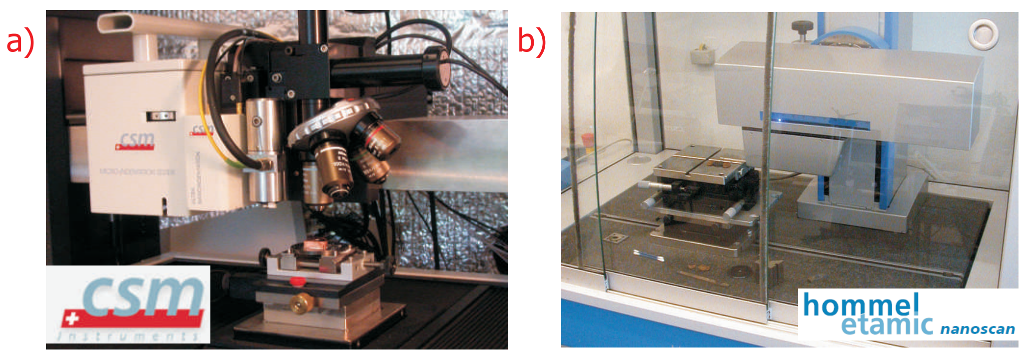
Our current research is concentrated on multiscale modelling of anisotropic friction and elasto-hydrodynamic lubrication at asperity scale. Efficient computational approaches are developed aimed at modelling of wear and associated changes of shape and contact conditions (Fig.7c).

Fig.7.
Micromechanics of contact:
a) rough interfaces,
b) nouniform temperature on interface,
c) wear at a single asperity.



EQUIPMENT OF SURFACE LAYER LABORATORY

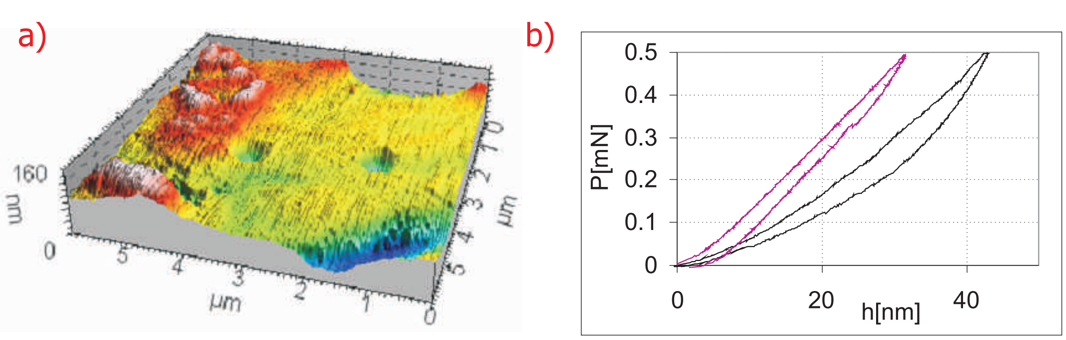
Fig.8.
a) Micro- and nano-indenter, atomic force microscope,
b) scanning profilometer "Nanoscan T8000".



IDENTIFICATION OF MATERIAL PROPERTIES BY MEANS OF MICRO- AND NANOINDENTATION TESTS

In the indentation test the mechanical response is registered in a form of load-penetration curves and residual imprints. Methods based on indentation tests are developed that enable specification of mechanical characteristics like work-hardening curve or anisotropy coefficients for a small amount of bulk material or thin layer. Current research is focused on a novel methodology for identification of selected mechanical properties of metals with account for anisotropy by means of nano- and micro-indentation test.

Fig.9.
a) Effect of nanoindentation tests in the metal phase of sintered metal-ceramics composite ($Mo+40\%Al_2O_3$).
b) Nanoindentation curves for ion implanted (red) andnon-implanted (black) shape-memory NiTi alloy.

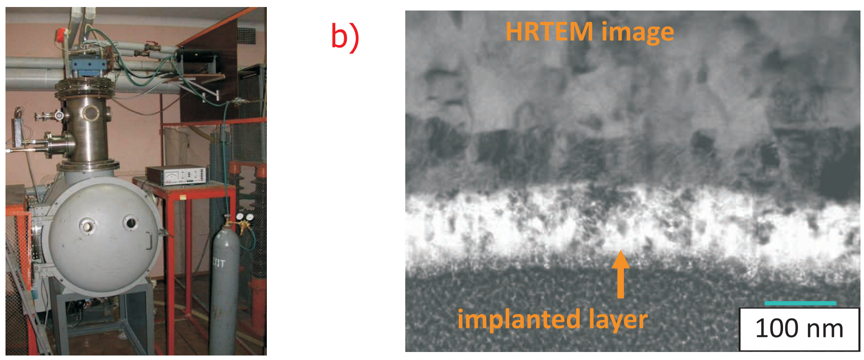


GENERATION OF THIN SURFACE LAYERS BY MEANS OF ION BEAM TECHNIQUES

Ion implantation is a well-known technology applied to produce thin (<600 nm) wear- and corrosion- resistant layers. Recently it is used in bio-medical applications. The implanted gradient layers are constituted on modern materials (shape memory alloys, high speed steels, Ti- alloys). Microstructure, implanted ions distribution and mechanical properties of modified layers are investigated. The goal is an optimal selection of process parameters for different materials.

Fig.10.
a) Ion implanter,
b) morfology of implanted layer.

a) b)

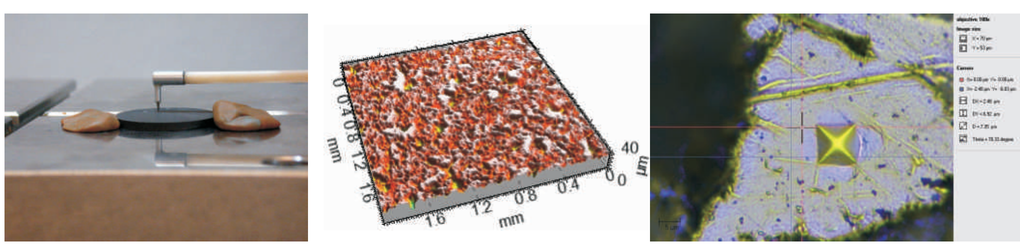


SURFACE METROLOGY

Micromechanics of contact of rough surfaces is investigated. Models are developed that enable predictions of real contact area and load-distance characteristics. Theoretical results are verified experimentally using surface topography measurement and unique special setup for contact loading.

Fig.11.
a) Roughness measurement,
b) scanned rough surface,
c) hardness measurement of single asperity.

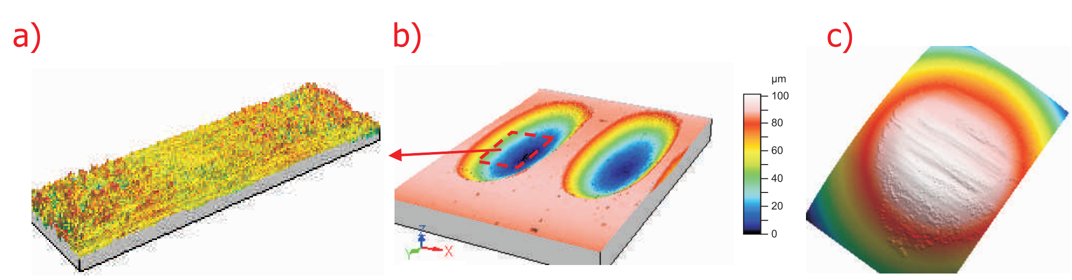
a) b) c)



INVESTIGATION OF WEAR

A novel approach to the analysis of wear problems has been developed. The available equipment (home made wear testers and scanning profilometer) enables more detailed observation of micro-contacts in wear process, that is, exact specification of contact area evolution and detailed measurements of wear scars (micro-topography) on both sample and counterpart (ball). The acquired data are used to develop advanced models of wear process.

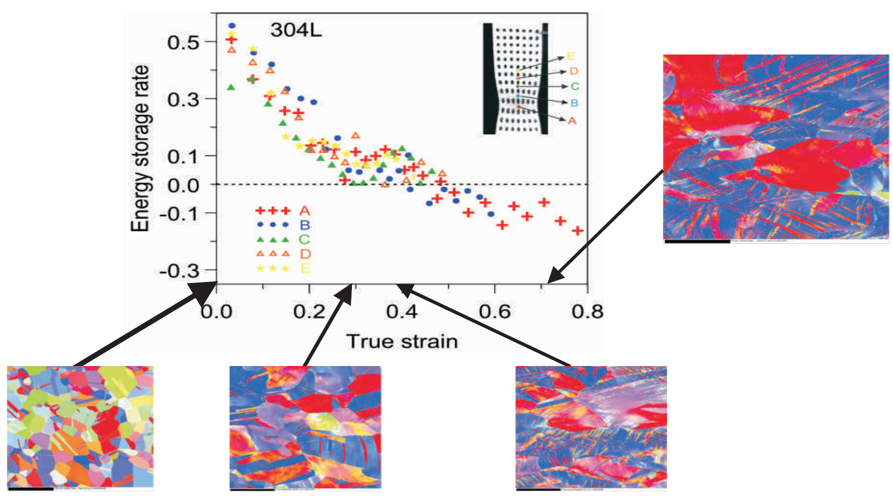
Fig.12.
a) Roughness at the bottom of wear track,
b) wear track on sample,
c) wear scar on ball (counterpart).



ENERGY STORAGE RATE DURING NON-HOMOGENEOUS PLASTIC DEFORMATION

The energy storage process during plastic deformation has been investigated. The experimental method of determination of energy storage rate distribution has been developed. It has been shown that before fracture the material reaches a state at which the energy storage rate is zero, which means that the material looses its ability to store energy. A zero value of the energy storage rate can be used as the plastic instability criterion based on energy conversion. In the area of localization, the evolution of crystallographic orientation to two dominant texture components is observed. It creates the conditions for forming crystallographic shear bands.

Fig.13.
Energy storage rate vs. true strain for selected points of specimen. The evolution of crystallographic orientation to two dominant texture components is observed by Electron Backscatter Diffraction.



PLASTIC STRAIN LOCALIZATION REVEALED BY NON-UNIFORM DISPLACEMENT AND TEMPERATURE FIELDS

Thermal effects accompanying the deformation process are investigated. Study of plastic strain localization using both the visible band and infrared cameras has been performed. It has been shown that only for nearly adiabatic conditions the non-uniform displacement and temperature fields are in good agreement.

Infrared thermography is used for analysis of Lüders' band propagation. The influence of strain rate on the band propagation is studied.

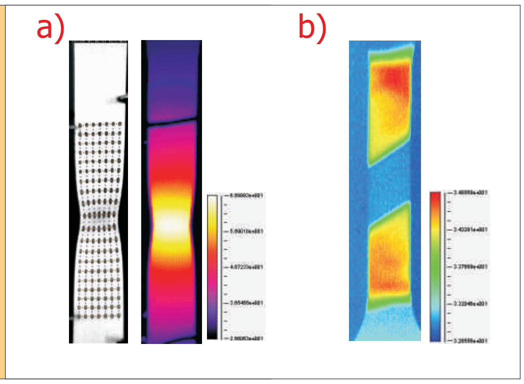


Fig.14.
a) Non-uniform displacement and temperature fields as indicators of plastic strain localization,
b) analysis of Lüders' band propagation using infrared thermography.

INVESTIGATIONS OF CELLULAR MATERIALS

Cellular solids and particularly foams are used in many applications where thermal insulation, light weight structures, filtering, flotation are needed. Finite element computation is used to predict the relative Young modulus (the modulus of the cellular structure with respect to that of the skeleton material). The solid structure is meshed using the regular scheme by replacing each voxel by a cubic isotropic element. The physical dimension attached to each voxel is of 8 μm. The finite element programs implementing own subroutines are used for all processing operations.

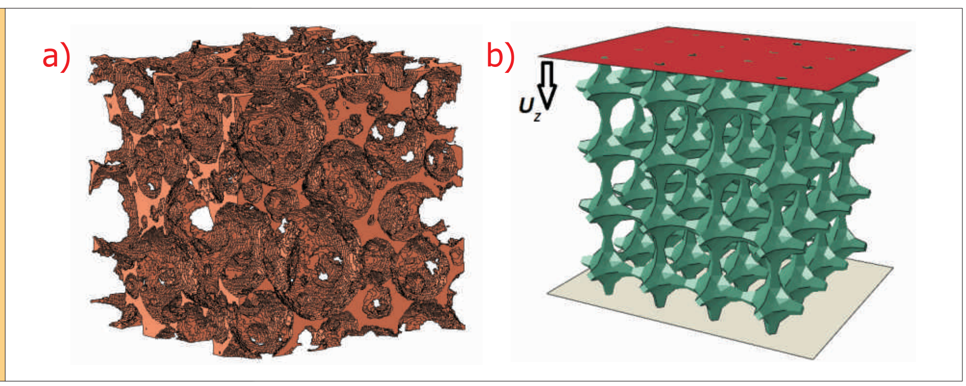


Fig.15.
a) Digital image-based reconstruction of real alumina foam, 86% porosity,
b) numerical simulation of the deformation process of regular foam structure.

EXPERIMENTAL INVESTIGATIONS OF INELASTIC MATERIALS IN A WIDE RANGE OF STRAIN RATES, CONSTITUTIVE MODELLING AND IDENTIFICATION OF MATERIAL PARAMETERS

Mechanical behavior and fracture of elastic-plastic solids is examined by using the Hopkinson pressure bar and electromechanical tension-compression testing machine and infrared (IR) thermography. Constitutive modelling includes a reasonable choice of effects which are most important for the explanation of the phenomena described by tools of mechanics of elastic-plastic continuous media.

Fig.16.
A new laboratory set-up for shear compression tests with use of laser extensometer, and examples of investigated shear compression specimens.

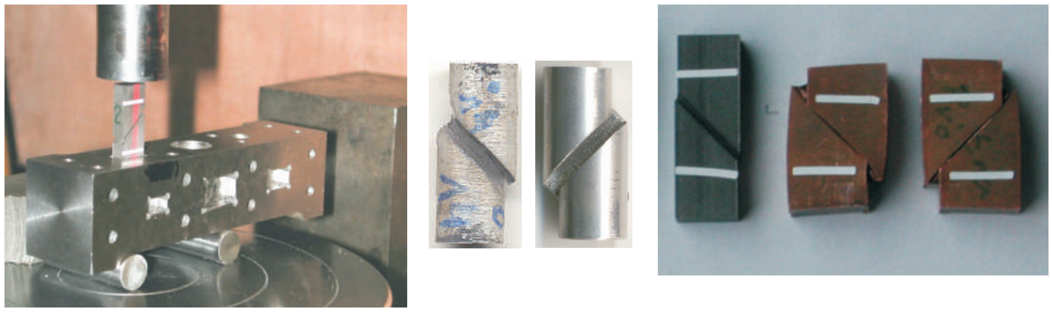
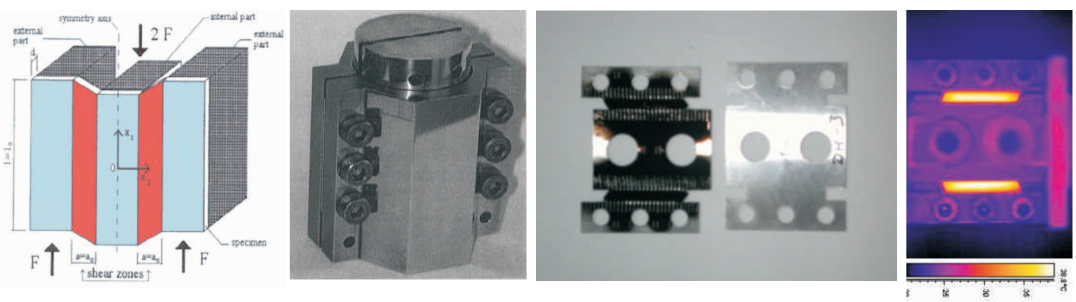


Fig.17.
Illustration of the double shear testing set, constructed by W.K. Nowacki, implemented for dynamic tests of metal sheets with use of IR thermography.



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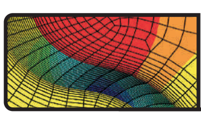

MAJOR PROJECTS

1. Micro and Nanocrystalline Functionally Graded Materials for Transport Applications (MATRANS), (EC). **2.** Metal-ceramic composites and nanocomposites for aircraft and automotive industry (KomCerMet), (NCBiR). **3.** Innovative materials solutions for Transport, Energy and Biomedical sectors by strengthening integration and enhancing research dynamics of KMM-VIN (INNVIN), (EC). **4.** Alliance for Materials – A value chain approach to materials research and innovation (MatVal), (EC).

DEPARTMENT OF COMPUTATIONAL SCIENCE

HEAD: Prof. Michał Kleiber

Graduated from Warsaw University of Technology and University of Warsaw. He received his Doctorate (Ph.D.) degree from Warsaw University of Technology in 1972 and habilitation from IPPT PAN in 1978. Director of IPPT PAN in 1995-2001. In 2001-2005 the Minister of Science in the Polish government, since 2007 the president of Polish Academy of Sciences.

DIVISIONS AND RESEARCH GROUPS

- Computational Methods in Nonlinear Mechanics — Head: Assoc. Prof. Jerzy Rojek
- Computational Materials Science — Head: Prof. Paweł Dłużewski
- Reliability and Optimization — Head: Assoc. Prof. Krzysztof Doliński
- Computational Analysis of Advanced Structures — Head: Prof. Krzysztof Wiśniewski

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Krzysztof Mróz, Ph.D.
Eligiusz Postek, Ph.D. Eng.
Piotr Tauzowski, Ph.D. Eng.
Jerzy Trębicki, Ph.D.
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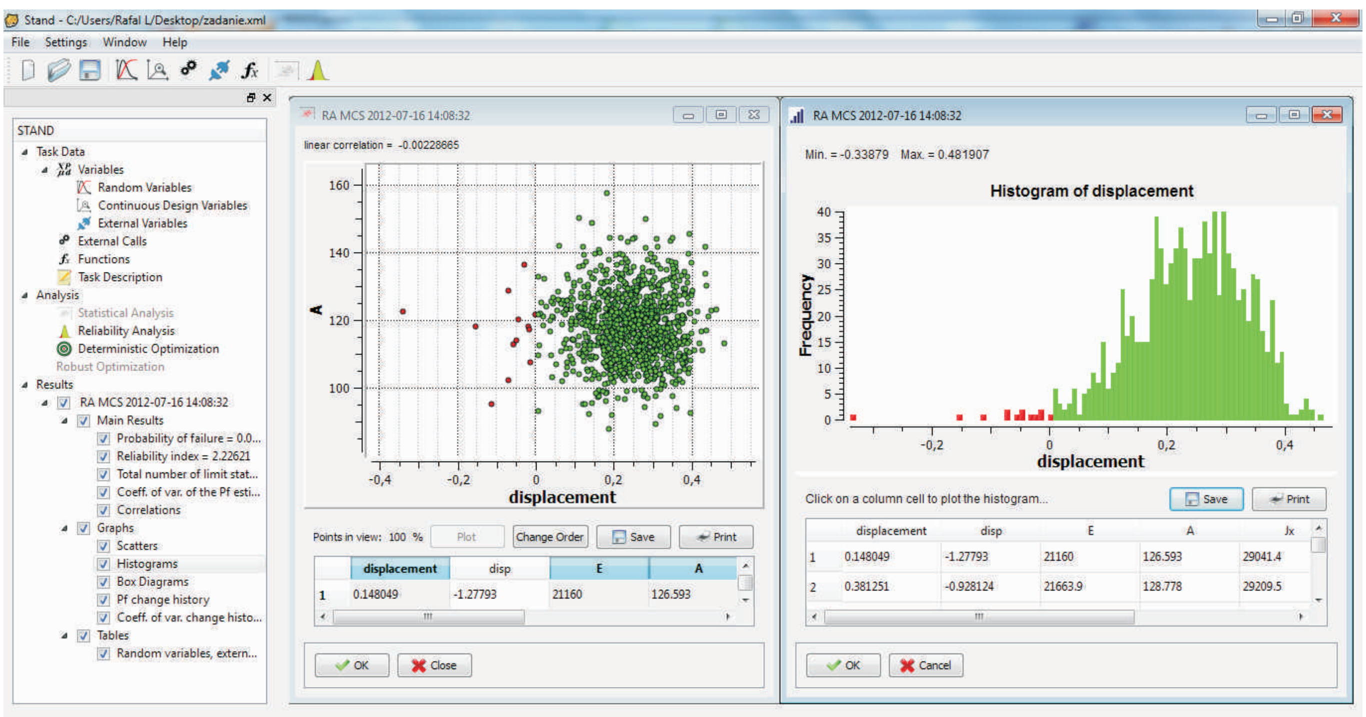
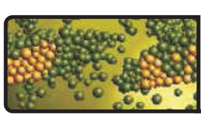
Krzysztof Wawrzyk, M.Sc. Eng.
Maciej Skarysz, Eng.

The main research area of the department is computational science. Our research activities are to a large extent interdisciplinary – they cover informatics, mathematics and a number of disciplines that embrace the particular areas of application of the research, like mechanics, biomechanics, etc. Universal character of computational methods and algorithms, based mainly on the finite element method (FEM), as well as on a number of other contemporary and novel numerical methods, allows us to undertake a wide spectrum of research challenges, frequently in cooperation with other research institutions from Poland and abroad.

The basic tools used in our research work are numerical codes dedicated to modelling of mechanical phenomena as well to parameter sensitivity analysis, optimization and reliability analysis. An important aspect of our research is investigation of theoretical background of the modelled problem and appropriate bridging between the mathematical formulation and the efficient and reliable computational algorithm. We focus our attention on developing our own codes, either from scratch or by enhancing and enriching renowned open source codes. Another important issue in our activity is massive concurrent programming and application of large computer clusters and grids in scientific computations.





SELECTED RESEARCH ACTIVITIES

DEVELOPMENT OF HYBRID DISCRETE ELEMENT METHOD ENGINEERING SOFTWARE

We develop our own original engineering software combining the finite element method (FEM) with the discrete element method (DEM). FEM is a suitable method to simulate problems involving linear and nonlinear continuous material behavior. DEM is a convenient method to model materials with discontinuities and material failure characterized by fracture. Combining different methods in one model allows us to take advantages of each method. In the proposed approach the DEM and FEM are treated as complementary methods. The software has many potential practical applications ranging from metal forming and powder metallurgy to geomechanics.

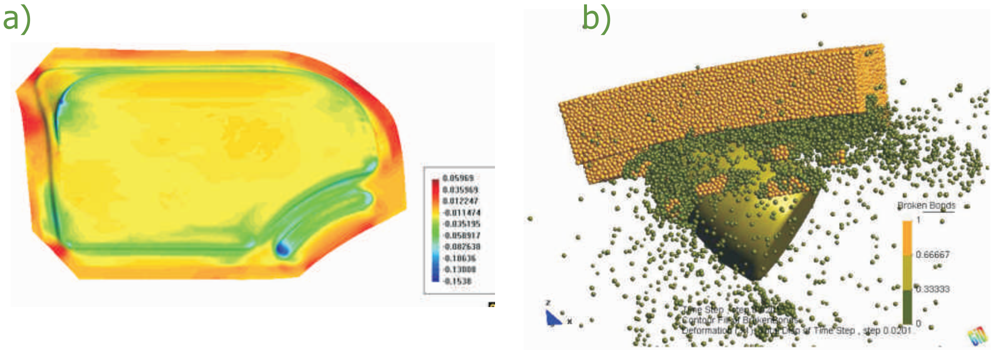
Simulation of sheet metal forming is one of the main applications of the finite element software developed in the department. Sheet metal forming is an important manufacturing process in automotive and aeronautical industries. The objective of the simulation is to check feasibility of a technological process and to optimize process parameters in order to obtain a product of good quality and minimize possibility of defects. Sheet forming processes are difficult problems characterized by complex geometries and large elasto-plastic deformation. The research work is focused on determination of failure criteria for metal sheets undergoing complex deformation and increasing numerical efficiency allowing to analyze real parts in a short time.

Fig.1.

a) Finite element simulation of forming of a car door – formed part with distribution of thickness strain.

b) Discrete element simulation of rock cutting.

a) b)

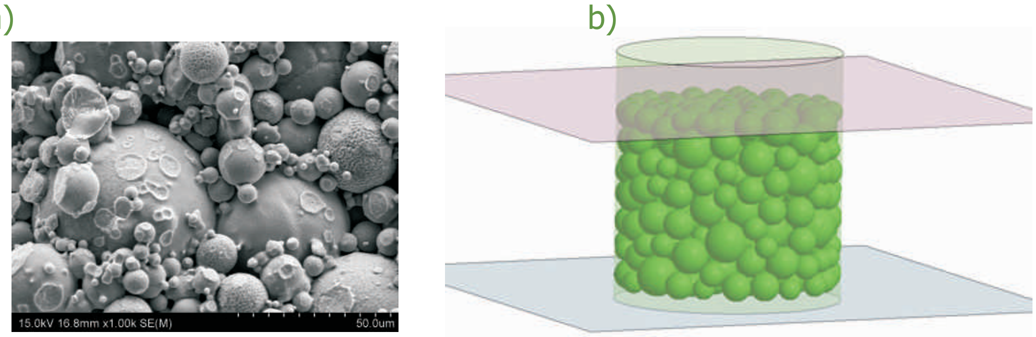


DEM is widely recognized as a suitable tool to model geomaterials: sands, soils and rocks. It takes into account, in a natural and simple way, a discrete nature of these materials. Numerical models developed in the department have been successfully applied to rock cutting processes typical for underground excavation and mining. The discrete element model can properly represent fracturing and fragmentation of a rock under mechanical action of a cutting tool. The model belongs to the class of micromechanical models. Determination of adequate micromechanical parameters to yield required macroscopic properties is a difficult and still investigated topic. Our research work has been focused on determination of micro-macro relationships and practical validation of the discrete element models.

A combined DEM/FEM program developed in the department is also capable of modelling processes of powder metallurgy such as powder compaction and sintering. Sintering is a complex manufacturing process used for making various parts from metal or ceramic powder mixtures. It consists in consolidation of loose or weakly bonded powders at elevated temperatures, close to the melting temperature, with or without additional pressure. Modelling can help to optimize and to better understand the process and improve the quality of sintered components.

Fig.2.
Microstructure and numerical model of a sintered component.

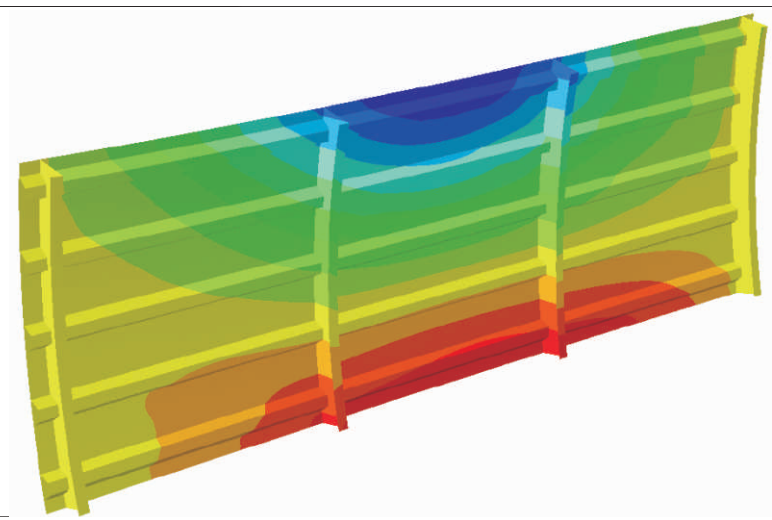
a) b)



ADVANCED FINITE ELEMENTS AND MODELLING OF COMPOSITE MATERIALS

Two aspects of numerical modelling are considered: (i) advanced finite elements, in particular the shell elements for large strains and unrestricted rotations and (ii) models of layered composite materials based on the concept of an effective material and taking into account microstructure of layers. Nonlinear phenomena and design sensitivity analysis are included in modelling. Our finite element code has been parallelized and tested for up to a half a million of unknowns and about 50 design parameters. Sensitivity analyses with respect to constitutive and structural parameters were conducted for a number of shell structures, including panels used in modern aircrafts.

Fig.3.
Sensitivity map of a stiffened aircraft structural panel displacement with respect to one of the composite microstructure parameters (Project MAAXIMUS).

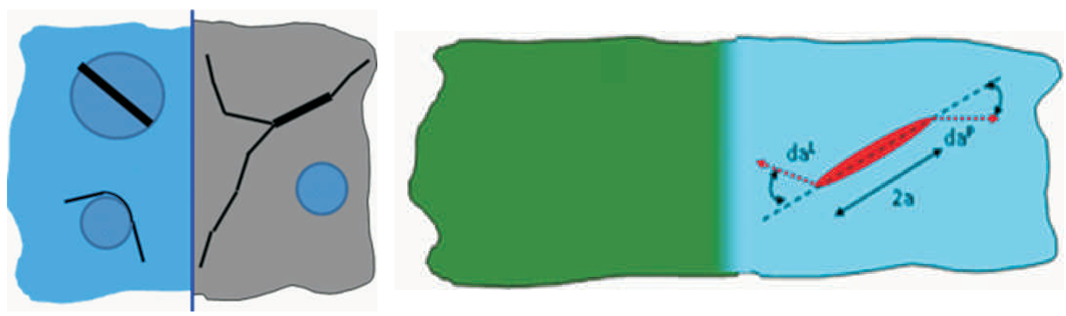


MODELLING OF FRACTURE AND FATIGUE PHENOMENA IN COMPOSITE MATERIALS WITH ACCOUNT FOR STOCHASTIC MATERIAL AND LOADING PROPERTIES

The proposed models describe the progressive and localized structural damage that occurs when a graded particulate reinforced composite is subjected to cyclic loading (fatigue). The model is based upon the energy concept. The competition between the brittle (for reinforcement) and ductile (for matrix) damage phenomena is proposed. Main physical quantity is fatigue life, defined as a number of stress/strain and/or temperature cycles that a specimen or structure sustain before the failure of a specified nature occurs.

Phenomenological approach based on the physical damage mechanisms developing in the material is employed in the modelling. Stochastic fields of the material properties and stochastic processes model the uncertainties of the actual material and service loading properties, respectively. Probabilistic features of the fatigue lifetime and reliability assessment of the composite structure are eventually attained.

Fig.4.
Modelling of fracture and fatigue phenomena in composite materials.



MODELING OF SEMICONDUCTING NANOSTRUCTURES

Coupled fields in semiconducting nanostructures, like defected heterostructures or quantum dots, are modeled by use of FEM. The morphology of nanostructures is provided by HRTEM measurements. The solution of the boundary value problem provides description for residual stresses, elastic/lattice strains, potential, and electric fields while a supplementary Schrödinger-Poisson self-consistent problem provides a description for the optoelectronic properties of quantum structures. Qualitative and quantitative effects of the crystallographic orientation and structure geometry on the resultant fields, and electron-hole configurations are investigated.

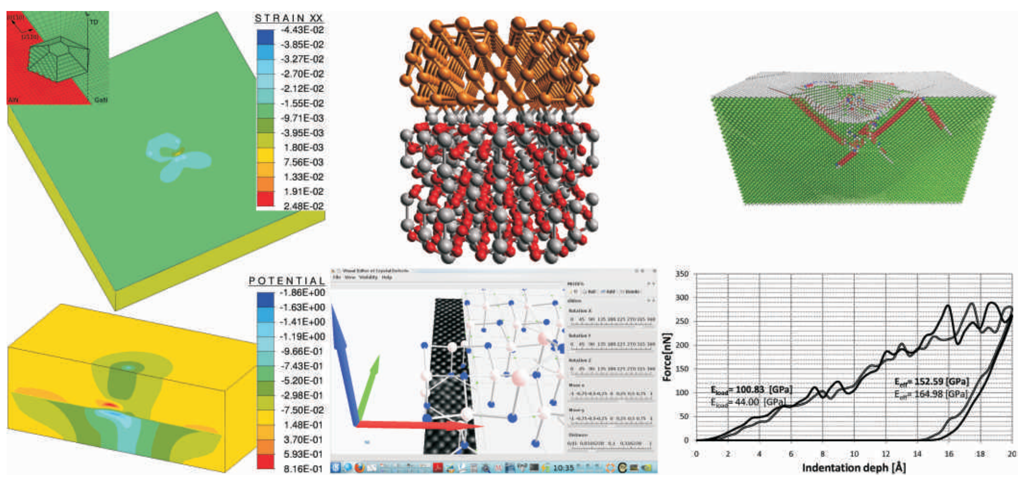
Reconstruction of defected crystalline structures and their further visualization can be applied to a single defect as well as to a periodic network of dislocations, for example, misfit dislocations on the heterostructure interface. Analytical equations for dislocations are used as the starting configuration in the iterative procedure for the reconstruction of an atomistic model of a dislocation network. A graphical application program, the Visual Editor of Crystal Defects utilizes the above mentioned procedure, and is developed by us under the GPLv3 license, http://sourceforge.net/projects/vecds.

Atomistic modeling of nanostructure deformation involves use of molecular dynamics and statics to model plastic deformations of mono and polycrystalline nanostructures. To model a crystal deformation accurately, parameterization and validation of atomic potentials for metals, metal oxides, and their interfaces is necessary. Parametrization and validation allow to reproduce elastic coefficients, cohesive energy, and stacking fault energy. Comparative analysis of hyperelastic finite deformation models for crystalline materials is performed to parameterize interatomic potentials, and to create a hybrid atomistic-continuum approach.

To calculate electronic states and optoelectronic features of quantum dots the Hartree-Fock method is used. The method is applied within an adaptive finite element framework to determine the free-standing electronic structure and the affect of external electromagnetic fields. The results from the real space basis method are compared to restricted state-bases methods, to verify the applicability of real space approaches to coupled problems.

Interdiffusion of elements in heterostructures or doping atoms in ion implanted crystals are modeled by use of the FEM. Lattice mismatch or defect concentration induces a residual stress field which provides a strong driving force for interdiffusion. Experimental evidences show a different mechanism for atom diffusion within a nanostructure, therefore material species (a chemical composition) for each diffusion branch are simulated in the initial boundary-value problem as an independent degree of freedom.

Fig.5.
From the left-to-right: elastic strain and electrostatic potential in a quantum dot - threading dislocation system (mixed type); visualization of reconstructed Al_2O_3/Cu interface with mismatch dislocation network and user interface of VECDS program; cross-section of mono-crystalline Cu crystal under nanoindentation (20 Å depth of indenter), and P-h (force-depth) indentation chart for polycrystalline Cu (grain size is about 6.9 nm).



STAND – STOCHASTIC ANALYSIS AND DESIGN OF STRUCTURES

The computational system STAND has been developed in the Department for many years in the framework of several national and European research projects. The main purpose of STAND is to facilitate structural reliability analysis as well as robust design optimization of a wide range of research oriented and engineering problems. Developing the program a special emphasis is put on the issues related to its interfacing with external general purpose computational codes. The adopted object oriented paradigm turned out to be very advantages in terms of the code organization as well as synchronization of the simultaneous work of many programmers. STAND facilitates performing a variety of nondeterministic analysis tasks taking advantage of multiprocessor architecture of the present-day computers.

NUMERICAL SIMULATIONS IN BIOMECHANICS

Advanced numerical models for simulations of biomechanical phenomena are developed in the department. They include constitutive modelling of cancellous bone, including the so-called parametric models of the tissue elasticity. The models are employed to simulate adaptive remodelling of bone microstructure in view of changing load conditions. Prediction of bone remodelling is of crucial importance, for example, for estimation of durability of endoprostheses and optimization of their shape and other parameters.

Fig.6.
Parametric model of cancellous bone treated as porous material with repeatable microstructure.

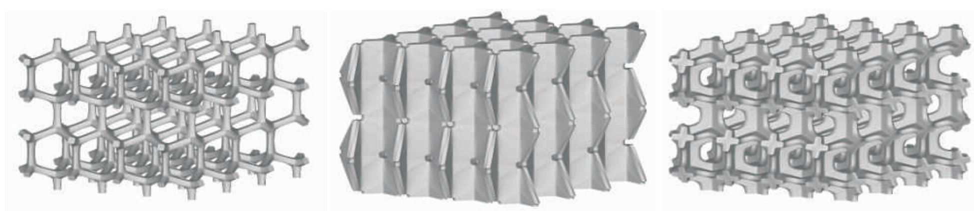
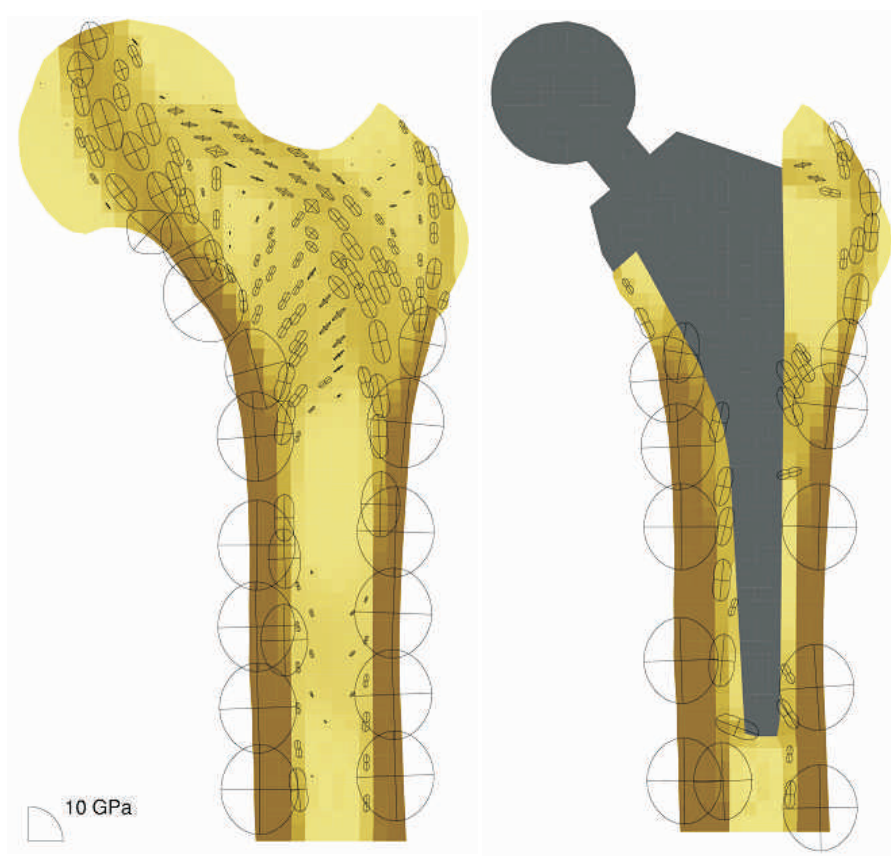


Fig.7.
Distribution of bone density and elastic anisotropy as a result of simulation of adaptive tissue remodelling in femur (without and with endoprosthesis).



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MAJOR PROJECTS

1. More Affordable Aircraft through eXtended, Integrated and Mature nUmerical Sizing (MAAXIMUS), (EC). **2.** Numerical Simulation in Technical Sciences, in the framework of the programme Support for Training and Career Development of Researchers (NUMSIM), International Research Staff Exchange Scheme, (EC). **3.** Early Recognition, Monitoring and Integrated Management of Emerging (iNTeg-RISK), New Technology related Risks, (EC). **4.** Advanced Numerical Methods of Analysis, Optimization and Reliability of Industrial Sheet Metal Forming Processes (NUMPRESS), (OPI).

DEPARTMENT OF INTELLIGENT TECHNOLOGIES

HEAD: Prof. Jan Holnicki-Szulc

Graduated from Warsaw University of Technology and the University of Warsaw. He received his Ph.D. degree (1973) and habilitation (1982) from IPPT PAN. Since 2002 head of the Department of Intelligent Technologies and Division of Safety Engineering (Smart-Tech Centre).

DIVISIONS AND RESEARCH GROUPS

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- Control and System Dynamics — Head: Prof. Czesław Bajer
- Intelligent Systems — Head: Jacek Szklarski, Ph.D.

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Jan Całka

By **intelligent technologies** (or smart technologies) we understand mechatronics applied to large, real structures, what involves taking into account the inertial reactions and structural control by modifications of structural parameters rather than by external forces. The Smart Technologies constitute a relatively new, dynamically developing and interdisciplinary (mechanics, control, electronics, informatics, etc.) research field that is closely linked to hi-tech and encompasses a wide spectrum of engineering applications including **safety engineering**.

The safety engineering can be understood as a collection of various techniques used for monitoring of technical condition of structures (**structural health monitoring, SHM**) and identification of potential defects. Such a process involves a distributed sensor system, a numerical model of the monitored object and software tools used for interpretation of measurements. Furthermore, if such a structure is equipped with sensors that monitor its loading conditions and with semi-actively controlled devices that are able to modify its local stiffness or damping characteristics, its structural capacity for absorbing unexpected, extreme loads can be significantly enlarged. Semi-active adaptation to critical conditions allows the structure to be much better protected from damage. Traditionally, optimal passive design of a structure (such as car structure) for the best crashworthiness reduces to maximization of its impact capacity in cases of a certain number of predetermined collision scenarios. Nevertheless, the same structure can be too hard for an impact of a smaller intensity or coming from a different direction. Structural adaptivity is the crucial factor in the new, challenging technological objective of **adaptive impact absorption** (**AIA**) and can lead to dramatically better structural responses in cases of critical overloading and to important improvement of its safety. Good examples of potential applications for AIA systems are adaptive road barriers for road transport safety, adaptive landing gears for air transport safety and adaptive airbags for emergency landings.

Historically, the term **smart structures** (comprising of a sensing system, actuators that are able to modify structural properties or exert loads and of control units) became the object of scientific research, mainly as hypothetical solutions, as a result of new demands that came from space engineering in the 1970's and 1980's. For example, the problem of shape preservation of a parabolic antenna within orbit is not a trivial task. The thermal shock that occurs while passing through the Earth's shadow can cause vibrations that are very difficult to damp. These vibrations occur because the high flexibility of space structures causes a lack in their natural damping characteristics. Consequently, intelligent systems that could reduce these vibrations had to be invented. Such a shape (and vibration) control problem can be formulated by making use of highly responsive piezo-sensors and piezo-based actuators. It requires work to be done against the resisting structure using actuators. In the case of large, on-land structures, such an actuation leads to substantial energy consumption, which cannot be supplied instantly. Consequently, application areas for this type of smart structure are significantly limited. Nevertheless, there exists an important class of large, real structures that can be effectively controlled with smart devices consuming little power. Such structures can be called **adaptive structures** (instead of s**mart or active structures**), and they are equipped with dissipative actuators (**dissipaters**) only.

Currently, the main stream of world research and development activities in the field of smart structures is focused on SHM and load identification (mostly used for suspension bridges and aerospace structures). Furthermore, there are several periodically organized international conferences (attracting around 200 participants each time) and scientific journals devoted to the subject. These mixed, academia-industry meetings demonstrate the rapid development of SHM hardware solutions. However, the lack of effective software tools for solving the related inverse problems, which requires processing huge amounts of measurements collected from large engineering structures, is also evident and remains an important research challenge.

SELECTED RESEARCH ACTIVITIES

STRUCTURAL HEALTH MONITORING

The term of structural health monitoring (SHM) system most often refers to an implementation of a damage identification strategy for a structure (e.g., aerospace, civil or mechanical engineering) based on measured structural responses. The damage is defined as a change in the material or geometric properties of the system that influences its current or future performance. Generally, the damage identification process is divided into the following levels: detection (presence of the damage), localization, quantification (severity of the damage) and classification (kind of the damage).

Our research is aimed at monitoring systems dedicated to skeletal structures such as railway steel bridges. Systems of this kind are composed of autonomous power supply, set of sensors (often piezoelectric), driving electronics, a data acquisition unit and a system for wireless data transmission of the collected signals to a computer center for further data processing. A vital part of many monitoring systems is a weigh- in- motion (WIM) subsystem installed near to the monitored bridge for identification of dynamic load exerted on the rail by passing trains. In the WIM subsystem, the piezoelectric sensors are mounted at underside of the foot rails.

The damage identification procedure is based on gradient optimization and performed at a computer center using measured responses and responses obtained from numerical simulation for a known moving load. Therefore, to this end a calibrated numerical model is required.

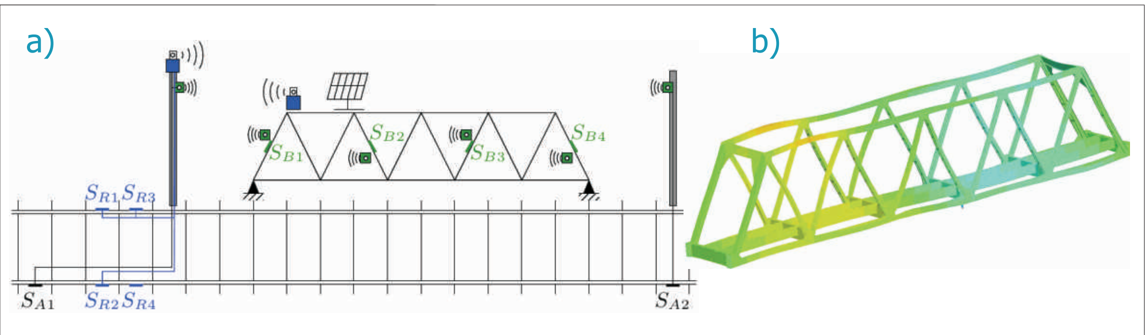


Fig.1.
a) Scheme of the instrumented railway track and bridge using sensors equipped with devices for wireless data transmission,
b) numerical model of the bridge.

The aim of the monitoring system is to detect undesirable modification of structural parameters, such as loss of stiffness (corrosion) element or defects in nodal joints. This information can be used by facility managers to make a decision about renovation of the structure or exclusion from use.

Another kind of SHM systems is devoted to load monitoring and identification. In many cases, direct load measurement is difficult or even not possible (wind loads, traffic loads, moving crowd loads), but accurate knowledge of operational loads is essential. In such cases indirect load monitoring is the only practical option: the load is identified indirectly, based on measured structural responses and knowledge of certain structural characteristics. Such systems are important for traffic monitoring and traffic control purposes or for forensic engineering; they might constitute a part of decision support systems in space engineering. If impact-type load is monitored, online identification results can be used as an input to an adaptive impact absorption (AIA) system and trigger optimal structural adaptation to the identified load.

ADAPTIVE IMPACT ABSORPTION (AIA)

The concept of adaptive impact absorption is based on a new approach to structural design, which requires the structure to be equipped with special devices that enable semi-active control (in real time) of its mechanical properties (e.g., local stiffness) in order to improve the dynamic response to impact scenario (e.g., reduction of deformation or acceleration peaks). As a consequence, the desired AIA process is dissipative, with an optimal amount of impact energy absorption, while the applied control devices (actuators with small external energy consumption) modify only the local structural properties without feeding the system with additional mechanical energy.

Pneumatic adaptive shock absorber

The research is focused on development of different types of valves for gas flow control, such as the ones based on a multilayer piezoelectric actuator and Hoerbiger plates. The intended application areas are adaptive pneumatic shock absorbers. In case of the absorber depicted in Fig.2, the valve is incorporated inside the piston. Its main objective is regulation of gas flow between the cylinder chambers in order to maintain the desired value of the reaction force generated by the shock absorber. Currently, valves shown in Fig.2 and Fig.3a are in laboratory testing stage, while valves depicted in Fig.3b and Fig.3c are under development.

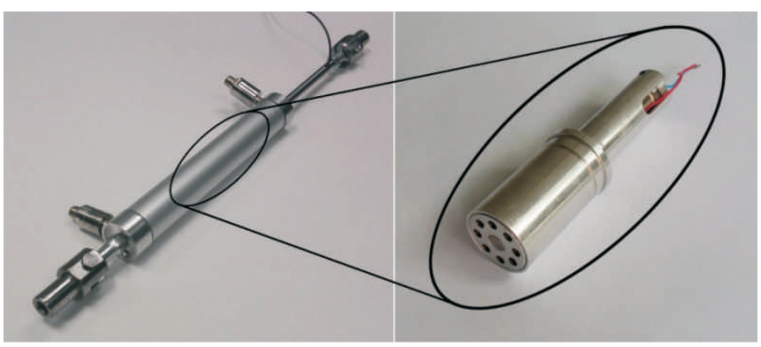


Fig.2. Pneumatic adaptive shock absorber and piezoelectric valve.

Innovative, high performance valves for adaptive pneumatic impact absorber

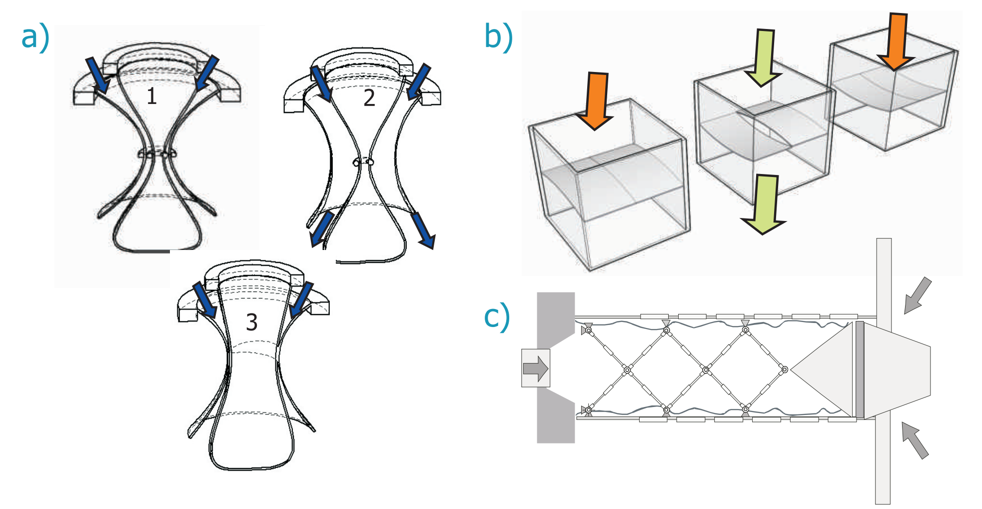
Fig.3.

Three investigated concepts of high performance valves being the core elements of adaptive pneumatic impact absorbers:

a) self-closing membrane valve with detachable rings,

b) valve based on piezoelectrically invoked bistable snap-through effect,

c) valve based on multi-folding micro structure (MFM).



ADAPTIVE VIBROACOUSTICS

Our important research activity is devoted to development of active, passive and adaptive systems for noise reduction. To this end, techniques for active structural acoustic control (ASAC), active vibration control (AVC), and active noise control (ANC) are actively studied, which consists of manufacturing of generic prototypes, experimental testing, and analysis involving fully-coupled modelling of relevant problems (Fig.4). The multiphysics analysis of vibroacoustic systems (Figs.4a-4c) takes into account the electro-mechanical coupling, acoustics-structure interaction (Fig.4c), biphasic modeling of poroelastic media. The development of smart systems for adaptive vibroacoustics implies also investigation of active sandwich composites with core made up of honeycomb or porous material (Fig.4d). Programming of control algorithms and manufacturing of electronic systems for active control are other important tasks which are realized.

Another important area of research concerning adaptive vibroacoustics are porous materials which typically posses excellent sound proofing and absorbing characteristics. Within this field of research experimental tests on porous materials are carried out using the so-called impedance tube (Fig.5a) in order to determine their acoustical properties, like acoustic impedance and absorption, transmission loss. Macroscopic models of porous media with rigid skeleton and advanced biphasic models of poroelastic materials are implemented; they are used to investigate designs of porous composites with embedded passive and/or active (piezoelectric) elements. Very important piece of research is micromechanical modelling of porous materials. Homogenization approach is used to derive some macroscopic characteristics or parameters from the very microstructure of porous medium. To this end, periodic representative volume elements (RVEs) are constructed (Fig.5b) which serve for FE analysis of viscous (Fig.5c) and thermal flows; then, after averaging some relevant macroscopic parameters are obtained. Finally, parameter identification techniques for macroscopic models of porous media are developed; measurements obtained from the impedance tube tests are used by the identification procedure and also for validation purposes.

Fig.4.

a) Experimental testing for active vibroacoustics,

b) FE analysis of active reduction of noisy vibrations,

c) sound pressure levels (SPL) around the vibrating plate,

d) active sandwich panel with poroelastic core.

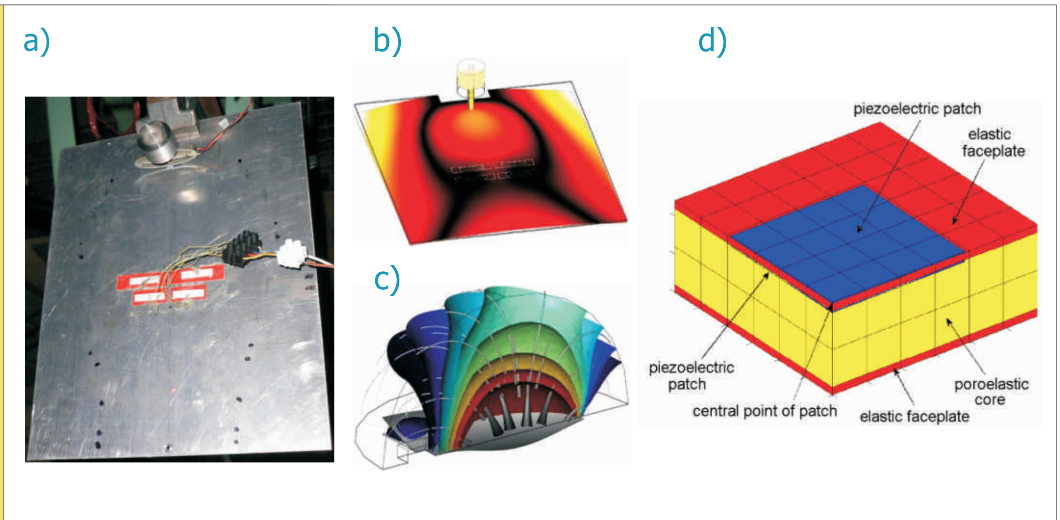
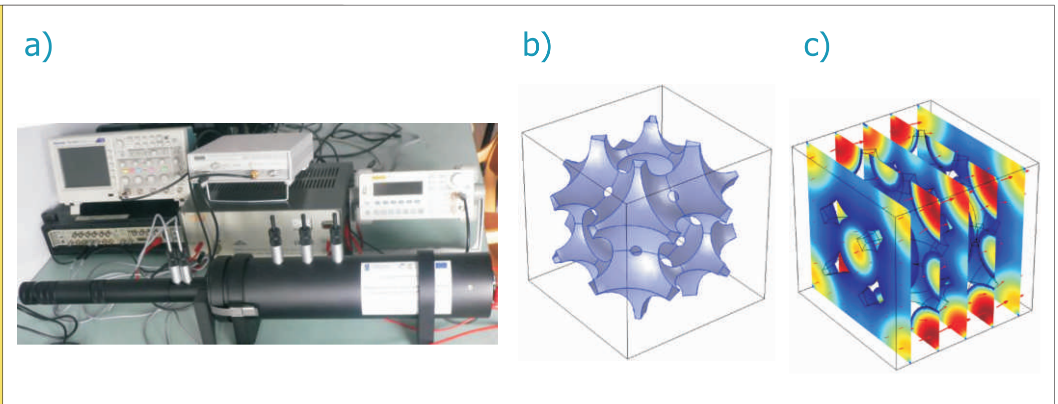


Fig.5.

a) Experimental set-up (impedance tube) for acoustical measurements of porous materials,

b) periodic representative volume element (RVE) of sound absorbing porous material,

c) viscous incompressible flow through periodic cell (for determination of permeability parameter).

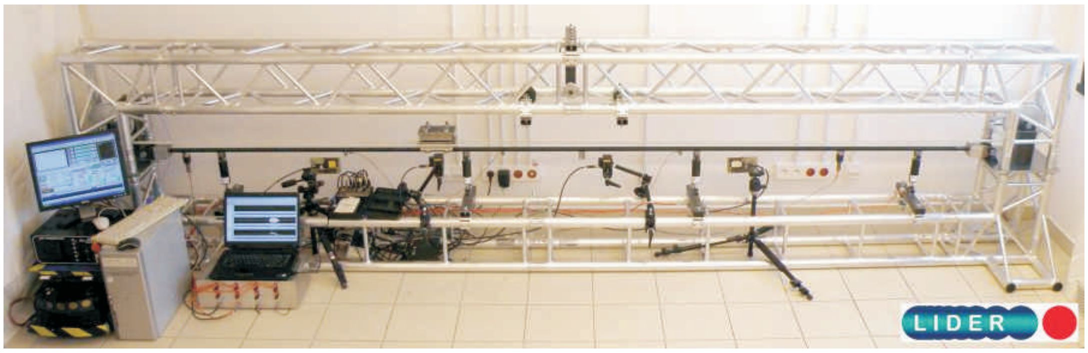


ADAPTIVE DAMPING OF VIBRATIONS

A widespread way to reduce dynamic disturbances is the use of vibration isolating materials – special mats with vibration isolating properties, elastic pads and plastic spacers. Using them, we can isolate the ground and the track excited by moving vehicles. Unfortunately, such passive damping methods have many disadvantages. In the track a large thermal expansion of the rails occurs, which is caused by temperature changes during the year. Insulation materials used in classical solutions are chosen to harmonize as far as possible the dynamic parameters, in both summer and winter. This phenomenon can be minimized by using smart materials. In a preliminary research work it was shown that a system of two parallel beams (in this case the rails) joined with semi-actively controlled dampers can reduce the amplitude of displacements, velocity and acceleration in the level several times higher than a system with permanently coupled beams.

In the frame of the LIDER project we elaborate the stabilization by using smart materials via adaptive damping caused by passage of rail vehicles. The properties of the material result in silencing. This was proved with analytical calculations, numerical simulations and bench testing system equipped with magnetorheological dampers controlled semi-actively (Fig.6).

Fig.6.
Test stand.



Damages affect the surrounding infrastructure, particularly vulnerable historic buildings. Historic brick buildings are fragile, very susceptible to deformation. The low susceptibility of the material, which does not succumb to excessive momentary or long-term deformation, is the main reason of damages. The negative impact of infrastructure on the surrounding buildings, particularly historic, forces us to take action to reduce the adverse external effects. In this aim, we assume the concept of modification of the track structure, to enable influencing its dynamic properties. The size of the load, the speed of movement, the effect of dynamic coupling as well as outside temperature amending the axial forces in rails, can all be considered as a variable factor.

For economic reasons, we strive to create an economical solution. A complex dynamic system that allows us external control of its parameters will be used for research. The ultimate goal is to replace it with a simple system in which an intelligent material, with appropriately selected rheological properties will be assumed as a factor determining the dynamic properties. Intelligent selection of the material is complex, however.

The project aims to carry on the research to propose a new foundation of the track, destined to pass vehicles in vulnerable areas. The solution will be specifically designed for selected sections, surrounded by historic buildings and sensitive buildings, such as concert halls, theaters, apartment buildings in the immediate vicinity of underground tunnels, and urban railway trams. Developed material will allow us to stabilize not only the traditional railway track, but also the cyclic systems such as the rotor turbine equipped with blades.

ROBOTICS

Current research topics include development and application of state-of-the-art algorithms used in mobile robotics. As a real life testbed used to validate proposed concepts, an experimental robotic platform "RoMeg" is deployed. The robot has been constructed together with the Technical University of Warsaw. It can operate as an indoor 3-wheel or an outdoor 4-wheel autonomous device and it can be equipped with various sensors (laser range finders, inclinometer, electronic compass, velocity radars, GPS, cameras, etc.). The tested algorithms are implemented on the on-board computer which controls velocity of the robot.

One of the achievements of our group was to give the robot the ability to recognize and identify certain objects (e.g. office equipment) with use of "depth images". Such images contain information about distance from the robot to an obstacle. Sometimes this technique can be superior to classical image recognition methods: for example, if laser range finders are used, it will work regardless of lighting conditions and can be applied even in a complete darkness.

Apart from classical problems related to mobile robotics, our group is involved in researched related to more general, real-world applications. We have designed and developed a universal system which is able to build 3D maps of environment. The system is based on planar laser range finders (arbitrary number of lasers can be used), inclinometer and velocity radars. For instance, it has been successfully used on the unmanned, remotely controlled military vehicle "Lewiatan" (work done together with the Military University of Technology). Such maps provide significant amount of information for the vehicle operator (using only visual cameras, the person who controlled the vehicle often got lost and was unable to accomplish tasks in darkness with lights off).

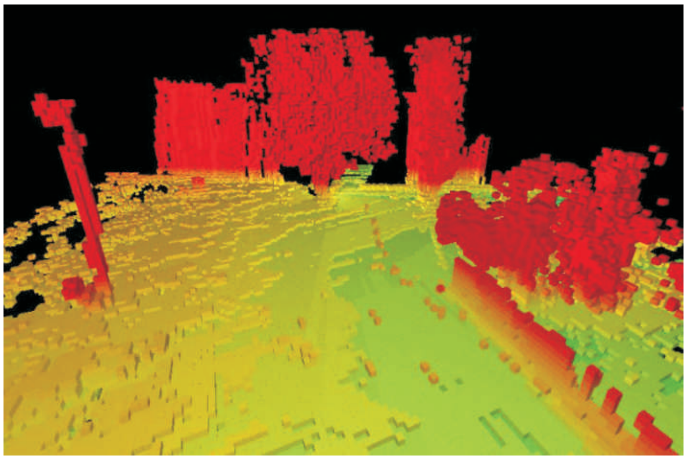
Recent research is devoted towards integration of "building information models" with autonomous navigation methods (detailed information about any modern building is available in some sort of electronic data sets). This will enable a robot to navigate in an unknown building without prior need to construct specific map of the entire environment.

Another aspect is to make use of four-valued logic inference methods in the field of mobile robotics. Such logic is based on four possible states: true, false, unknown, and inconsistent. This approach seems to be very promising due to large uncertainties present in any robotic system embedded in a changing and often unknown environment.

Fig.7.
The universal mobile platform "RoMeg".

Fig.8.
A test of the unmanned, remotely controlled military vehicle "Lewiatan" equipped with the system for construction 3D maps (see Fig. 9).

Fig.9.
A sample 3D map – the red boxes denote obstacles: a street light on the left, a tree and part of a building in the center, a fence with some plants behind it on the right.



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MAJOR PROJECTS

1. Smart Technologies for Transport Safety – Innovation Cluster Nesting, (SMART-NEST), (EC). **2.** Health Monitoring and Lifetime Assessment of Structures (MONIT), (NCBiR). **3.** Innovative Material Technologies for Aviation Industry (PKAERO), (NCBiR). **4.** Smart Technologies for Safety Engineering - SMART and SAFE, (FNP). **5.** Protection of buildings using adaptive damping of a vibration caused by rail vehicles using smart materials, (NCBiR). **6.** Innovative, high performance valves for adaptive pneumatic impact absorbers, (NCBiR) **7.** Interactive computer environment for solving optimal control problems (IDOS), (NCBiR). **8.** Adaptive Impact Absorption (AIA), (NCN). **9.** Feasibility Study of its Application to Damage Reduction in Transport Collisionsl, (NCN).

DEPARTMENT OF THEORY OF CONTINUOUS MEDIA

HEAD: Prof. Leszek Jarecki

Graduated from Faculty of Physics, University of Warsaw. Research Scientist at IPPT since 1974. Ph.D. and habilitation obtained at IPPT. Full professor of technical sciences since 2009. Awarded by the Committee of Mechanics and the Scientific Secretary of Polish Academy of Sciences. Head of the Department of Theory of Continuous Media since 2009 and head of the Polymer Physics Division in the Department in the period 2004-2012.

DIVISIONS AND RESEARCH GROUPS

- Analytical Mechanics and Field Theory — Head: Prof. Jan J. Sławianowski
- Polymer Physics — Head: Assoc. Prof. Pawel Sajkiewicz
- Nanofotonics — Head: Prof. Wojciech Nasalski
- Acoustoelectronics — Head: Assoc. Prof. Piotr Kiełczyński

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In the department, linear and non-linear theories of low- and high-molecular materials as well as photonic and acoustic structural effects are investigated with the application of the continuous media methods. Since 1972, the research teams were involved in the development of the continuous media theory of the materials of complex structure by introducing to the classical theories additional degrees of freedom, internal structures and local constraints being responsible for specific properties of real materials. The Department was a pioneer of such research in Poland. Significant achievements concern theories of gradient and fibrous materials, defects, liquid crystals, optical and acoustic surface waves in the complex media and topological methods in the physics of continua. At present, the theories are developed to account for substantial nonlinearities resulting from the structure on various scale levels. It concerns nonlinear theory of systems with complex hierarchical structure, quantum and quasi-classical models of kinetics and dynamics of the media with micro- and nanostructure, non-linear transport phenomena of phonons, quantum gases and molecules in biological systems. In the future, problems of nonlinear theory of acoustic and optical wave propagation will be considered with potential applications in ultrasonic physics and optics. The research on the geometry, symmetry and conservation laws in the mechanics and physics will be continued, including the nonlinearity-symmetry relationships, quantum and quasi-fluids, nonequilibrium radiation streams, weak discontinuity wave propagation and the transport problems in pharmacodynamics.

Substantial contribution to the research topics, limited earlier in the department to low molecular species, are theoretical and experimental investigations on polymer physics. The unique feature of polymers is high-molecular topology which results in entropic nature of thermodynamics and the constitutive relations, as well as the time scale of structural processes longer by the orders of magnitude. The polymer theory of continua is supplemented by the specific structure development and constitutive equations where substantial nonlinearity of the theory results from coupling between the molecular and supermolecular structure, processing conditions and material properties. Significant achievements concern nonlinear deformation and molecular orientation, investigations on the nucleation and crystallization kinetics in variable conditions, kinetics of polymorphic phase transformation and theory of liquid crystalline phase transformations under external fields. At present, the research on polymers focuses on the development of the structure under fast changes of temperature and stresses, mathematical modeling of formation of nano- and super thin fibers, as well as on the structure of scaffolds of super thin fibers obtained by electrospinning for cell culture in the tissue engineering.

The domain of the research topics was extended last years to several important phenomena of interactions of optical and acoustic waves with complex material structures. It covers linear and nonlinear optics, diffraction and scattering of electromagnetic waves on the specific structures of micro and nanotechnologies, nonophotonics, plasmonics, and nano-metamaterials. Composition of the metamaterials structure can be tuned into the sub-wavelength range to achieve desired material-electromagnetic properties. Such structures are expected to open new possibilities in searching for electromagnetic medium properties unavailable from usual materials. The research on electromagnetic properties of metamaterials, complex linear and nonlinear interactions with external light beam and on their various optoelectronic, photonic and plasmonic applications is under current progress.

Present research conducted on the theoretical and experimental methods of physical acoustics in the investigations of material structure and properties concerns inverse methods in the study of physical properties of solids and liquids, as well as physico-chemical properties of organic liquids under high pressure. A number of ultrasonic techniques of liquids' physical parameters such as internal pressure, free volume and relaxation times are tested by measurements of the ultrasonic wave velocity and viscosity, as well as phase transformations in liquids under high hydrostatic pressure.

SELECTED RESEARCH ACTIVITIES

SYMMETRY AND THE CONSERVATION LAWS. MECHANICAL SYSTEMS AND FIELDS WITH LARGE SYMMETRY GROUPS

The main topics of the research concern:

- In-depth analysis of the dynamics of systems with large symmetry groups, i.e. groups with the elements indexed by arbitrary functions and symmetry groups of the action functionals based on quadratic forms of the derivatives with the coefficients irreducibly dependent on the configurations. Between the both types, a close relationship takes place leading to significant nonlinearities. Influence of the nonlinearities is analyzed based on the group and dynamical systems theories. In particular, by taking into account the effects of instability of the solutions for the systems with the dynamics ruled by functionally parameterized symmetry groups in large elastic deformations, hydrodynamics, gravitation theory, gauge theories of fields and defects.

- Analysis of the symmetry-nonlinearity relation. By the analogy to the theory of defects and field theory with the Euclidean group in three-dimensional and the Lorentz group in four-dimensional space-time, the hierarchy of theories ruled by the projective, conformal and affine groups is investigated. Taking into account importance of the quantum issues in nano-physics, the theory is formulated in terms of the covering groups, such as SU (2,2) which is the covering group for the Minkowski space-time conformal group including spin. The aim is to elaborate the field theory and theory of defects with local SU (2,2) symmetry group.

CLASSICAL AND QUANTUM MECHANICAL THEORIES. QUANTUM FOUNDATIONS OF THE THEORY FOR MICRO- AND NANO-SCALE SYSTEMS

The main topics concern:

- Formulation of a quantum theory based on the classical models, i.e. geometrical and group theory of internal and collective degrees of freedom, and quasi-classical models starting from the rigid-body model to more complicated: affinely-, projectively- and conformally-rigid bodies. The aim is to elaborate quantum version of this theory and the quasi-classical models. Quantum and classical approach can be employed with the use of notions such as Lagrange and Legendre manifolds, two-point characteristic function, Van Vleck determinant, etc. The approach provides possibility of operating with the notions which are classical, but being in agreement with quantum nature of the problems, and can be particularly useful for micro- and nano-scale systems.

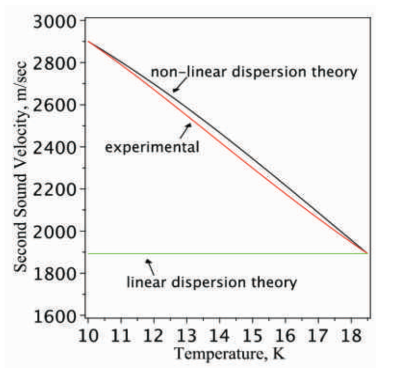
- Analysis of quantum many-body systems as a model for molecular crystals or micro-polar media in the limit of classical continuum. Especially interesting is the quantum problem of mutually interacting tops with dipole and/or higher electrostatic or magnetic moments.

- Analysis of quantum systems of affinely-rigid bodies. It corresponds in the theory of media to molecular crystals with micro-deformation of the grains. In the limit of classical continuum, the Eringen micro-morphic medium is obtained.

TRANSPORT THEORY OF MASSLESS QUANTUM PARTICLES

The research focuses on the moment methods of the kinetic theory of gases consisting of massless quantum particles. We use the maximum entropy closure of the moment equations and modified methods of Chapman-Enskog and Grad types to derive nonlinear equations of the particles hydrodynamics. The equations are directly applicable to macroscopic description of the radiation fields' dynamics, in particular of the photon and neutrino fields, as well as phonon heat transport which prevails in the dielectrics and semiconductors. The figure illustrates experimental velocity of the second sound pulses vs. temperature in NaF crystal and its good approximation by the velocity of thermal wave front predicted by our four-moment theory of the phonon hydrodynamics with the nonlinear dispersion.

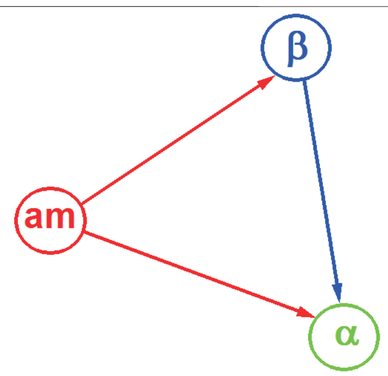
Fig.1.
Velocity of thermal wave vs. temperature in NaF crystal predicted by the four-moment phonon hydrodynamics with nonlinear dispersion (black line) compared with experimental velocity of the second sound pulses (red line). Green line - prediction at the linear phonon dispersion.

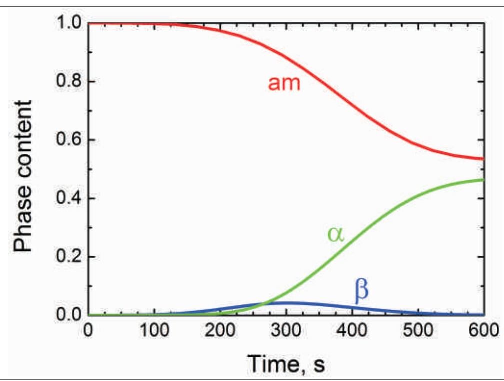


KINETICS OF POLYMORPHIC PHASE TRANSITIONS - THEORY AND EXPERIMENT

Existence of several phases with different physical properties plays important role in the materials science. Various polymorphic phases can appear and exist off the thermodynamic equilibrium in polymers for a long time. Kinetic and thermodynamic factors allow for appearance of different phases at the same external conditions. Detailed relations between the transition rates, material characteristics and external conditions are simulated based on our theory of nucleation-controlled crystallization kinetics. The example illustrates transitions between the amorphous phase (am) and the crystalline α and β polymorphs computed for isotactic polypropylene during isothermal crystallization.

Fig.2.
Polymorphic transformations between amorphous (am) α and β crystalline polymorphs in isotactic polypropylene during isothermal crystallization.

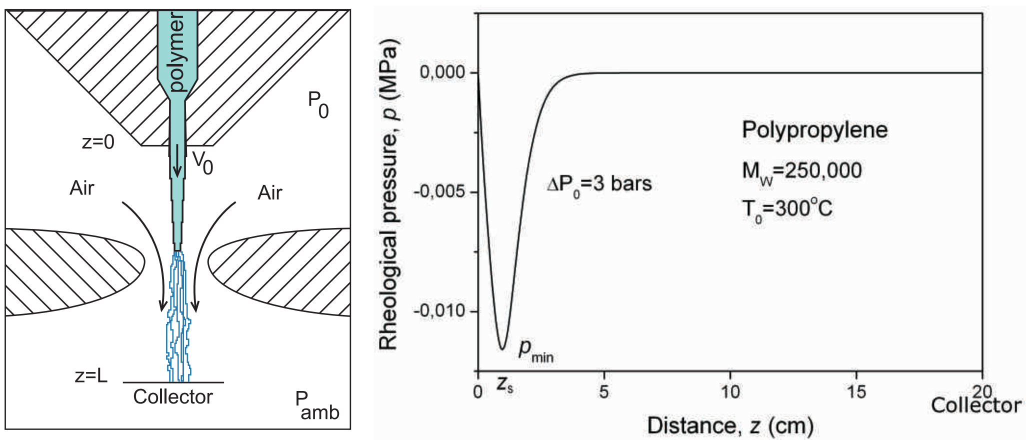




MODELING OF SUPER-THIN FIBERS FORMATION FROM POLYMER MELTS

Dynamics of a novel pneumatic processes of formation of super thin fibers from polymer melts is studied using computer modeling. The approach is based on mathematical models of the air flow and drawing of thin polymer filaments by the air friction forces. Our model predicts development of the supermolecular fiber structure (crystallinity, molecular orientation) under fast elongation of the polymer melt in the pneumatic process. The influence of all important processing and material parameters is accounted for. Negative rheological extra-pressure is predicted in the polymer melt subjected to supersonic air jet in the Laval nozzle which may lead to observed longitudinal splitting of the filament into high number of sub-filaments.

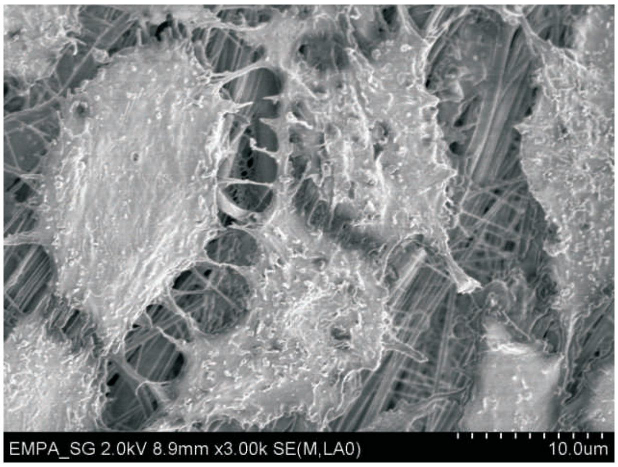
Fig.3.
Splitting of the polymer filament in the Laval nozzle under negative rheological pressure.



MICRO- AND NANOSTRUCTURE OF SCAFFOLDS FOR TISSUE ENGINEERING

Our involvement in tissue engineering focuses on formation of artificial extra-cellular matrix by electrospinning of submicron polymeric fibers, as well as bicomponent fibers spun from solutions of biocompatible and biodegradable polymers in non-toxic solvents. The aim is to establish correlation between the conditions of fibers formation, the matrix structure and the scaffold in-vitro bioactivity.

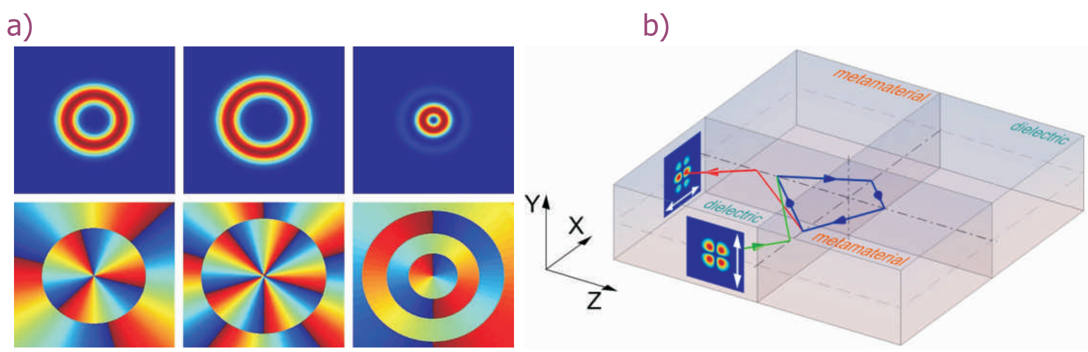
Fig.4.
Mouse fibroblast cells on the scaffold of bicomponent polycaprolactone/gelatin electrospun fibers (in cooperation with EMPA, St. Gallen, Switzerland).



PHOTONICS AND PLASMONICS OF METAMATERIAL NANOSTRUCTURES

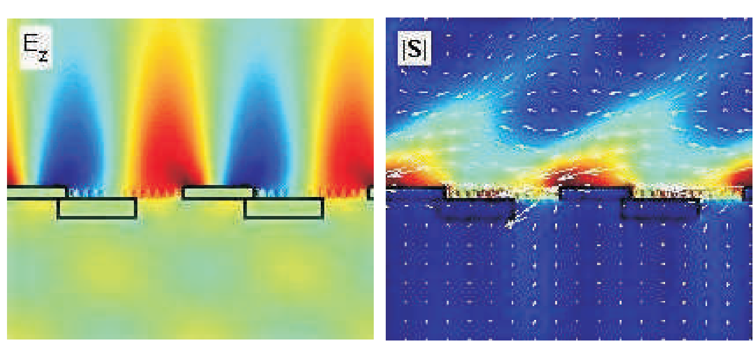
The research concentrates primarily on the modern near-field and far-field optical methods of subwavelength imaging at nano-meta-structures. Theoretical analyses and advanced numerical simulations are carried on the higher-order vector beams, pulses, vortices and surface waves. The cases of arbitrary polarization and spatio-temporal shapes are considered, as well as the cross-polarization effects of reflection and transmission, photon spin and orbital angular momentum entanglement, Hermite-Gaussian and Laguerre-Gaussian normal modes of planar nanostructures. Negative diffraction, refraction, focusing and guiding at metamaterials, and at photonic periodic and aperiodic nano-meta-multilayers are also under investigation. The research topics remain within nanophotonics, plasmonics, technological physics and metamaterial science. Examples of new phenomena can be found, from the subwavelength imaging by a metamaterial slab commonly understood as the "superlens" action, through the lens plasmonic realizations obtained by the composite nanoparticle lattices, to the annihilation of an optical image known as the "optical illusions".

Fig.5.
a) Amplitude (upper) and phase (lower) of optical vortices with topological charges 3, 5 and 1,
b) nano-meta-material cavity with the cross-polarization switch of elegant Hermite-Gaussian beams. Spatial decompositions and polarizations of the beam (white arrows) are shown.



The other techniques range from those which rely on evanescent fields superlenses and near-field plates, to those based on hyperbolic dispersion of planar anisotropic metamaterials and metallic nanostructures – plasmon concentrators and directivity switches, Fresnel's gratings, hypergratings and metalens, devised for subwavelength focusing and light manipulation in both, near-field and far-field ranges. Their potential applications in high-resolution visualisation, nanolithography and sensing are expected. Illustrated are examples of numerical simulations of the action of the periodic, layered plasmonic structure.

Fig.6.
Spatial field distribution (left) and power flow direction (right) excited at the assymetric periodic multilayered plasmonic structure.



THEORETICAL FOUNDATIONS OF THE ULTRASONIC SENSORS TO STUDY PHYSICAL PROPERTIES OF LIQUIDS

Investigations concern theoretical foundations of the design, as well as construction of ultrasonic sensors and their use to study physical properties of liquids. The methods are non-destructive, computerized, do not require large quantities of the tested material and can be used to investigate organic and inorganic species. Shown is the novel ultrasonic set-up designed for measuring viscosity of liquids under high hydrostatic pressure (Fig. 7).

One of the main themes are ultrasonic studies on physical properties of major components of the vegetable oils - triglycerides, diglycerides and fatty acids under high pressure. High pressures up to several hundred MPa are used in the industry for food preservation and processing. Vegetable oils are also major components of biofuels. Classical mechanical methods of measuring viscosity are practically useless in the range of phase transformations in the oils under high-pressure and decompression. The new method for measuring viscosity uses sensors of surface acoustic waves of the Love and Bleustein-Gulyaev type. The measurements are carried out in the pressure range up to 700 MPa and various temperatures.

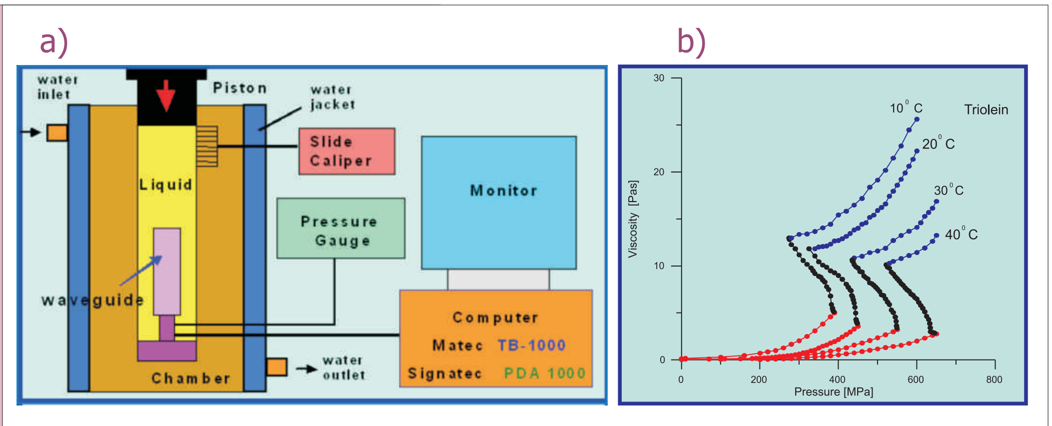


Fig.7.

a) The ultrasonic set-up for measuring viscosity of liquids under high pressure (up to 700 MPa).

b) Viscosity isotherms of triolein vs. hydrostatic pressure. Black dots indicate phase transition.

The research with the application of ultrasonic methods concerns also inverse methods in determining elastic properties of thin films and graded materials. The investigations are carried out with the use of advanced numerical and mathematical methods including optimization problems and nonlinear programming.

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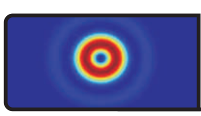


MAJOR PROJECTS

1. Modeling of super-thin fibers formation in ultrasound air jet with the use of the Laval nozzle, (National Found). **2.** Non-linearity, geometry and quantum processes in complex structural materials, (NCN). **3.** Identification of the profiles of the elestic parameters development in the gradient materials by the metod of ultrasound surface Love waves, (NCN).

DEPARTMENT OF ULTRASOUND

HEAD: Prof. Andrzej Nowicki

Graduated from Faculty of Electronics, Warsaw University of Technology in 1969. He got his Doctorate (Ph.D) degree in 1976 and habilitation in 1980 at IPPT PAN. He became a full Professor in 1992 and Head of Department of Ultrasound in 1994. Corresponding Member of the Polish Academy of Sciences since 2007 and Director of IPPT PAN since 2009.

DIVISIONS AND RESEARCH GROUPS

• Ultrasonic Introscopy	Head: Assoc. Prof. Janusz Wójcik
• Acoustic Microscopy	Head: Assoc. Prof. Jerzy Litniewski
• Biomechanics	Head: Assoc. Prof. Barbara Gambin

STAFF

Assoc. Prof. Tamara Kujawska
Katarzyna Falińska, Ph.D.
Ziemowit Klimonda, Ph.D.
Eleonora Kruglenko, Ph.D.
Marcin Lewandowski, Ph.D.
Andrzej Mizera, Ph.D.
Hanna Piotrzkowska, Ph.D. Eng.
Jerzy Podhajecki, Ph.D. Eng.
Wojciech Secomski, Ph.D. Eng.
Yuriy Tasinkevych, Ph.D. Eng.
Zbigniew Trawiński, Ph.D. Eng.

Norbert Żołek, Ph.D.
Ihor Trots, Ph.D.
Piotr Karwat, M.Sc. Eng.
Kazimierz Krawczyk, M.Sc. Eng.
Piotr Kulesza, M.Sc. Eng.
Beata Witek, M.Sc. Eng.
Bogusław Zienkiewicz, M.Sc. Eng.
Krzysztof Sielewicz Eng.
Mateusz Walczak, Eng.
Ryszard Tymkiewicz

Ultrasound is not only a complementary method to traditional imaging techniques, such as X-ray, computed tomography, magnetic resonance, or radioisotopes but, in addition, it has unique properties in comparison with these imaging modalities. Non-ionizing character of the ultrasonic radiation should be noted among them. On the basis of contemporary knowledge there is an absence of side effects. Ultrasound images of organs are obtained in a real time at a speed of tens of frames per second, and simultaneously to the imaging of tissues a color "map" of blood flow velocities in vessels can be recorded. The ability to distinguish and detect small lesions in the organs is approximately a millimeter, thus the ultrasound diagnostics is among the latest achievements such as computed tomography or magnetic resonance imaging. Small dimensions of contemporary ultrasound devices are of great significance. Many of them are portable enabling diagnostic investigation at the bedside. Obviously, there are some limitations as well.

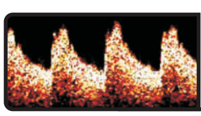
In the last decade a qualitative breakthrough in the ultrasound and echocardiography has been made. New technologies of the broadband ultrasound imaging transducers have appeared. A digital processing of signals almost completely replaced analog technologies. In diagnostic procedures, an increase in application of ultrasound contrast agents, that enable to distinguish areas of impaired circulation in organs that undergo imaging, has been noted. A future-oriented application of the contrast investigations will be a synergistic interaction between the therapeutic and diagnostic contrast agents, that exhibit properties of amplifying tissue echogenicity, and at the same time being carriers of drugs, specific for certain lesions. A harmonic ultrasound, the basis of which are non-linear properties of ultrasound propagation in tissues, is the next technological breakthrough. In a short time, only a few years, it has provided means for the selected organs imaging with unprecedented accuracy. Without a doubt, the harmonic imaging, and some of its mutations, including a coded ultrasound, will become a field of intensive scientific research and new implementations.

After years, when an interaction between the ultrasonic beams and biological tissue was considered only under the very low acoustic pressure and terms similar to the beam geometrical optics, we developed intensive research of nonlinear phenomena associated with the propagation of waves in tissues. It means that the wave equations, usually solved numerically, take into account non-linearized force equations, thus including both derivatives of the liquid motion velocities - local and convectional. The local changes in wave velocity due to instantaneous local density of tissues, varying in a function of acoustic pressure, are studied.

An important research field concerns the grainy “background” of the ultrasound images – being a consequence of diffraction properties that scatter the waves on local variations in acoustic impedance of tissues. In the image speckles, the information about a tissue local structure, different for healthy tissues from pathologically altered, is hidden. The speckles signal is nearly two times larger than the acoustic noise. That enables to study its statistical properties. In normal tissues the speckles statistics is similar to the Rayleigh distribution, while in the pathologically changed tissues the statistics significantly deviates from it.

The main topics of the research at the Department of Ultrasound include:

- Ultrasonic diagnostics of bones – in the research, the bone parameters, such as a ratio describing the dependency of attenuation on frequency and sound velocity, are determined. Simultaneously, the intensive research on the use of information which is contained in the wave scattered in the cancellous bone, and the phenomenon of wave velocity dispersion in bones, is conducted. These values depend on the micro-architecture of the cancellous bone and they associate the process of osteoporosis.
- Ultrasound diagnostics at the increased penetration range using coded transmissions with the specific signature and synthetic apertures.
- Non-linear acoustics and harmonic imaging, based on the use of higher harmonics which undergo self-generation due to nonlinear propagation of ultrasound pulses that have sufficiently large amplitude; they improve quality of the ultrasound images, increase their contrast and reduce artifacts.
- Parametric imaging – tissue characterization.
- Transcutaneous measurement of hematocrit with the use of the pulse Doppler technique and assessment of wave attenuation in blood.
- High-frequency ultrasound diagnostics for studies of the skin lesions, at a resolution of tens of micrometers, with the use of scanning beams at frequencies above 30 MHz, and new piezoelectric thick-film type transducers with a wide bandwidth.
- Thermal effects associated with the ultrasound propagation in tissues.



SELECTED RESEARCH ACTIVITIES

PARAMETRIC IMAGING

The long term goal of this research is to create an ultrasound imaging system which can quantitatively measure the physical properties of tissues and accurately discriminate pathological tissue from the normal one in early stages of the disease. This leads us to "quantitative sonography", the modern scientific discipline that allows to characterize the tissue microstructure by processing and analyzing ultrasonic echoes. Several tissue parameters are considered like backscattering coefficient, attenuation coefficient, sound velocity and statistical properties of backscatter. All are potentially very attractive while until now we have focused on attenuation and statistics.

SYNTHETIC APERTURE

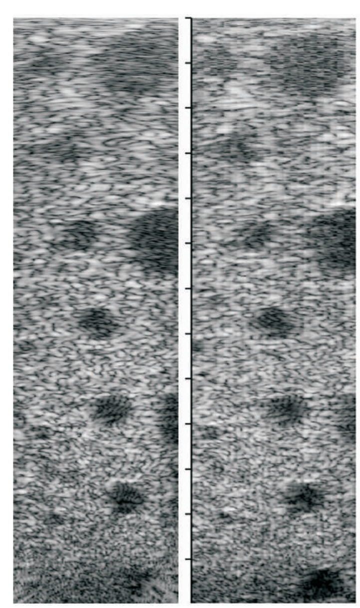
The method of Synthetic Aperture (SA) is a new solution for the ultrasound diagnostics and is particularly important in applications where the frame rate, as well as the image resolution, play a crucial role. In particular, they represent completely new areas of application in cardiology, for example, for investigations of heart wall motion dynamics.

Another very important application is the treatment of cancer with the use of a focused beam of the ultrasonic waves. It should be noted that the high-resolution imaging gives possibility of more accurate diagnostics in investigating the lesions with pathological changes; thus, it ensures earlier and better therapy.

The application of synthetic aperture is a radical change in relation to the currently applied scanners where the image is built sequentially, line by line. In contemporary ultrasound diagnostics a method of image formation significantly limits the resolution, the rate of acquisition as well as the ability to obtain a sufficient number of data of the high quality imaging.

Fig.3.

Synthetic aperture. Images of the tissue standard obtained with the 64 element head. The synthetic transmit aperture (STA) method: 4 transmissions with16 elements, on the left. The standard STA method: 25 acquisition matrix elements, 25 transmissions with 16 elements every 2, on the right.



The Synthetic Aperture method allows to solve most of these problems because having a broad spatial spectrum of transmitting tranducers enables to acquire echoe data within the wide angular range, simultaneously in a few to dozens of transmissions. The optimization in the SA method leads to an adequate compromise between the memory size, time and computing power, necessary for acquisition of echoes from the imaged organs and the reconstruction of the image and the required resolution and the noise level.

LINEAR AND NON-LINEAR PROPAGATION

For many years we have been applying our own efficient solvers of the non-linear acoustics equations (also for non-axisymmetric boundary conditions). They enable: determining the spatial distribution of fields of non-linear propagation of acoustic beams, modeling the associating phenomena, such as heating of medium, modeling the beams for harmonic visualization, and determining the material parameters (especially non-linear) of medium.

In linear description of propagation we can numerically determine the fields which are scattered on complex material structures, heterogeneous in reference to their physical or geometrical parameters (for example bone tissue). The solvers support the novel approach of developing the algorithms for the tissue signal analysis.

Parametric imaging of attenuation is applied at standard imaging frequencies and we expect that it will help in localization of the pathological states of tissue including tumors and diffused liver diseases. Although the ultrasound attenuation estimation problem is not new, there is a lack of reliable methods operating with satisfactory resolution and precision. We have developed a procedure of attenuation determination from the downshift of mean frequency of the interrogating ultrasonic pulse propagating in the medium. The developed technique consists of several steps including mean frequency determination with correlation estimator, trend extraction with singular spectrum analysis technique and averaging. Also, various techniques of data acquisition like the synthetic Aperture Focusing, Spatial and Frequency Compounding are applied, considerably increasing the image resolution.

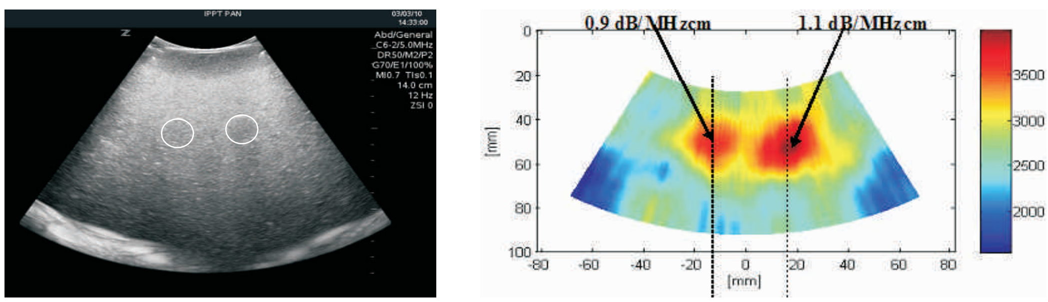


Fig.1.
B-scan of the tissue mimicking phantom with two regions of increased attenuation (not seen in the gray scale presentation) – left, and image of attenuation regions after parametric processing - right.

STATISTICAL PROPERTIES OF THE ULTRASONIC ECHOES FROM TISSUE

The statistics of the received ultrasonic echoes are used for detection and characterization of basal cell carcinoma (BCC) that is the most common cutaneous malignancy representing 80% of all cases of skin cancer. In this case, 30 MHz ultrasonic scanner is used to record the echoes from the pathological and healthy regions of the skin from patients with diagnosed BCC. The K distribution is used to estimate the statistics of the echo signals envelopes and to determine the effective number M of scatterers. We have found that the averaged M parameter for BCC lesions is significantly, up to 50%, lower than for healthy skin. We explain the drop of M parameter of K distribution for BCC by the lower spatial density of tumor cell clusters in comparison to the spatial density of cells in healthy skin.

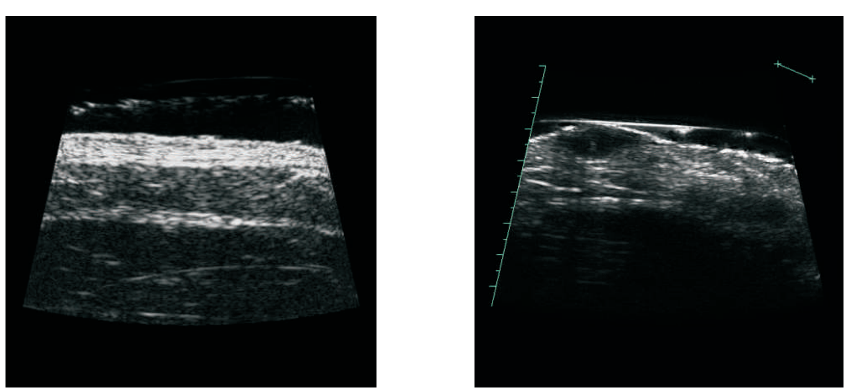


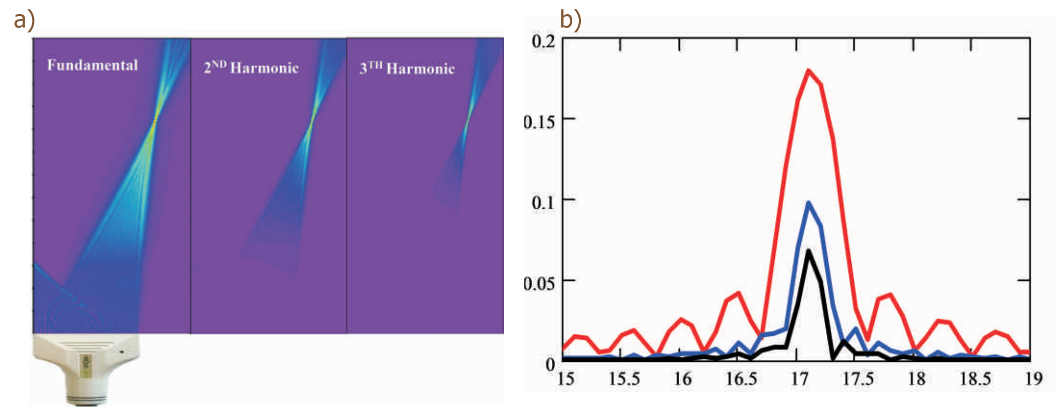
Fig.2.
The ultrasound images of skin generated with the uSCAN: normal skin (left), images of basal cell carcinoma (right).

Fig.4.

Nonlinear propagation.

a) 128 element linear array field distributions for fundamental (7.5 MHz), 2nd and 3rd harmonics,

b) lateral beam width for three harmonics in focal plane – beam's width and amplitude decrease considerably with higher order harmonics.



TOWARDS ENHANCEMENT OF OSTEOPOROSIS DIAGNOSIS

Osteoporosis induced by aging and as a side effect of certain drugs is a serious public health problem. It is a skeletal disease characterized by low bone mass and architectural deterioration of trabecular bone structure. In consequence, bone fragility and susceptibility to fracture increase. The lack of adequate means for early detection of bone deterioration is the most critical issue in the problem of diagnosing and monitoring osteoporosis therapy in general and in minimization of side effects of pharmaceutical treatment on skeletal system.

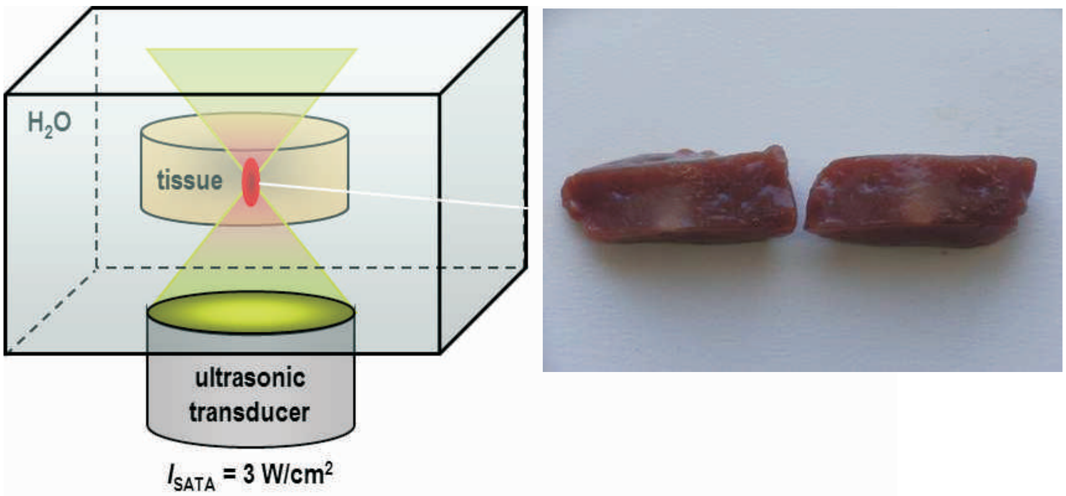
“Bone sonometry” is an accepted technique for diagnosis of osteoporosis. It is based on sound transmission through the examined bone, which enables the determination of the frequency-dependent attenuation coefficient correlating well with bone density. However, the applicability of transmission techniques for *in vivo* measurements is limited to peripheral bones only while the most frequent and dangerous osteoporotic fractures of bone occur deep in the body. Our research is focused on the assessment of the trabecular bone status using the waves scattered in deeply located bones. To determine the bone properties from the ultrasonic echoes we have performed a lot of simulations modeling the bone internal structure and waves scattering. Influence of bone structure variation on simulated backscatter was applied to explain the properties of the backscattered echoes obtained in *in vivo* experiments. The dependence was found between the backscattered waves envelope statistics and bone trabeculae disorder. Modeling was also used to assess the contribution of the higher order scattering to the total backscatter in bone and to determine the frequency ranges where the calculations may be limited to the zero order scattering only. Physical properties of trabecular bone like the frequency dependent attenuation coefficient, the backscattering coefficient and the speed of sound were measured in vivo showing particularly the link between the attenuation and bone density. Particularly we are interested in examination of femoral neck bone as this bone is often subjected to osteoporotic fracture. Successful realization of the project will expand application areas of medical ultrasound in skeletal system. Development of bone deterioration monitoring method will provide a substantial benefit to society by diagnosing patients at risk of increased bone fragility. It will enable intervention to prevent further bone loss and debilitating fracture.

THERMAL AND NON-THERMAL EFFECTS OF FOCUSED ULTRASOUND ON TISSUE

A few years ago we extended our research field of the active ultrasound, in particular of the thermal effects associated with the ultrasound propagation in tissues. A slight increase in temperature, above 37° C, affects a local blood perfusion. Local hyperthermia, in the range not exceeding 43° C, slows down a division of cells. The rapid, not exceeding three seconds, rise of temperature above 56° C leads to the immediate death of cells. The ultrasound that generates such a significant rise in temperature is called high intensity focused ultrasound (HIFU).

Fig.5.

The local non-invasive heating of the calf liver sample with the ultrasonic pulse focused wave at the intensity $I_{SATA}=3W/cm^2$. The intensity of the beam at the focal point is proportional to the square of the ratio - R to width of the beam on the transducer surface, to the beam width in plane of the focus (the example is for R=20). Temperature in the focus is higher than 56°C. Time of the exposure is three min.

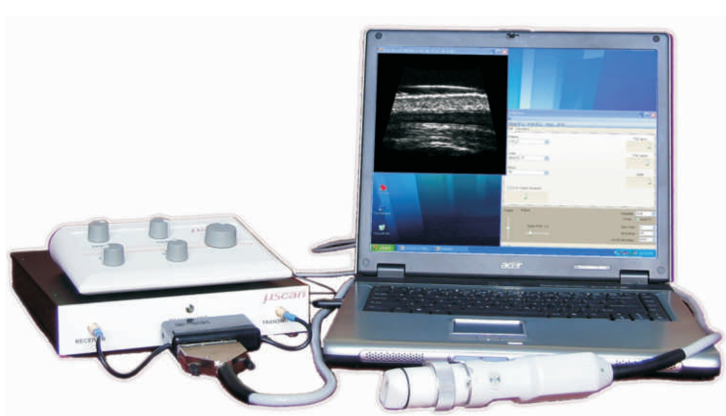


THE uSCAN SYSTEM

The high-frequency ultrasound is applied in dermatology, ophthalmology and investigations of blood vessels. The uScan system, developed in the Department of Ultrasounds, provides imaging of skin lesions with a resolution of about 50 µm. Application of the high frequency ultrasound (20-35 MHz) and the technology of coded transmission was possible due to digital signal processing of the high frequency ultrasound echoes in frequency domain. Nowadays, uScan is applied in clinics to conduct research on the methods of parametric imaging as well as tissue characterization.

Fig.6.

The view of the high-frequency ultrasound system uSCAN.



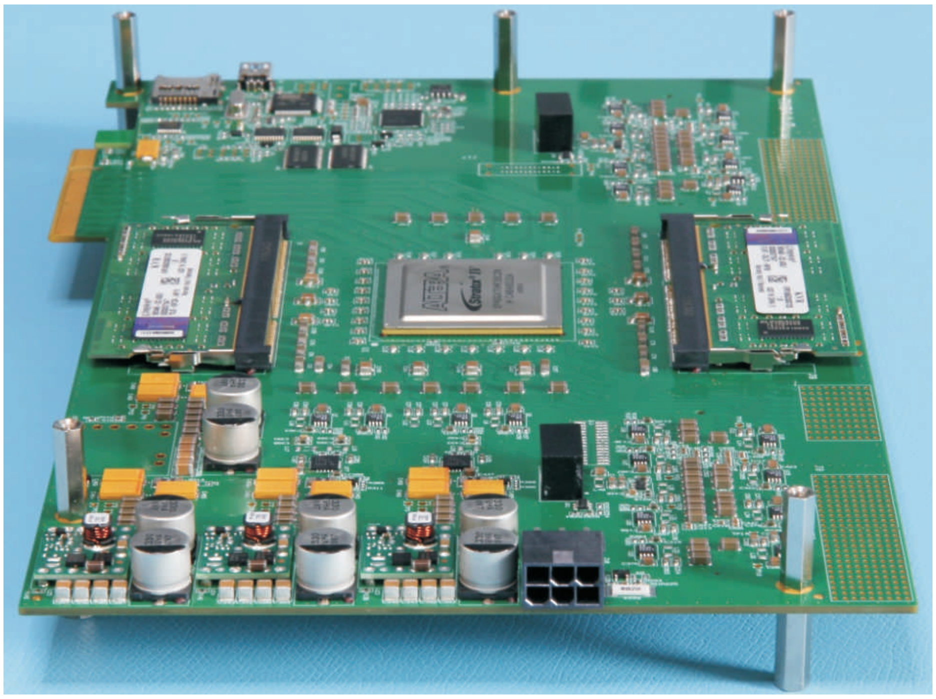
ELECTRONIC SYSTEMS OF DIGITAL SIGNAL PROCESSING

In the Department of Ultrasound a resilient team conducts works on designing the electronic systems and digital signal processing. Technical facility of the electronic laboratory includes modern measuring and control equipment, the system for prototyping electronic assembly as well as the CAD/CAE advanced software for designing and electronic simulating. The aim of current projects is a development of multi-purpose ultrasound systems for transmission and signal acquisition. The designed systems will enable implementation of new methods of imaging and signal processing of the ultrasound echoes in medical and industrial applications. The team has experience in implementing the algorithms of digital signal processing in the DSP processors, the FPGA programmable logic systems and the GPU graphic processors. Moreover, a close cooperation with industrial partners provided us a know-how knowledge in designing and issues of medical device certification.

A practical application of the SA requires new systems of multi-channel signal acquisition and high-performance parallel systems of data processing – these issues are a mainstream in R & D work that is carried out at the department. The current works are focused on implementation of the SA algorithms on graphic processors (GPU) in order to provide the processing and visualization in real time. The developed algorithms and the platform of multi-channel acquisition of ultrasound signals will represent a complete realization of the ultrasound device.

Fig.7.

View of the RX64 (developed in the Department of Ultrasound, IPPT PAN) which is part of the ultrasound platform being built. The RX64 provides simultaneous acquisition of 64 ultrasonic receiver channels, their preliminary digital processing and data transfer to PC/GPU through the PCIe interface.



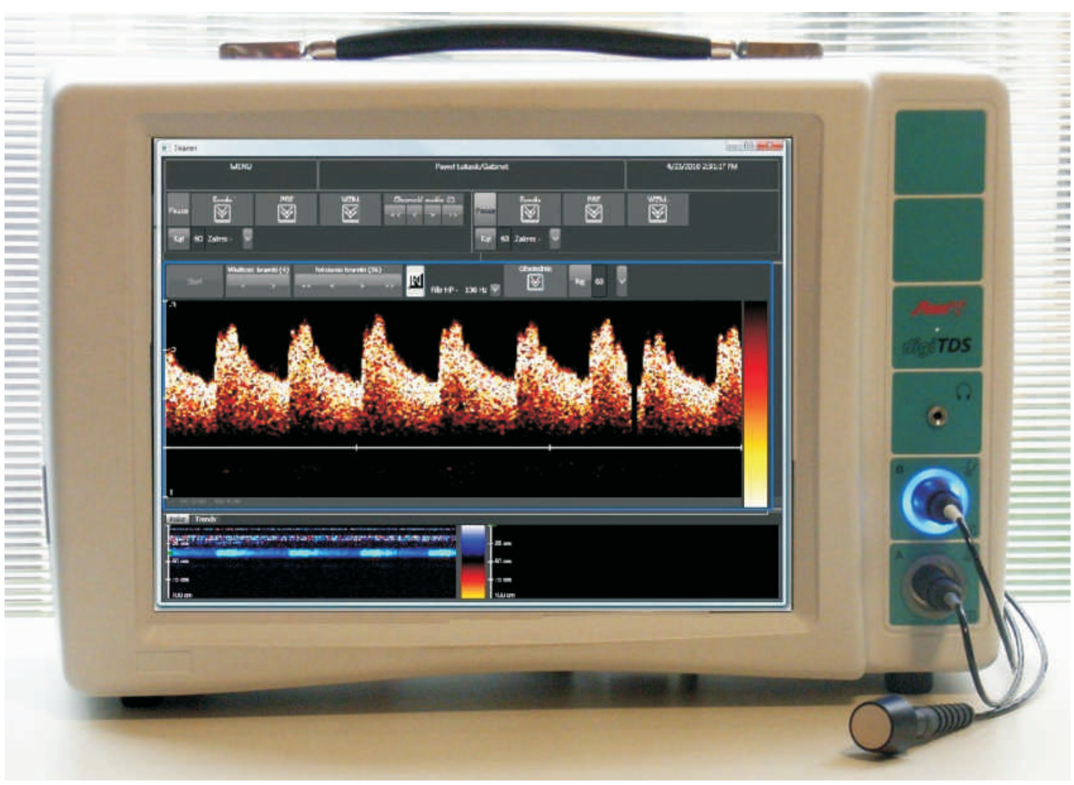
DOPPLER'S METHODS AND SYSTEMS

The ultrasound Doppler methods enable assessment and measurement of the blood flow in organs and blood vessels. The department has a long history of developing the Doppler methods and instrumentations. Recently, the modern Doppler platform, based on a direct digital high frequency signal processing, has been developed. The platform was applied in design and fabrication of a complete dual-channel transcranial flowmeter, digiTDS. The unit has a direct application in research and clinical diagnostics.

Universality of the developed Doppler platform was the basis for its application in measurements of volumetric blood flow in an artificial heart ventricle built in the heart assistance system (developed in the frame of the Polish Artificial Heart Program). At present, the feasibility studies on the new detection algorithms for micro-embolism material originated from the left ventricle in the artificial heart they are a serious threat to patients who undergo cardiac assistance, are carried out.

Fig.8.

The view of the TDS (with the blood flow spectrum on the screen).



SELECTED PUBLICATIONS

Nowicki A., Wójcik J., Secomski W., Harmonic imaging using multitone nonlinear coding, Ultrasound in Medicine and Biology, 33, 7, 1112-1122, 2007

Wójcik J., Kujawska T., Nowicki A., Lewin P.A., Fast prediction of pulsed nonlinear acoustic fields from clinically relevant sources using time averaged wave envelope approach: comparison of numerical simulations and experimental results, Ultrasonics, 48, 707-715, 2008.

Lewandowski M., Nowicki A., High frequency coded imaging system with RF software signal processing, IEEE Transactions on Ultrasonics Ferroelectrics and Frequency Control , 55, 8, 1878-1882, 2008.

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Trots I., Tasinkevych Y., Nowicki A., Lewandowski M., Golay Coded Sequences in Synthetic Aperture Imaging Systems, Archives of Acoustics, 36, 4, 913-926, 2011.

Nowicki A., Lewandowski M., Wójcik J., Tymkiewicz R., Lou-Moller R., Wolny W., Zawada T., Thick Film Transducers for High Frequency Coded Ultrasonography, Archives of Acoustics, 36, 4, 945-954, 2011.

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Danicki E.J., Analysis of comb transducers with sliding teeth, European Journal of Mechanics A- Solids, 30, 510-516, 2011.

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Kujawska T., Nowicki A., Lewin P.A., Determination of nonlinear medium parameter B/A using model assisted variable-length measurement approach, Ultrasonics 51, 8, 997-1005, 2011.

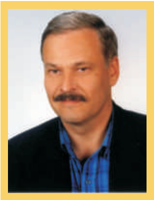
Gambin B., Ivanova J., Valeva V., Nikolova G., Precracking and interfacial delamination in a bi-material structure: Static and dynamic loadings, Acta Mechanica Sinica, 27, 1, 80-89, 2011.

Mizera A., Gambin B., Modelling of ultrasound therapeutic heating and numerical study of the dynamics of the induced heat shock response, Communications in Nonlinear Science and Numerical Simulation, 16, 5, 2342-2349, 2011.

MAJOR PROJECTS

1. Model and design of the ultrasonographic phantom of the left ventricle for the speckles analysis changes of the echographic imaging for the physiological and pathological cases, (NCN). **2.** Modelling and measurements the temperature increase in soft tissue phantom and tissue samples in vitro by analysis of backscattered ultrasound field, (NCN). **3.** Medical ultrasound instruments - new methods of testing and visualization of tissue structure of human organs, (EU Funds). **4.** Controlling of depth of necrosis induced locally in a rat liver in vivo using pulsed focused nonlinear ultrasonic beam with electronically sliding focus, (NCN). **5.** Assessment of bone density using frequency-dependent attenuation of ultrasound determined from backscattered waves. Application to diagnosis of osteoporosis in femoral neck bone, (NCN). **6.** Parametric ultrasonography - imaging of attenuation using synthetic aperture, (NCN). **7.** The system for measurement of blood flow and microemboli detection for pulsatile prosthetic cardiac support ReligaHeart EXT, (NCBiR).

DEPARTMENT FOR STRENGTH OF MATERIALS



HEAD: Prof. Zbigniew L. Kowalewski

Graduated from Faculty of Mechanics, Warsaw University of Technology. Ph.D. and habilitation obtained at IPPT. He has been the British Council Fellow and has spent 1992/93 academic year at the University of Manchester Institute of Science and Technology, England. In 2010 became the head of the Department for Strength of Materials.

DIVISIONS AND RESEARCH GROUPS

- Experimental Mechanics — Head: Prof. Zbigniew L. Kowalewski
- Mechanics of Plastic Flow — Head: Assoc. Prof. Elżbieta Pieczyska
- Technological Laser Applications — Head: Prof. Zygmunt Szymański
- Strain Fields — Head: Prof. Michał A. Glinicki
- Non-Destructive Testing — Head: Assoc. Prof. Jacek Szelążek

STAFF

Assoc. Prof. Zbigniew Ranachowski
Joanna Radziejewska, Dr. Hab. Eng.
Przemysław Ranachowski, Dr. Hab.
Piotr Gutkiewicz, Ph.D
Jacek Hoffman, Ph.D.
Daria Jóźwiak-Niedźwiedzka, Ph.D. Eng.
Dominik Kukla, Ph.D. Eng.
Sławomir Mackiewicz, Ph.D.
Wojciech Moćko, Ph.D. Eng.
Tomasz Mościcki, Ph.D. Eng.
Agnieszka Rutecka, Ph.D. Eng.
Jacek Widłaszewski, Ph.D. Eng
Tomasz Dębowski, M.Sc. Eng.
Karolina Gibas, M.Sc. Eng.
Paweł Grzywna, M.Sc. Eng.
Jolanta Wołowicz, M.Sc. Eng.
Justyna Chrzanowska, Eng.
Krzysztof Mizerski, Eng.
Maria Staszczak, Eng.
Mirosław Wyszkowski, Eng.
Andrzej Chojnacki
Erwin Grzebielichowski
Jan Kraskowski
Jacek Ściborowski

Department for Strength of Materials is an experimentally oriented research group. The total staff of the Department is 30 persons.

The Department was a part of the National Centre of Excellence for Safety-Critical Pressure Systems established and nominated by the State Committee for Scientific Research for a period from 2000 to 2002 in the framework of the Phare programme SCI-TECH II PL9611/03.01.1/5. It was also nominated by the European Commission in Brussels as a Centre of Excellence for Laser Processing and Material Advanced Testing (LAPROMAT) for a period from 2003 to 2005.

One of the main goals of the research activity being carryied out at the department is to develop advanced testing techniques for fatigue/creep investigations of materials under multiaxial stress states and to model fatigue/creep behavior of engineering materials using appropriate constitutive equations. Studies of this problem have been initiated more than 35 years ago.

During this 35-year period many fatigue/creep tests were carried out for different metallic materials, shape memory alloys and composites under uniaxial tension as well as complex stress states realized by different combinations of an axial force and twisting moment. These data are stored on hard discs of computers to create the base for constitutive modelling. The main aim of the modelling was to assess the ability of a number of mechanisms-based constitutive equations to describe fatigue/creep behavior of different materials in question. In this scientific area the department has a strong co-operation with British experts.

The effect of plastic prestrain induced in engineering materials due to industrial forming processes and during operation of fabricated workpieces on creep/fatigue is the next problem of great importance which is being analyzed by the staff of the department.

Currently, the activity of Division of Mechanics of Plastic Flow, Division of Experimental Mechanics and Division of Non-destructive Testing is focused on assessments of damage development due to fatigue or creep by finding correlation between mechanical parameters from destructive tests and parameters of non-destructive ultrasonic or magnetic testing methods.

The major objective of the Division of Strain Fields investigations is to recognize the relations between the microstructure and physical and mechanical properties of composites, particularly the long term durability in combined aggressive environment. Advanced concepts of smart curing, self-healing of cracks, monitoring of cracking and optimization of fibre reinforcement in brittle matrix cement-based composites are being developed. Microscopic methods with digital image analysis are applied for quantitative characterization of the microstructure. Accelerated methods for testing durability in aggressive environmental conditions are being elaborated, including combined action of variable temperature, humidity, exposure to CO_2 or chlorides. Selected soft computing methods, including machine learning, are used to generate rules to predict the durability.

Activity of the Division of Nondestructive Testing is focused on development of ultrasonic methods for damage assessment of materials subjected to exploitation loading on the one hand and to ultrasonic evaluation of stresses on the other. Ultrasonic evaluation of stresses is based on precise measurements of time of flight of ultrasonic pulses or continuous wave phase changes due to stress application. Two systems of live stress monitoring in steel structures were developed. The first one was based on time of flight of subsurface longitudinal wave propagating parallel to stress direction. Due to high elastoacoustic constant of longitudinal wave the time of flight is dependent mostly on elastoacoustic phenomena (ultrasonic velocity changes due to stress). The second system is based on continuous surface wave phase monitoring. Phase changes of surface wave are mostly proportional to deformation of the structure due to stress and only to a small degree due to elastoacoustic effect.

Analysis of laser ablation process is the main problem studied by the staff of the Division of Technological Laser Applications. Research activity in this area concerns mainly pulse laser deposition of thin film as well as synthesis of carbon-related nanostructures as nanoparticles, carbon nanotubes, etc.

SELECTED RESEARCH ACTIVITIES

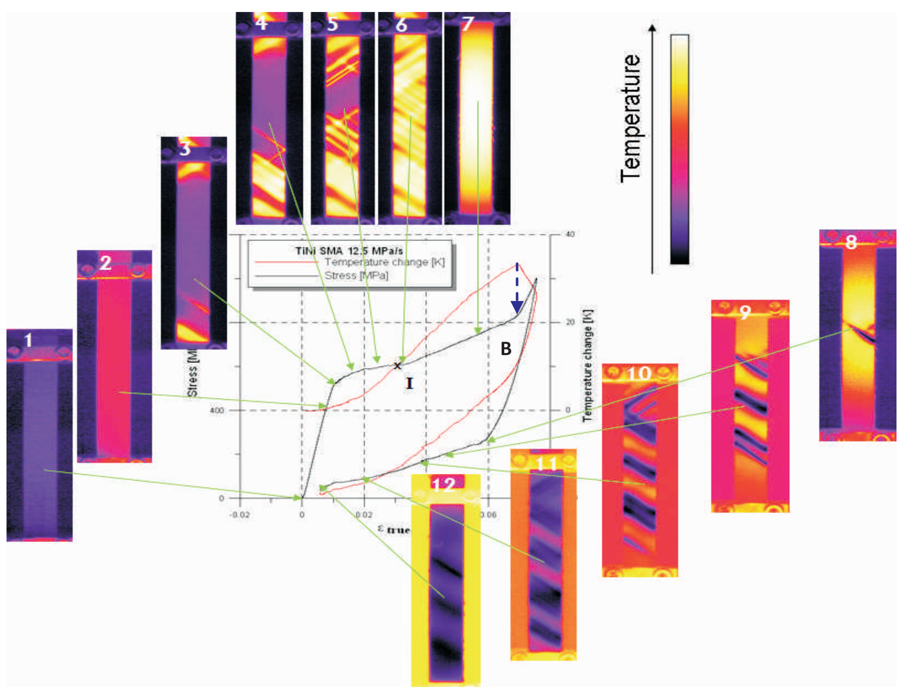
EXPERIMENTAL THERMOMECHANICS OF SHAPE MEMORY MATERIALS

Investigations of nucleation and development of Stress-Induced Martensitic Transformation (SIMT) in Shape Memory Alloys (SMA) subjected to various kinds of loading in wide spectra of strain rates, by comparison of mechanical characteristics and their related temperature changes are the main problems studied at the department.

Taking into account that the martensitic forward transformation observed during the SMA loading is exothermic while the reverse transformation observed during unloading is endothermic, the SIMT onset, morphology of development of the transformation patterns, as well as the conditions of the transformation saturation, are monitored and recorded.

Fig.1.

Stress and temperature change vs. strain curves obtained for TiNi SMA during tension at stress rate 12.5 MPa/s. Cross mark x indicates inflection point I, point B the martensitic transformation saturation stage. Thermograms show nucleation and evolution of macroscopic transformation bands, related to martensitic forward (3-7) and reverse (8-12) transformation.



Using high-quality testing machine and fast sensitive infrared camera a new generation of much thinner transformation bands can be identified at the stage of the advanced martensitic forward/reverse transformation.

The research on SMA, polymers and composites is carried out in cooperation with the Aichi Institute of Technology (AIT), Japan. Thanks to this cooperation a project of new shape memory alloy engine was elaborated.

COMPRESSION TESTS OF THIN METAL SHEETS ENABLING DEFORMATION UP TO 20% WITHOUT BUCKLING EFFECT

The compression-tension test fixture worked out at the department enables to avoid buckling during compression of specimens made of thin metal sheet. The fixture changes its length while a specimen elongates or shortens during the test and this is the main and characteristic feature of the fixture. The friction force which is generated due to a movement of both parts of the fixture is measured by a special strain gauge system during the test. The fixture has been delivered in version adapted to a tension – compression MTS frame with nominal load 25 kN equipped with the MTS type 647 Side-Loading Hydraulic Wedge Grips. The fixture is adapted to the MTS extensometer type 634.31F-24 with a range of 20% on base of 10 mm.

a) b)

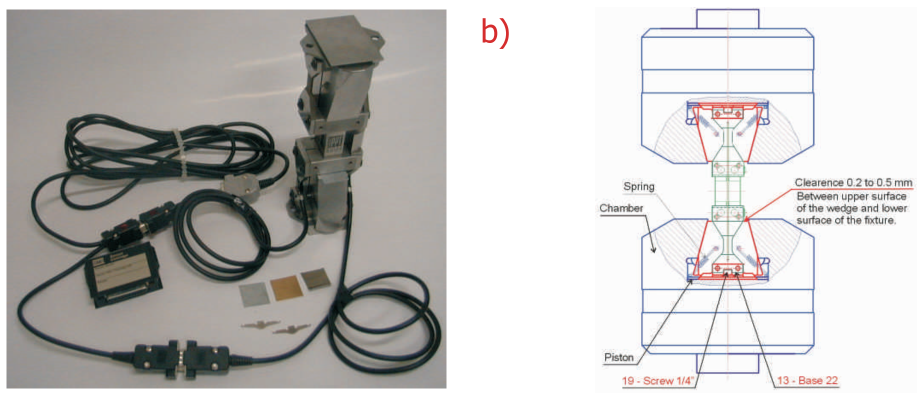


Fig.2.

a) A photograph of a fully assembled fixture with measuring and mounting elements.

b) The specimen, the test fixture and measuring bars fully assembled on the MTS system – side view.

DYNAMIC INVESTIGATIONS OF MATERIALS OVER A WIDE RANGE OF STRAIN RATES

The department has one of the most popular experimental techniques applied in determination of visco-plastic properties of materials at strain rates from ~ $5*10^2$ s^{-1} to ~10^4 s^{-1}, the so-called Split Hopkinson Pressure Bar (SHPB). In the testing stand for this technique a wafer specimen is placed between bars.

The miniaturized direct impact compression testing stand enables to increase a range of strain rates to be measured up to 10^5 s^{-1}. The stand was elaborated at the department and subsequently patented. Modification in the mechanical part lies in an introduction of the decelerator tube in which a small Hopkinson bar with miniature SR gauges is inserted. The original and not expensive optical technique to measure displacement of the interface striker-specimen has been applied.

Combination of the quasi-static precision compression test, along with application of SHPB and the miniaturized DICT, makes possible the determination of the rate sensitivity of materials for very wide strain rate spectrum, from $5x10^{-4}$ s^{-1} to 10^5 s^{-1}.

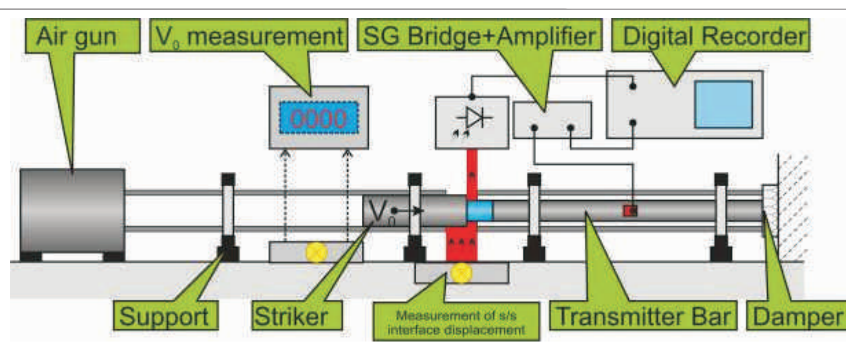


Fig.3.

Direct Impact Compression Testing stand.

DAMAGE DEVELOPMENT ASSESSMENTS DURING FATIGUE/CREEP – IDENTIFICATION OF DAMAGE MECHANISMS

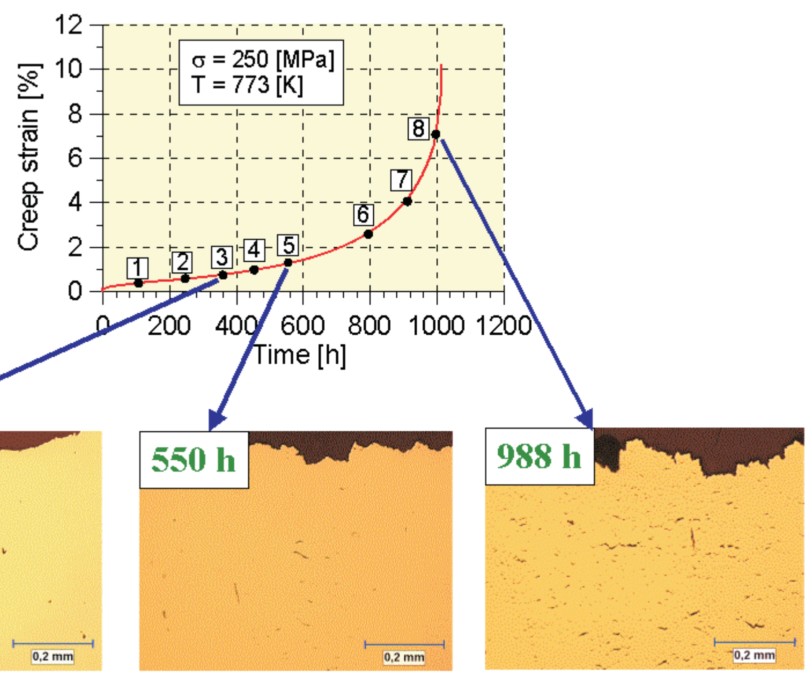
Originality of the approach for damage assessments steams from the fact that both the mechanical investigations for strength parameter determinations and the non-destructive testing for acoustic or magnetic parameters may be carried out parallely. Such a realization of the testing programs gives an opportunity to find mutual correlation between both types of parameters for a range of deformation processes taken into account. Moreover, observations on the microscopic level of the tested materials may be conducted for various degrees of damage. It gives additional opportunity of the damage analysis, namely, assessment of mutual correlation between macro- and micro-parameters.

The creep and fatigue results are used to verify the fundamental rupture criteria, and moreover, due to better understanding of the phenomena experimentally observed they may be applied to formulate new and more effective criteria capable to capture macro- and micro- effects.

The experimental data achieved during realization of tests create a comprehensive source of knowledge stimulating theoretical analysis in the field of constitutive modelling of material behavior under multiaxial stress states after various types of prestraining.

Fig.4.

Demage development due to creep. Creep curve of 40 HMNA steel grade and microscopic pictures of micro voids in material after 360, 550 and 988 hours of creep test.



Material degradation due to fatigue is also investigated at the department. Mechanisms like cyclic plasticity and ratcheting can be identified in various metals.

LASER ABLATION PROCESS

Pulsed laser deposition system consists of vacuum chamber from Prevac (with carousel mechanism of target selection, six targets selectable, mechanism of substrate rotation, substrate heater, etc.) and Nd;YAG laser Quantel YG 981E with 1th, 2nd, 3rd and 4th harmonic. Recent works were concerned with pulsed laser deposition of hydroxyapatite (a biocompatible ceramic), graphite (diamond like carbon – DLC coatings), and super-hard composite coatings.

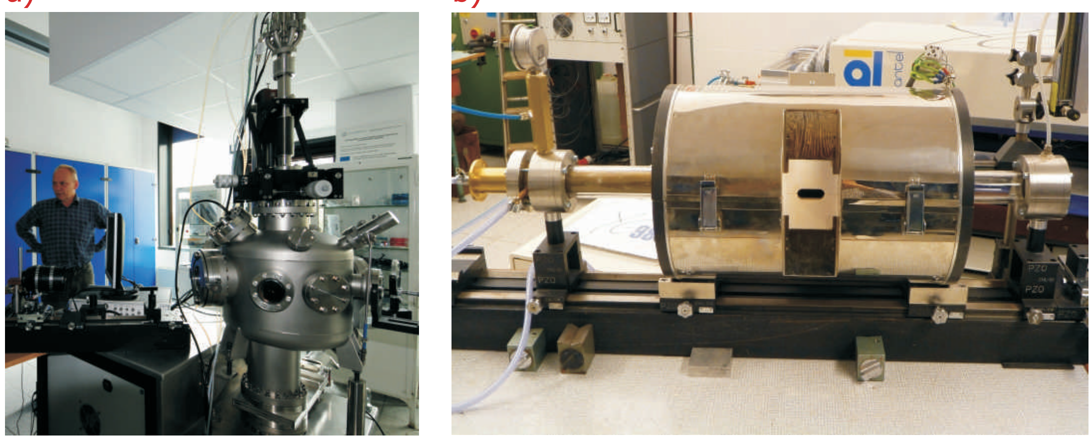


Fig.5.
a) Pulsed laser deposition chamber.
b) Reactor for synthesis of carbon nanotubes.

The reactor for synthesis of carbon nanotubes has been assembled by research workers of the laboratory. The ablation of the target occurs in a background gas – argon at a pressure of 660 Pa is slowly flowing in a quartz tube 50 mm in diameter. The quartz tube is mounted inside a cylindrical furnace operating at 1000 °C. The target is situated in the centre of the furnace. Graphite target irradiation is performed using the pulsed Nd :YAG laser (Quantel, 981 E). The argon flow rate is 100-200 sccm. The graphite target containing cobalt and nickel nanoparticles is used as carbon nanotubes synthesis catalysts. The carbon soot containing nanotubes is collected from the surface of the brass water-cooled collector located at the exit of the furnace.

DESIGN OF MICROSTRUCTURE AND THE DEVELOPMENT OF DIAGNOSTIC METHODS FOR ADVANCED CEMENT BASED COMPOSITES

On-going large research project concerns the development of innovative cement binders based on calcareous fly ash that is a by-product of power generation. The fundamentals for material design for structural applications are to be developed, aiming at major reduction of the carbon footprint of cement technology. Recently finished NATO Science for Peace project resulted in the development of sophisticated experimental methods for diagnostics of concrete on the basis of quantitative evaluation of its microstructure.

Starting from 1985 every three years an international symposium on brittle matrix composites (BMC-10 in 2012) is organized. The international research is principally related to the activity within RILEM - International Union of Laboratories and Experts in Construction Materials, Systems and Structures.

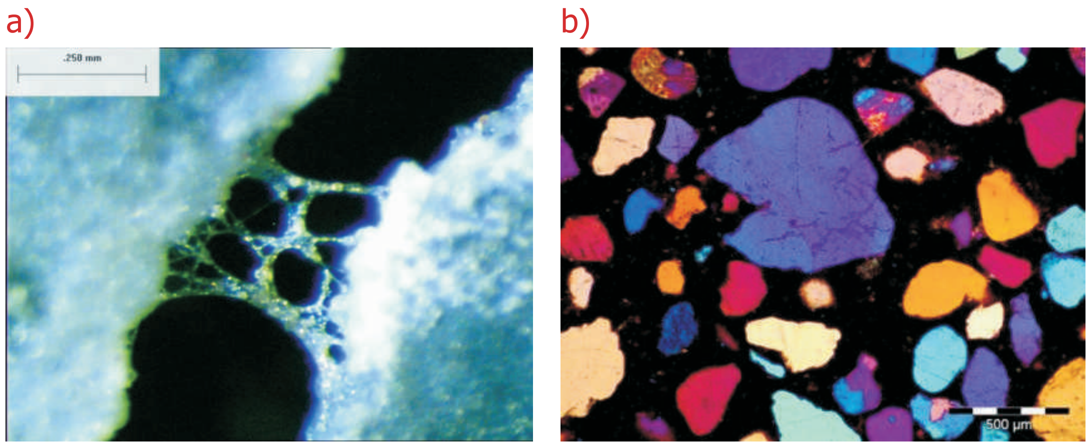


Fig.6.

a) Self-healing of cracks.

b) Mineral grain distribution in composite.

ULTRASONIC EVALUATION OF CREEP DAMAGE IN MATERIALS

Ultrasonic birefringence measurements on specimens subjected to creep (or to accelerated creep test) allow to evaluate their level of damage. If in the late creep stage small voids are formed in the material, their influence on velocities of shear ultrasonic waves can be measured. Velocity of the wave polarized perpendicular to dominant plane of semi-flat voids, oriented perpendicular to dominant stress direction, decreases resulting in the increase of acoustic birefringence. If, due to creep, material is plastically deformed without any voids arising in the bulk of the sample, value of acoustic birefringence decreases. These relations allow to differentiate the state of material subjected to creep. Methods average information from the sample or pipe wall thickness.

Tests performed on steel specimens showed that acoustic birefringence is a sensitive and practical tool with respect to damage development evaluation of metal subjected to creep conditions. The technique, based on precise measurement of time of flight of ultrasonic pulses, is metal-temperature independent what makes it able to be used in many industrial applications. It was also shown that the material in the vicinity of the final macro crack in the late creep stages leading to element failure also exhibit increased level of acoustic birefringence caused by presence of oriented voids.

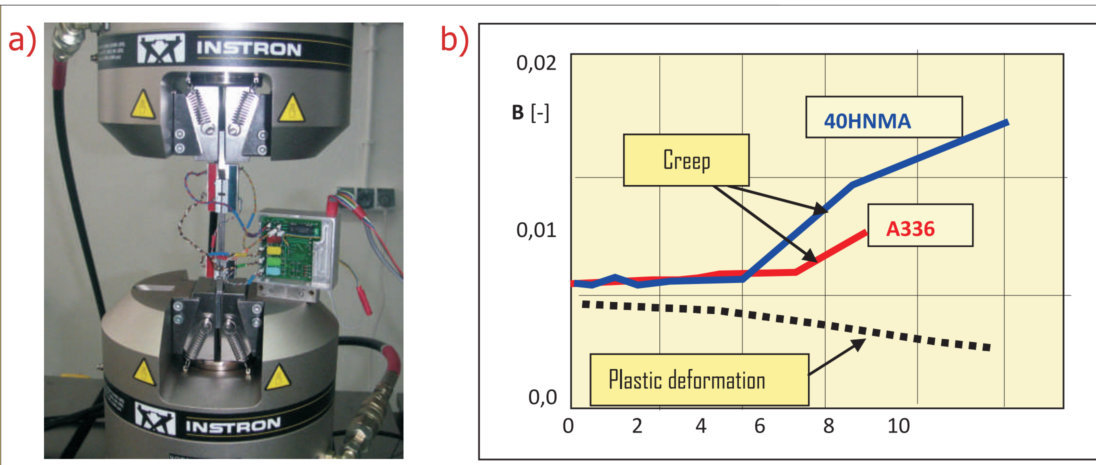


Fig.7.

a) Ultrasonic probes on a specimen during fatigue investigations.
b) Acoustic birefringence changes as result of creep and plastic deformation.

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MAJOR PROJECTS

1. Innovative cement based materials and concrete with high calcium fly ashes, (NCBiR). **2.** Passive protection of mobile objects (air and ground) from the impact of bullets AP (PANCERMET), (NCBiR). **3.** Development of a system for monitoring and analysis of the degree of damage to the materials in power plants due to operating loads, (NCBiR).

JOINT LABORATORY OF MULTIFUNCTIONAL MATERIALS

HEAD (IPPT):
Assoc. Prof. Paweł Ł. Sajkiewicz

Expert in the field of polymer physics, structure of polymers, biopolymers, scaffolds for tissue regeneration. He graduated from Faculty of Materials Science at Warsaw Technical University, Ph.D. and habilitation obtained at IPPT.

HEAD (WIM PW):
Assoc. Prof. Wojciech Święszkowski

Expert in the field of biomaterials, including biomaterial synthesis, cell-biomaterial interactions, smart biomaterials for tissue regeneration, drug delivery, advanced design, fabrication and fabrication of scaffolds.

SCIENTIFIC BOARD :

IPPT PAN:
Prof. Tomasz A. Kowalewski
Assoc. Prof. Jerzy Litniewski
Assoc. Prof. Paweł Ł. Sajkiewicz

WIM PW:
Prof. Krzysztof J. Kurzydłowski
Assoc. Prof. Wojciech Święszkowski
www.bio.materials.pl

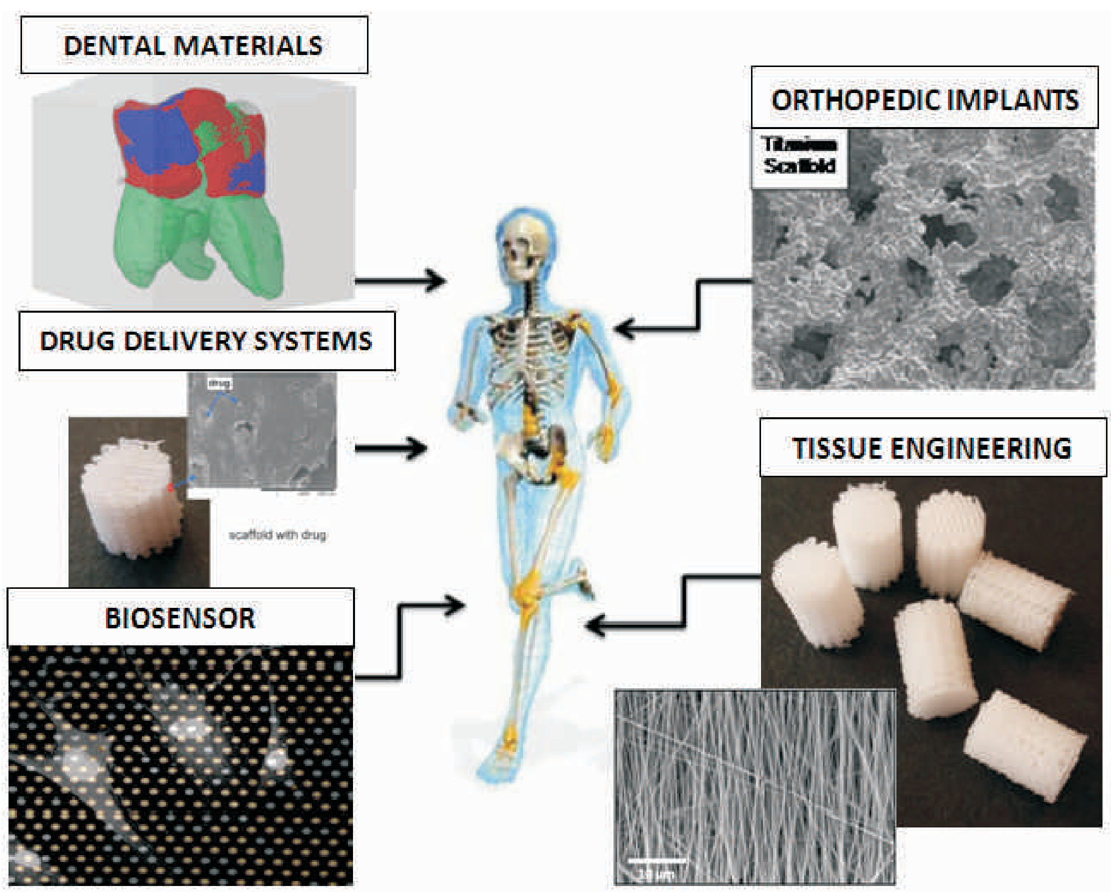
STAFF:

Monika Bil, Ph.D.
Bogdan Dąbrowski, Ph.D
Ida Dulińska-Molak, Ph.D.
Jakub Jaroszewicz, Ph.D.
Michał Wozniak, Ph.D.
Ewelina Zawadzak, Ph.D.
Magdalena Płocińska, Ph.D.

Joint Laboratory of Multifunctional Materials has been established at the Institute of Fundamental Technological Research in 2009. The basic research group of this laboratory is Biomaterials Group, Materials Design Division, Faculty of Materials Science and Engineering. The Joint Laboratory of Multifunctional Materials has been established in order to integrate human and equipment resources of the Warsaw University of Technology group with the whole structure of the IPPT PAN.

The Biomaterials Group is a research group focused on investigation and development of advanced materials for medical application. The main aim of the Biomaterials Group is to develop and initiate new technological solutions for biomaterials, implants, tissue engineering products and drug delivery systems for the purpose of treatment of human diseases as well as for improving health.

Especially, the research is concentrated on finding solutions for the cartilage and bone tissue repair and regeneration.



SELECTED RESEARCH ACTIVITIES

Particular strengths and interest of the group are in the following research topics:

- biomaterials and advanced scaffolds for the repair of articular cartilage and bone defects including advances in micro- and nanotechnology to design and process biomaterials (e.g., polymeric and metallic porous structure, biodegradable synthetic polymers as well as polymer-ceramic composites, nanofibers) that can guide, accelerate, and/or act as a temple for tissue regeneration and/or formation;
- biomaterials for artificial joints including development of new materials for implants (artificial cartilage hydrogels and nanotitanium, magnesium alloys), ceramic coatings (CaP and TiO2) and study on performance of orthopedic total joint replacement (e.g., hip, knee, elbow, and shoulder implants) through fundamental materials studies including materials testing and implant retrieval analysis;
- biomaterials for dental restoration including optimization of the microstructure of composites for restorative materials in stomatology with the aim to improve mechanical properties and reduce the contraction during polymerization by reinforcement of the composites with nanoparticles;
- drug delivery systems including development of nano-structure polymeric systems for drug delivery;
- computational modeling (e.g., using finite element methods) for biomaterials and implant-tissue systems including computation of stress concentration in non- homogenous materials and biological systems, and scaffold design and optimization.

Equipment:

1. High Resolution TEM Jeol JEM 3010
2. Field Emission Scanning Electron Microscope Hitachi High – Tech Launches SU800
3. X-Ray micro-CT SkyScan 1174
4. X-Ray nanotomograph SkyScan 2011
5. High Resolution Scanning Auger Micropobe Microlab 350
6. Fourier Transform Infra Red (FTIR) Spectrometer Nicolet 8700 from Thermo Electron Corporation
7. Atomic Force Microscope (AFM) Nanoscope Multimode III
8. Contact Angle Goniometer
9. DSC (Differential Scanning Calorimetry) DSC Q200 from TA Instruments
10. Thermo Gravimetric Analyzer (TGA) TGA Q5000 from TA Instruments
11. Dynamic Mechanical Analyzer DMA Q800 from TA Instruments
12. Gel-Permeation Chromatography (GPC)
13. Selective Laser Melting device ReaLizer SLM 50
14. Plotter 3D
15. Electrospinning setup Nanon-01A
16. Raman Microscope - Renishaw
17. Confocal Microscope – Leica TCS SP8
18. Phenom proX desktop scanning electron microscope
19. FLUOstar Omega – fluorymeter, luminometer, spectrometer

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MAJOR PROJECTS

1. Bio-implant - Development and preparation of tissue engineering products which will support regeneration and restoration of large bone tissue loss,(NCBiR). **2.** Polymer-ceramic composite, extracellular matrix mimicking biomaterials for tissue engineering needs: processes of degradation of the structure and mechanical properties, (National Fund). **3.** Three- dimensional composite scaffold based on biodegradable polymers and bioceramic with incorporated growth factors for bone tissue engineering. Research on the manufacturing process and the material influence on living cells function, (NCN). **4.** Hybrid growth factors delivery system supporting bone tissue regeneration, (NCN). **5.** A mathematical model of aliphatic polyesters degradation as an efficient tool for preclinical evaluation of biodegradable tissue engineering implants, (NCN).

SCIENTIFIC CENTERS

SCIENTIFIC CENTERS

In 2012 three scientific centers were established at IPPT to promote and consolidate forefront multidisciplinary research in biomedical and engineering areas.

CENTER FOR BIOMEDICAL RESEARCH (CBB), headed by Professor Tomasz Lipniacki - groups experimentalists and theoreticians, conducting work in systems biology and bioengineering. The Center aims to fill the gap between physics, math and chemistry on one side and biology and medicine on the other. The group includes researchers from various backgrounds, including mathematicians, computer scientists, physicists, chemists and biologists. The main research focus areas are:

- Cell signaling including immune responses, calcium signaling, kinase pathways, DNA damage responses and neuronal signaling. These studies combine experimental techniques based on live single- cell imaging, using confocal microscopy, as well as classical population studies with mathematical and numerical modeling involving ordinary and partial differential equations and stochastic processes.

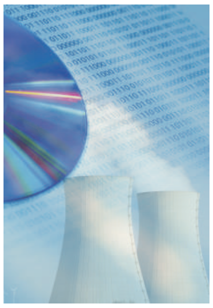
- Investigations of material structures, in particular polymers, with a perspective of application in tissue engineering as scaffolds for tissue regeneration. The main focus is on biomedical engineering and biotechnology and it is related to synthetic bioresorbable polymers and biopolymers – the methods of formation of scaffolds (e.g., electrospinning of nanofibers), investigations of their structure and properties as well as invitro studies of biological functionality of scaffolds.

- Analysis of micro- and nano-particles in viscous fluids, simulations of biochemical processes in membranes, analysis of dynamical properties of biomacromolecules including DNA proteins. The experimental techniques involve atomic force microscopy and total internal reflection fluorescent microsopy. Development of numerical techniques based on multipole approach (for nanoparticles in Stokes flow), molecular dynamic simulation, and the kinetic Monte Carlo method.

- Development of high resolution ultrasonic techniques for tissue and cells diagnostic, therapy and visualization. Live single- cell imaging using acoustic microscopy.

CENTER OF EXCELLENCE AND INNOVATION OF COMPOSITE MATERIALS (CDIMK) headed by Professor Michał Basista has been created to exploit and further develop the knowledge and experience accumulated at IPPT in the field of advanced multicomponent materials due to the participation in a number of European and national projects such as AMAS, KMM-NoE , MATRANS and KomCerMet .

The underlying idea of the Center was to gather a group of researchers with complementary expertise necessary to conduct an integrated research on composite materials comprising processing technologies, characterization of microstructure and properties, and modeling of materials at a design phase and under service conditions. It is a horizontal component in the IPPT organogram comprising three research groups: Advanced Composite Materials, Laser Technological Applications and Mechanics of Inelastic Materials. The primary focus of the Center is on metal-ceramic bulk composites with metal or ceramic matrices, functionally graded composites (FGM) and composite coatings. The Center carries out fundamental and applied research on structural and functional materials from these materials classes. Its strategic research directions and specific research topics are inspired by the R&D needs of the national and European industry mainly from automotive, aerospace, energy and electronics sectors.



SMART TECHNOLOGY CENTER headed by Professor Jan Holnicki-Szulc has been created at the Division of Safety Engineering and it is devoted to new technologies in safety engineering, applicable for sector of energy production. This new field of activities creating various innovative concepts fits well with strategic plans of the Institute, leading to opening of a new laboratory under construction (PAN Research Center for Renewable Energy, located in Jablonna near Warsaw). Examples of the major research challenges can be listed as:

- designing protective systems (against transport collisions and environmental impacts) for off-shore installations of wind turbines and oil platforms,
- telemonitoring (and control) of technical conditions for energy transporting grid installations (including so-called "smart grid" problems),
- monitoring (and control) systems for thermal stress development during maturing and exploitation stage for massive concrete installations (e.g., dams or nuclear plant fenders),
- other SHM (structural health monitoring) and AIA (adaptive impact absorption) systems.

HEAD: Assoc. Prof.
Tomasz Szolc

DOCTORAL STUDY

IPPT Doctoral Study plays an important role as the third level education utilizing the potential of highly qualified academic staff. We invite graduates with a strong motivation for scientific work, determined to sacrifice a few years to realize their ambitious research plans.

IPPT as one of the largest technical institutes of Polish Academy of Sciences offers a wide range of research profiles in the fields of basic science, technique and technology. IPPT is a member of the Biocentrum Ochota Consortium. It creates new opportunities related to the synergy of technology, experimental medicine and biology using the potential of research institutes located at the Campus Ochota.

Doctoral education at the Institute is largely based on the student's personal research project, which is complemented with courses and clearly specified knowledge requirements. Studies must be concluded in four years and the Ph.D. is awarded on the submission of a thesis subject to its passing a public defence.

We offer modern research equipment and cooperation with renowned research institutions both at home and abroad. Outstanding doctoral candidates we offer internships abroad and participation in European projects conducted by the Institute. Doctoral students receive attractive fellowships and may attend free of charge language courses at different levels.

Local association of Ph.D. students helps to assimilate newcomers and to integrate with Ph.D. students of the Biocentrum Ochota.

ABOUT PH.D. STUDENTS' COUNCIL AT IPPT PAN

At the beginning of March 2010 the first Ph.D. Students' Council of the Institute of Fundamental Technological Research, Polish Academy of Sciences came into existence. It represents the interests of Ph.D. students both within and outside of the Institute. Ph.D. Students' Council represents the rights of students, as well as organizes and directs campaigns and activities to defend and promote students' rights, and improve the students' general welfare. The Council also participates in conferences and annual meetings of Polish Ph.D. students during which, matters concerning the Ph. D. students' status and opportunities of future career paths are discussed.

On the Ph.D. Students' Council website: http://samdok.ippt.pan.pl/ the members of Council inform about the activities and important events of Ph.D. students' life at IPPT PAN.

PROMOTION OF SCIENCE

The most important goal of the Ph.D. Students' Council mission is to promote knowledge of the Institute both for/to the scientific community, as well as for those people, who are not part of scientific community. We actively participate in projects and activities that are aimed at popularizing science and promoting scientific research. Our every day work contributes to interdisciplinary intergation of Ph.D. students. We have also organized and co-organized many popular science and intergation evens, such as:

- The Science Picnic of Polish Radio and the Copernicus Science Centre, which is the biggest open-air/outdoor scientific meeting in Europe. Inside the exhibition tents and on stage you could watch over a thousand shows, most of them were related to the theme of the current Picnic.

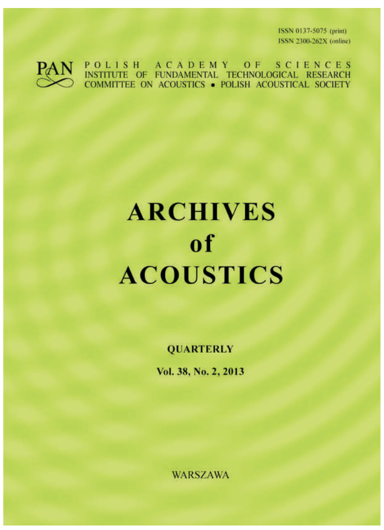

- Each year IPPT participates in Science Festival.


- The BioCentrum Ochota Ph.D. Carnival, which is annually organized in cooperation with other Ph.D. Students' Council at BioCentrum.


PUBLISHING OFFICE

Publishing Office of IPPT PAN provides provisional editorial and publishing services that are responsive to the needs of the Institute. Currently five international journals and four book series are regularly appearing under copyright mark of IPPT PAN. In addition our Publishing Office supports needs of scholars to publish lecture notes, monographs, and proceedings of activities organized by the Institute.

ARCHIVES OF ACOUSTICS



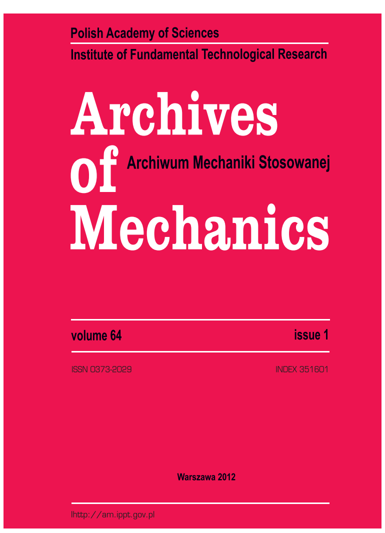
"Archives of Acoustics" – (http://acoustics.ippt.pan.pl/) is peer-reviewed quarterly journal publishing original research papers from all areas of acoustics and abstracts from some specialised acoustical conferences. It gives free internet access to its full content for years 2000-2011 and limited access (abstracts of research papers) to current issues (2012) and to earlier volumes starting from 1991.

Indexed and abstracted (from vol. 32(1) 2007) in Science Citation Index Expanded (SciSearch) and Journal Citation Reports.

Impact Factor 2012: 0.829.

Editor-in-chief: prof. Andrzej Nowicki

ARCHIVES OF MECHANICS



"Archives of Mechanics" – (http://am.ippt.pan.pl/) is a refereed international journal founded in 1949. The journal provides a forum for original research on mechanics of solids, fluids and discrete systems, including the development of mathematical methods for solving mechanical problems. Archives of Mechanics is abstracted/indexed in:

Science Citation Index Expanded (SciSearch, Thomson ISI, Philadelphia), ISI Alerting Services, Current Contents/Engineering, Computing and Technology, Materials Science Citation Index, EBSCO Academic Search Complete, Applied Mechanics Reviews, Current Mathematical Publications, Mathematical Reviews, MathSci, Zentralblatt fur Mathematik, UnCover, Inspec.

Impact Factor 2012: 0.566
Editor-in-chief: prof. Henryk Petryk

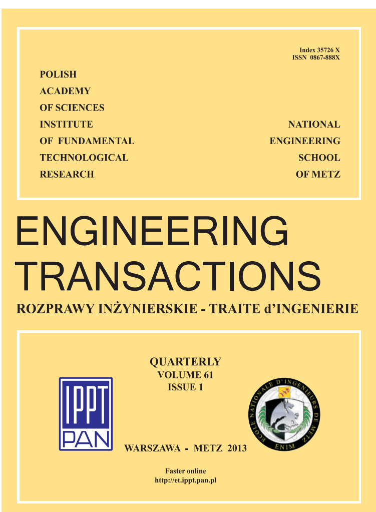
ARCHIVES OF MECHANICS

"Computer Assisted Methods in Engineering and Sciences" (CAMES- http://cames.ippt.pan.pl/) – former title (up to 2011) Computer Assisted Mechanics and Engineering Sciences – is a refereed international journal, published quarterly, providing a scientific exchange forum and an authoritative source of information in the field of broadly understood computational engineering and applied sciences. The objective of the journal is to support researchers and practitioners by offering them access to newest research results reported by leading experts in the field, publication of own contributions and dissemination of information relevant to the scope of the journal. CAMES is published under the auspices of European Community on Computational Methods in Applied Sciences (ECCOMAS).

Editor-in-chief: prof. Michał Kleiber

Co-editor-in-chief: prof. Tadeusz Burczyński

ENGINEERING TRANSACTIONS



"Engineering Transactions" (http://et.ippt.pan.pl/) – formerly "Rozprawy Inżynierskie" – is a refereed international journal founded in 1952. Since 2011 the journal is published in cooperation with the National Engineering School of Metz (Ecole Nationale d'Ingénieurs de Metz – ENIM). The journal provides a forum for interdisciplinary publications combining mechanics with material science, electronics, medical science and biotechnologies, environmental science, photonics, information technologies and other engineering applications.

Engineering Transactions is abstracted/indexed in: Applied Mechanics Reviews, Current Mathematical Publications, Inspec, Mathematical Reviews, MathSci, Scopus, Zentralblatt für Mathematik.

Editor-in-chief: prof. Ryszard Pęcherski (IPPT PAN)

Co-editor-in-chief: prof. Alexis Rusinek (ENIM)

IPPT REPORTS ON FUNDAMENTAL TECHNOLOGICAL RESEARCH

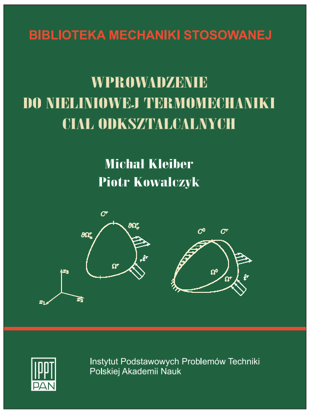
The journal "IPPT Reports on Fundamental Technological Research" (IPPT Reports on FTR, http://reports.ippt.pan.pl) is the international open-access publishing medium for high quality research focused on fundamental aspects of applied science and engineering. (Former title: "Prace IPPT. IFTR Reports"). The scope of the journal includes – among others – theoretical, experimental and computational research in mechanics and materials science, acoustics and electronics, fluid and molecular physics, photonics and plasmonics, physics of nanostructures, crystals and polymers, ultrasonic medical diagnostics, interdisciplinary physics in biology and medicine, informatics and applied mathematics, as well as development of advanced numerical methods within a broad range of science and engineering.

Editor-in-chief: prof. Wojciech Nasalski

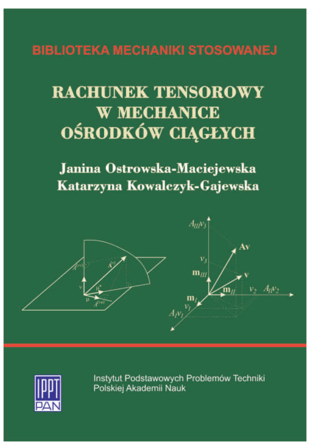
In addition to journals the Editorial Office of IPPT PAN publishes (in Polish and in English) four book series:

- **Library of Applied Mechanics** (Biblioteka Mechaniki Stosowanej)

Editor of serie: prof. Zenon Mróz
Last published:



Michał Kleiber, Piotr Kowalczyk – Wprowadzenie do nieliniowej termomechaniki ciał odkształcalnych (Introduction to Nonlinear Thermomechannics of Deformable Solids – in Polish), Warszawa 2011.

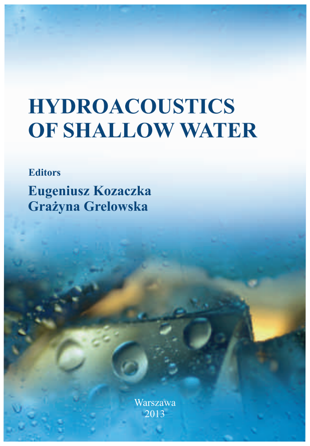


Janina Ostrowska-Maciejewska, Katarzyna Kowalczyk-Gajewska – Rachunek tensorowy w mechanice ośrodków ciągłych (Tensor calculus in continuum mechanics – in Polish), Warszawa 2013.

- **Library of Acoustics and Ultrasounds** (Biblioteka Akustyki i Ultradźwięków)

Editor of serie: prof. Andrzej Nowicki
Last published:

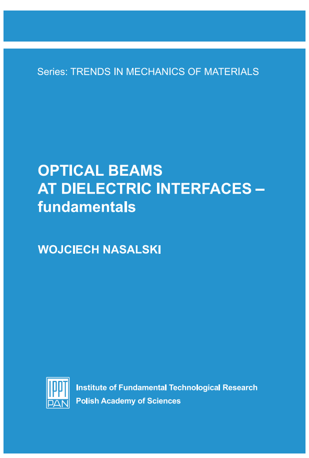
Andrzej Nowicki – Ultradźwięki w medycynie – wprowadzenie do współczesnej ultrasonografii (Ultrasounds in medicine – introduction to modern ultrasonography – in Polish), Warszawa 2010.



Eugeniusz Kozaczka, Grażyna Grelowska (Editors) – Hydroacoustics of shallow water, Warszawa 2013.

- **Trends in Mechanics of Materials** (Trendy w Mechanice Materiałów)

Editor of serie: prof. Zenon Mróz
Last published:



Wojciech Nasalski – Optical beams at dielectric interfaces – fundamentals, Warszawa 2007.

- **Technological Mechanics** (Mechanika Techniczna)

Editor of serie: prof. Witold Gutkowski
Last published:

Romuald Będziński (Editor) – Biomechanics (Biomechanika – in Polish), Warszawa 2011.

LIBRARY MISSION

The library was established in 1953 as a department attached to the Institute. Since than the library creates a dynamic environment for learning and discovery.

It is one of the largest Bio-Info-Tech Sciences libraries in Poland with publications of Polish mechanics and acoustics founders within its collections. The library stock is over 83 000 bound volumes (books, journals and manuscripts) and 300 titles of current periodicals, mostly foreign.

The library is expending both its paper and electronic collections in many disciplines of bio-technological sciences: acoustics, acoustical methods in medicine, nanotechnology, nanomaterials, nonlinear mechanics, mathematical and physical foundations of the theory of solid media and materials, mechanics of solids and fluids, analytical mechanics, statistical physics, finite element method, optimization, reliability, adaptive structures, quantum mechanics, strength, fatigue and fracture of materials, physics of plasma, biomedicine, biophysics, biomechanics, biomathematics, bioengineering, theory and mechanics of structures, rheology, theory of mechanical systems, civil engineering, ecology in civil engineering, electrodynamics of continua, theory of electromagnetic waves, physics of polimers, materials engineering, automatics and robotics, informatics, nondestructive testing of materials and structures, physical acoustics, aeroacoustics, acoustoelectronics, vibrations and noise, noise control, acoustics of speech and music, psychoacoustics, acoustics of environment, acoustics in urbanistic and civil engineering, hydroacoustics, quantum acoustics, nonlinear acoustics, acoustic emission, ultrasounds in biology, medicine and industry, acoustic experimental equipments.

The IPPT PAN library is continuously gathering resources of library collections and simultaneously recording the current purchases and donations (including the cases of interchanging between libraries) for the library collections, the recording process consists in giving merits shape to each new component of the collections. The Scientific Committee is responsible for purchasing decisions on books and serials.

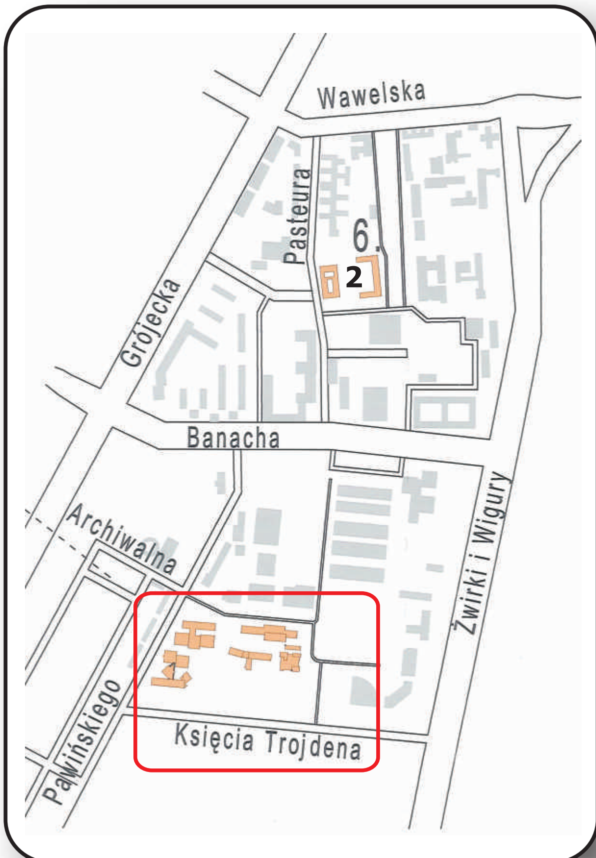
The library belongs to the Polish research libraries resource-sharing networks for providing computerized systems to acquire materials from institutions throughout the world. The library is a member of the Consortium of the Scientific Libraries of the Polish Academy of Science for developing the union catalogue of the libraries (making a system base of data supported by automatic integrated library system Horizon). The IPPT PAN library participates also in the Project for developing the Polish Academy of Sciences Digital Library. Activity of the library includes also interchanging of the IPPT PAN publications between the host institute and 60 scientific organizations and institutions both native and foreign.

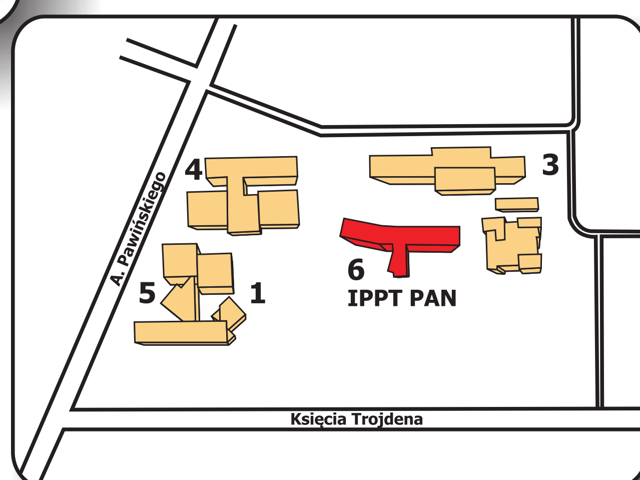
THE LIBRARY SERVICE

- The library makes available library print and electronic collections within the library rooms and over the Internet.
- The library supports the research needs of the IPPT PAN employees by obtaining print and electronic documents which are not available at IPPT PAN library.
- The library provides computers for their users. Research access is available to all visitors and includes use of catalogs, article database and licensed library resources.
- The library guests can use both black/white and color printing or scanning service.

BIOCENTRUM OCHOTA

(www.biocentrumochota.pan.pl)





1. International Institute of Molecular and Cell Biology in Warsaw
2. Nencki Institute of Experimental Biology, Polish Academy of Sciences
3. Mossakowski Medical Research Centre, Polish Academy of Sciences
4. Institute of Biochemistry and Biophysics, Polish Academy of Sciences
5. Nałęcz Institute of Biocybernetics and Biomedical Engineering, Polish Academy of Sciences
6. **Institute of Fundamental Technological Research, Polish Academy of Sciences**

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