INSTITUTE OF THERMOMECHANICS

Czech Academy of Sciences

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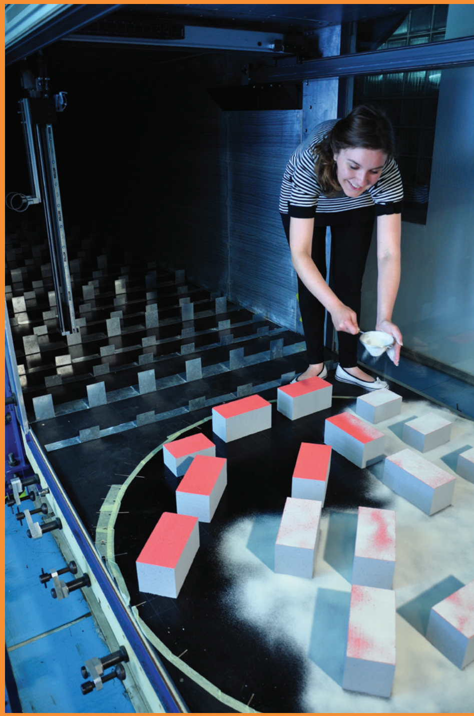
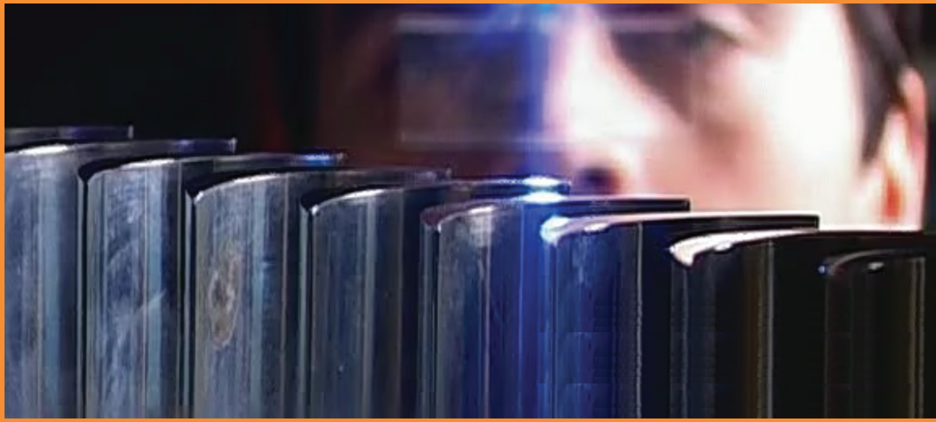




INSTITUTE of THERMOMECHANICS of the CAS

The Institute of Thermomechanics of the Czech Academy of Sciences is a public research institution focusing on basic and interdisciplinary research in applied physics, with several branches across the country. The Institute cooperates intensively with domestic and foreign research institutions and universities of technology and natural sciences. Our staff includes many young researchers, primarily doctoral and postdoctoral students, to whom we provide opportunities for professional development in our research programs. Although the Institute is focused primarily on basic research, it maintains extensive collaboration with large industrial companies as well as dynamic and technology-oriented SMBs.

The history of the Institute reaches back to 1953 when the then-Czechoslovak Academy of Sciences formed the Laboratory of Mechanical Engineering in Prague, the nucleus of the current Institute of Thermomechanics. Its early research was focused on technical sciences and their applications in mechanical and power engineering industries. These two core specialisations have been central to our research up to the present day, though over the course of time the Institute's research scope has extended to new and perspective fields such as biomechanics, environmental engineering, mechatronics and electrical engineering. As a result, the Institute has acquired a largely interdisciplinary character.

Our researchers are members and chairs of international scientific organisations and they supervise doctoral students and educate high-school talents. The Institute is the seat of several scientific societies: Czech Society for Mechanics, Czech Society for the Properties of Water and Steam, Czech National Committee of IFToMM and Czech Pilot Centre of ERCOFTAC.

Do you want to collaborate or partner with us? Are you interested in our research? Would you like to visit the scientific conferences and seminars regularly organized by our Institute? Are you a student looking for a thesis topic or a research opportunity? For more information, please join us on Facebook or YouTube where you will find all you will need and more. We encourage you to visit us to discuss how our knowledge and research can help your business. We never forget the general public – our selected laboratories in Prague, Pilsen and Nový Knín are open to everyone during the annual Open Days held every autumn.

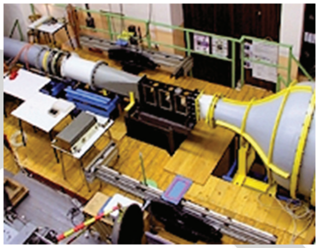
FLUIDS AND THERMAL SCIENCES RESEARCH

HIGH-SPEED AERODYNAMICS

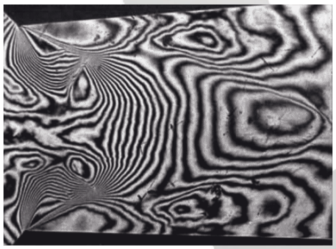
The experimental research of high-speed flows in steam and gas turbines, compressors, ejectors and steam valves has more than 60 years of tradition in the Institute of Thermomechanics. Internal gas flows in models of flow machinery are studied in the wind tunnels in Nový Knín near Prague using the Mach-Zehnder interferometer and other optical and pneumatic methods.

Our key partner in aerodynamic research is Doosan Škoda Power. This collaboration began in the 1970s, when ŠKODA Pilsen concern signed a contract for long-term cooperation with the Institute of Thermomechanics. In the 1980s, our scientists and their colleagues from Škoda were awarded a medal at the International Engineering Fair in Brno for the design of a 240-MW turbine for nuclear power plants. In recent years, we have been collaborating with Doosan Heavy Industries, a South Korean manufacturer of compressors.

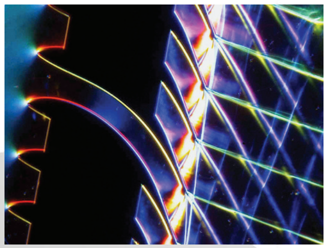
Today our laboratories are equipped with several wind tunnels suited for different applications. The research continues in its rich tradition and focuses on modern power engineering applications as well as core research topics



Modular wind tunnel in the Aerodynamic Laboratory in Nový Knín.



Interferogram of air flow in a control valve, the fringes correspond to regions of the same density.

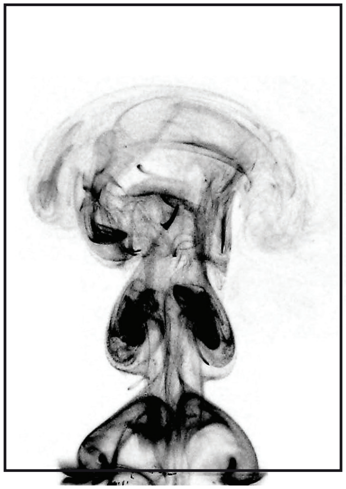


Colour schlieren image of the flow in the blade cascade of the last stage of a large steam turbine. The flow velocity in the right part is 1.9 times higher than the speed of sound.

HEAT AND MASS TRANSFER

Our research of heat and mass transfer in gases and liquids is focused on the passive and active control of flow and thermal fields. Using an experimental approach we strive to discover new ways to intensify the transport of heat and mass during forced convection in wakes and impinging and synthetic jets.

The results are useful in fluidics/microfluidics, the cooling of electronic components or gas turbine blades, improving the efficiency of mixing in chemical reactors or in external and internal aerodynamics.



Smoke visualization of a synthetic jet.

Coherent vortex lines in the shear layer and their breakdown, smoke visualization of submerged air jet.

Wake flow behind a cooled circular cylinder (Von Kármán vortex street).

NON-EQUILIBRIUM MULTIPHASE SYSTEMS

Changes of states of matter (or, more accurately, phase transitions) in nature and in engineering applications occur at a finite rate and under conditions that are more or less distant from the thermodynamic equilibrium (for example from the equilibrium boiling point). The non-equilibrium phase transitions include the formation (nucleation) of droplets in steam turbines and in the atmosphere, the nucleation of ice inside the droplets,the deposition of ice on the leading the deposition of ice on the leading edges of airplane wings or the formation of cavitation bubbles in pumps and liquid turbines. Our research is focused on the measurement and modelling of these non-equilibrium phase transitions, on studying the properties of metastable liquids (e.g. supercooled liquid or supersaturated vapour) prior to the phase transition and on the characterisation of multiphase systems in sprays, aerosols and bubbles.

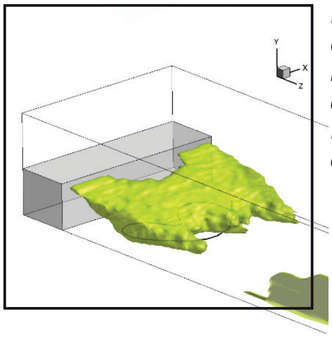
MEASUREMENT OF THERMOPHYSICAL PROPERTIES OF LIQUIDS

Density, thermal conductivity, viscosity, surface tension and other thermophysical properties of liquids serve as the input parameters for the design of power engineering and chemical devices and for the modelling of geophysical and biological processes. We carry out very precise measurements of thermophysical properties of liquids and use the obtained experimental data and the laws of physics to develop mathematical models of the properties. We measure relations between pressure, volume and temperature for environmentally friendly refrigerants and new ionic liquids using the constant-volume method and a vibrating tube. Tensiometric methods and the method of capillary elevation help us to determine the surface tension of the substances.

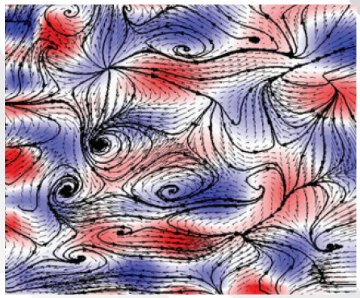
A significant part of our research of multiphase systems and the thermophysical properties of liquids is motivated by the priorities of the International Association for the Properties of Water and Steam (IAPWS), whose national committee is headquartered from the Institute of Thermomechanics.

TURBULENT FLOWS

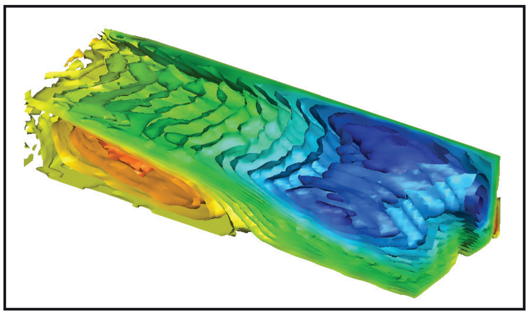
Despite the recent advances in experimental and computational techniques the fundamentals of turbulent flows continue to puzzle scientists, being arguably the last unsolved problem of classical physics. We concentrate on the experimental and numerical modelling of turbulent flows and the transition to turbulence in 3D geometries, measuring the velocity fields and turbulent flow characteristics and studying fluid-solid interactions. Our results are applied in the aerodynamic optimisation of flow past bodies (e.g. aircraft or automobiles) or flow machinery (turbines and compressors).



Isosurfaces of the vertical component of the time-averaged mean velocity downstream of a step in a narrow channel. Kidney-shaped impact object at the channel bottom.



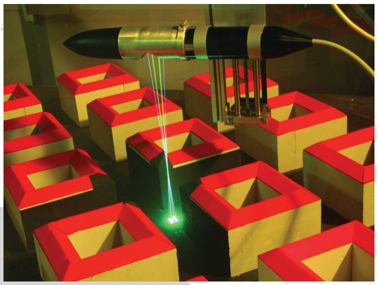
Turbulent flow of air in a rectangular-cross-section channel. Energy dynamic mode characterizing velocity field fluctuations.



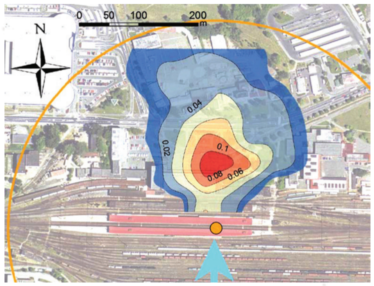
Channel flow; the isosurfaces of the component of the time-averaged mean velocity normal to the channel bottom characterize the space topology of the flow field.

ENVIRONMENTAL AERODYNAMICS

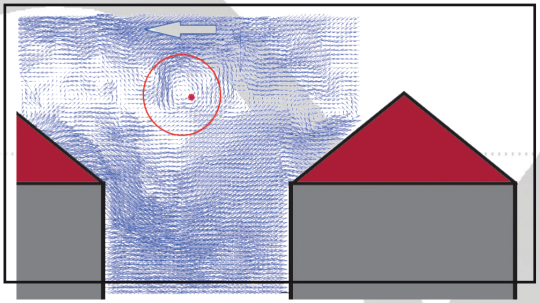
The atmospheric dispersion of emissions and dangerous substances from local and area sources or road traffic or during chemical accidents or terrorist attacks affects a society's health, safety and quality of life. Simulating atmospheric pollution and studying the interaction between urban areas and atmospheric flow helps us to improve our environment and brings benefits to all of us. The results of our studies have been used to build more accurate city evacuation plans in, for example, Prague and Pardubice. We use the physical and mathematical modelling of flow and diffusion in the atmospheric boundary layer, various flow visualization techniques and measurements of flow velocities in a specialized wind tunnel in the Aerodynamic laboratory in Nový Knín.



Detection of turbulence in a model of an urban area using LDA (Laser-Doppler Anemometry).



Simulation of chlorine dispersion over Pardubice train station, concentration 10 m above ground level.

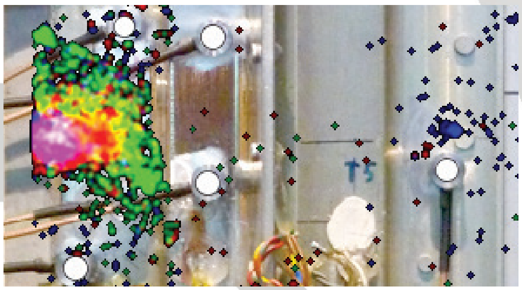


Particle Image Velocimetry (PIV) analysis of turbulent flow within street canyon in atmospheric boundary layer.

RESEARCH OF SOLIDS AND MECHANICAL SYSTEMS

DIAGNOSTICS OF MATERIALS AND STRUCTURES

The reliability and safety of aircraft, nuclear power plants, chemical plants, civil structures, pipelines, storage tanks and certain machines require the periodic health monitoring. Our methods of nondestructive testing (NDT) and evaluation of defects are based on the propagation of elastic waves in solids. We use advanced signal analysis (e.g. time reversal mirrors) and data processing (e.g. artificial neural networks). With the use of acoustic emission and nonlinear ultrasonic spectroscopy and other methods we are able to localize material defects, evaluate the damage caused by the loading, fatigue, corrosion or wear of structural parts and predict their lifetime. The methods can be used to predict building failures and detect leakages of gases and liquids from pressurized vessels and tubes. Ultrasonic methods can be used in medical diagnostics of the properties of human skin and their changes due to mechanical loading or UV radiation. We have developed a special probe that will allow surgeons to instantly measure the main directions of stress in a particular skin tissue and therefore the most appropriate direction of the incision.



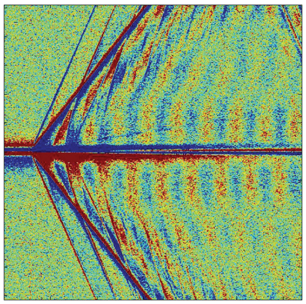
Acoustic emission sources and zones with cracks detected by nonlinear ultrasonic spectroscopy with time reversal mirrors during the fatigue test of an aircraft wing flange.

We also conduct measurements of changes during the thermal aging of materials after their cyclic thermal loading (e.g. the aging of the polymer insulation of electric cables) or nanoindentation measurements of changes in hardness and the ratio of elastic and plastic deformations of materials. We can also evaluate gradual changes of mechanical properties and the behaviour of materials under low-cycle and high-cycle fatigue loading with combined tension and compression or even torsion.

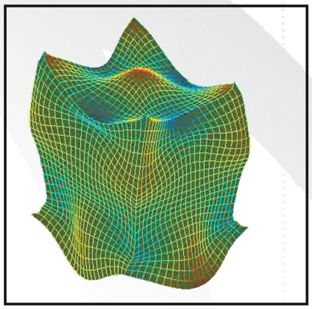
ELASTIC AND THERMOMECHANIC PROPERTIES OF MATERIALS AND THIN LAYERS

Studying elastic and thermomechanic properties of solids and thin layers helps us to better understand modern functional materials such as ferromagnetic and ferroelectric materials, fibre composites, ceramics, shape-memory alloys and thermal spray coatings. To measure the elastic properties of materials we use Resonance Ultrasound Spectroscopy (RUS), which was developed in our laboratories. Using other methods, including laser ultrasound methods, the ultrasonic pulse-echo method, scanning acoustic microscopy and the surface acoustic wave method, we measure and characterize the elastic properties of materials, we measure the plane elasticity of thin coatings and surface layers (such as plasma coatings), the elastic anisotropy of extremely fine-grained materials and the mechanical properties and temperature changes in solids in-situ during their loading and we characterize phase transitions in solids.

We analyse relations between microstructure and macroscopic properties and model thermomechanic properties of materials.



Propagation of elastic wave in silicon wafer over time .

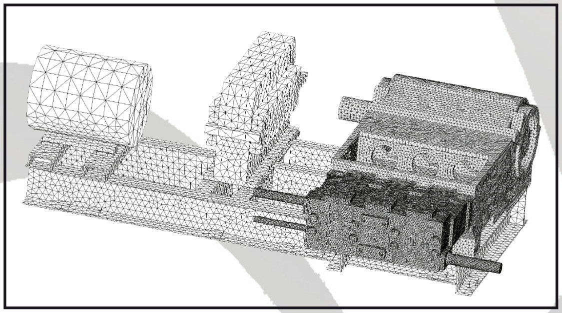


Eigenmode of 3D vibration of prismatic body (measurement by RUS)

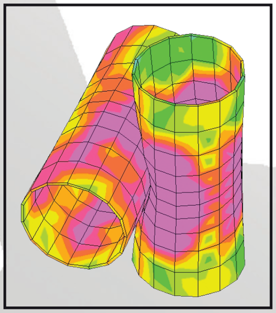
COMPUTATIONAL MECHANICS OF SOLIDS AND MECHANICAL SYSTEMS

In our institute we develop, implement and test numerical and analytical methods for continuum mechanics. Our main interest lies in linear and non-linear static and dynamic problems, stress wave propagation, problems of the contact and impact of deformable bodies and the development and implementation of constitutive equations for solids. We also develop an in-house computational system PMD (Package for Machine Design) based on the Finite Element Method (FEM), which has received the certificate of the State Office for Nuclear Safety. Our in-house system is used to solve industrial problems in various engineering fields.

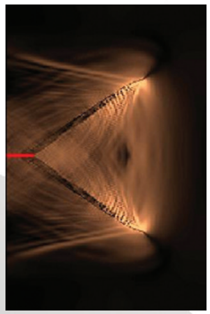
We put a vast effort into studying material defects, crack-growth mechanisms and crack propagation in crystalline materials using molecular dynamic (MD) simulations and multi-scale methods. We also collaborate on the calculation of electron structures and total energies of non-periodic systems using FEM and pseudopotential methods.



Example of FEM-based mesh for the mechanical analysis of a complex structure.



Snapshot of a stress state of two thin-walled tubes at impact.



Molecular dynamics simulation of transonic propagation of crystal defect in the BCC phase of iron with shock waves.

VIBRODIAGNOSTICS AND ROTOR DYNAMICS

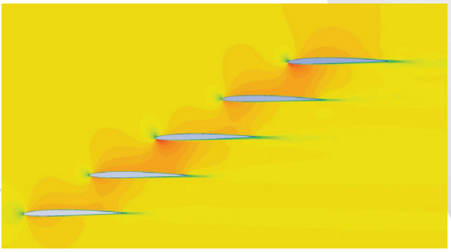
The contactless analysis of the vibrations, state and potential damage of complex mechanical systems during operations enables the advanced planning of maintenance shutdowns. The system developed in our Institute measures the motion, vibrations and loading of rotating mechanical parts (such as turbine and compressor blades). The system is installed in several power stations in the Czech Republic, where it has helped to achieve significant savings in maintenance.

The vibrodiagnostics of rotating machines and vibroacoustics also help to study the vibrations of railway wheels, bearings, shafts, brakes, rolling mills, crushers and other machines. These techniques have a broad application – e.g. they can help to suppress the noise generated by railway or tramway traffic, which has an adverse effect on the quality of life and the environment. We are helping one of the largest manufacturers of railway wheels in Europe to develop technology for the optimum damping of railway wheels. We also measure the dynamic characteristics of rubber materials and develop models of vibrations and interactions of non-linear dynamic systems.

Laboratory of Rotational Laser Vibrometry with a test blade wheel.

FLUID-STRUCTURE INTERACTION AND AEROELASTICITY

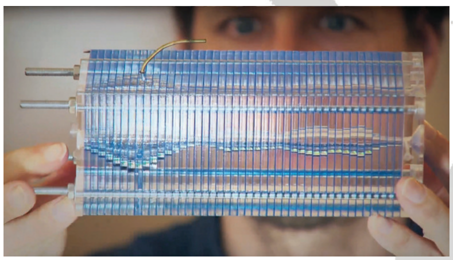
We study the aeroelastic behaviour of bladed disks in power turbines and axial flow compressors including aeroelastic stability in 2D and 3D and blade flutter. For this purpose we use state-of-the-art experimental facilities and instrumentation and develop efficient reduced-order numerical models designed to significantly shorten the simulations of fluid-structure interaction (FSI) in turbomachinery, thus speeding up the blade design.



Flow past blade cascade.

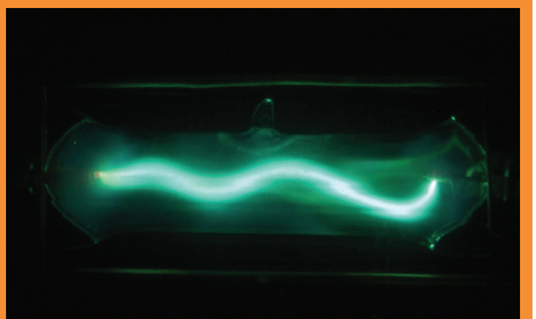
BIOMECHANICS OF HUMAN VOICE

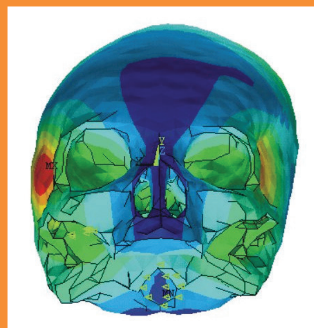
We improve the computational and physical models of human voice production to aid the development of a vocal-fold prosthesis for patients with serious voice disorders. In 2016, as part of a joint project of four institutions, our research received the Prize of the President of the Czech Science Foundation.

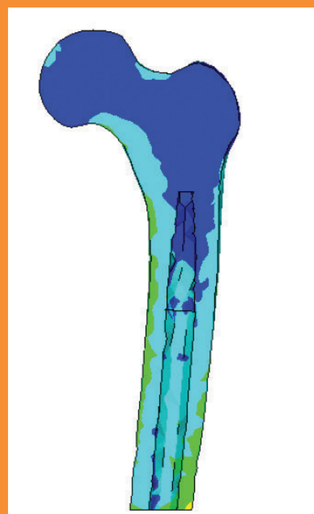


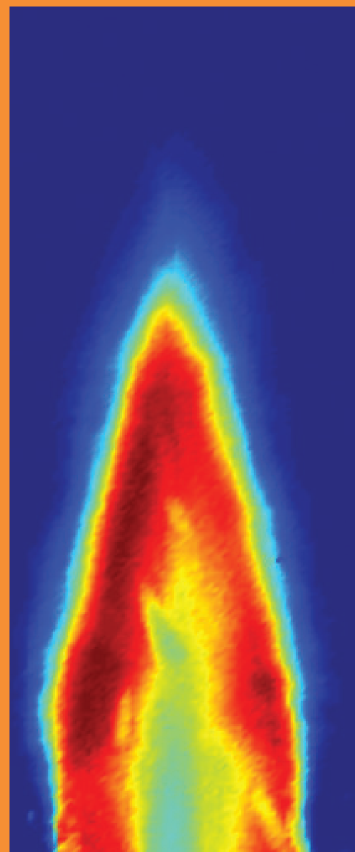
Simplified model of the vocal tract.

ELECTRICAL ENGINEERING AND INTERDISCPLINARY RESEARCH



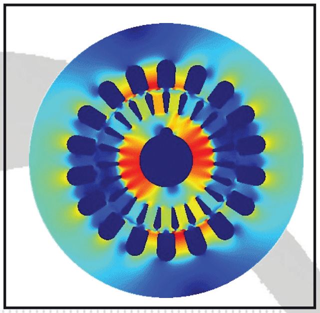






ELECTRIC DRIVES AND POWER ELECTRONICS

The current challenges of power engineering, such as power quality and the stability of the power grid with a large ratio of renewable energy sources, place new demands on electrical engineering research. In our laboratories we focus on the research of electric drives, electric rotating machines and power electronics and on other electromechanical conversions. The results of our research can be applied, for example, in the design of electric generators for wind and hydro power plants. We study the circuit structure of solid-state power converters and the mutual interaction of power inverters, machines and the power grid and develop advanced control and diagnostic algorithms for inverters. In collaboration with Elektrotechnika a.s. (formerly ČKD Elektrotechnika) we are developing AC drives fed from multi-level, high-voltage inverters for demanding industrial applications. The design of a power inverter for a new-generation drive for mining equipment, developed as a joint effort of ČKD Elektrotechnika and our Institute, was awarded the GOLDEN AMPER award at the 2011 and 2015 AMPER international trade fairs. We are a competence centre of the European Centre for Power Electronics.



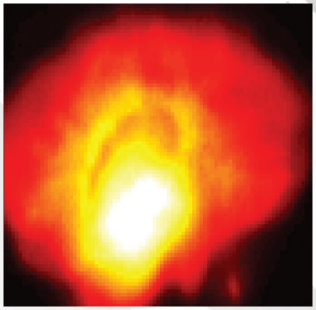
Numerical model of a magnetic field in an induction machine.

ELECTROPHYSICS

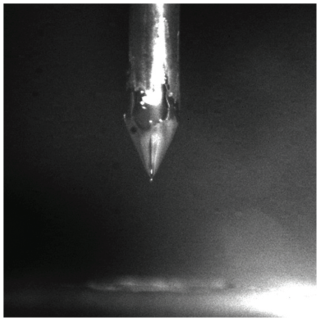
Complex phenomena in electrical engineering require insight into other fields such as electrophysics or electrical power engineering. We use experimental techniques to study dynamic phenomena in electric arcs and thermal plasma jets, which are used in plasma coating, metal cutting and waste disposal technologies.

We are developing new drop-on-demand methods of electrostatic generation and motion control of droplets of reactive and high-melting metals for application in additive manufacturing (3D metal printing).

3D tomographical reconstruction of turbulent thermal plasma jet.



Microphotography of molten hafnium pool at cathode tip of plasmatron cutter. Different colours denote different temperatures of the molten hafnium.

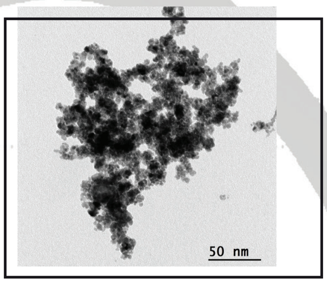


Electrostatic forming of metal droplet.

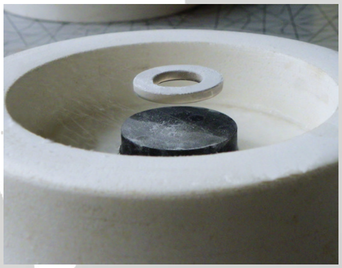
NEW TECHNOLOGIES FOR EFFICIENT ENERGY CONVERSION AND STORAGE

Since 2015, the Institute of Thermomechanics of the Czech Academy of Sciences has been coordinating the "Efficient Energy Conversion and Storage" research programme of the Strategy AV21 initiative of the Czech Academy of Sciences. In the programme, about ten research institutes of the Czech Academy of Sciences and their partners from academia focus on promising topics applicable in the energy sector. The Institute is developing a new method of *direct conversion of kinetic energy of thermal plasma to electricity* without moving parts and a method of producing *nanomaterials for the more efficient and cheaper conversion of hydrogen chemical energy into electricity* in fuel cells. One of the options for storing and releasing electricity is to use *high-speed flywheels.* Our levitating flywheel utilizing the interaction of permanent and high-temperature superconducting magnets presents a modern technical implementation of these devices.

To reduce primary energy consumption and compensate for fluctuating power consumption and production, thermal energy storage can be used - low-temperature storage for short or seasonal storage of heat or cold (especially for residential purposes) or high-temperature storage for batch processes and concentrated solar power plants. We study the properties of materials and systems achieving high energy storage density.



Platinum nanoparticles under electron microscope.



Model of a flywheel-superconducting bearing.

Magnetocumulative implosive plasma generator for direct conversion of plasma kinetic energy to electricity