Vibrations suppression and energy harvesting of nonlinear oscillators: novel ideas, modelling, control and experimental investigations

The scientific project concerns mathematical modeling, experimental, numerical and analytical research of complex mechanical/mechatronic systems that may also be a part of various types of components of machines and mechanisms in industry. The aim of the project is to develop new concepts for suppressing (damping) vibrations of mechanical systems using originally designed vibration sensors/exciters using magnetic and electromagnetic elements and obtaining energy from vibrations. Mathematical modeling is a mathematical description of a previously developed physical model, i.e. an idealized concept of a real physical phenomenon. A correct physical model allows to study, explain and predict phenomena occurring in a real system without conducting expensive and sometimes impossible to carry out experimental research. It also allows to design and test technical devices, including control systems, before they are manufactured. In the project, we examine mechanical systems with friction, impacts, and subjected to electric and magnetic fields, i.e. configurations often occurring in industrial practice. In particular, these are mechatronic systems, i.e. mechanical systems with advanced control and magneto-electric elements, developed and built based on knowledge of mechanics, physics, mechatronics, electronics and computer science. In systems of this type, previously unknown nonlinear dynamic phenomena may occur (preliminary studies indicate their existence), including various bifurcation scenarios, i.e. sudden changes in dynamic behavior under the influence of very small changes in the system parameters or small changes in the surrounding environment. These may be dangerous phenomena that must be avoided, for example by appropriate design of the device or its control. However, they can also be used, for example, in systems that harvest energy from vibrations. Therefore, it is necessary to know and understand them well, what is possible by developing their mathematical models and then experimentally validating them. The project includes the following research tasks:

(1) Mathematical modelling, analysis, and control of bifurcation dynamics of mechanical systems with impacts;
(2) Analysis and control of bifurcation dynamics of mechanical/mechatronic systems subjected to nonlinear friction and parametric excitations;
(3) Parametric and self-excited vibrations of mechanical systems exposed to electric and magnetic fields;
(4) Modelling and dynamics of the system of oscillators coupled by the electromagnetic field and its application to passive/active control (mitigation and suppression) of vibrations, and energy harvesting;
(5) Dynamics of the systems with nonlinear stiffness and controllable damping effects coming from magnetic spring and eddy current damper;
(6) Modelling and analysis of spring and variable-length pendulum systems forced by periodic magnetic excitation and energy harvesting constant-length pendulum systems;
(7) Dynamics of horizontal magnetic oscillators with special nonlinear spring mechanisms;
(8) Tuneable magnetic pendulum for energy harvesting and vibration mitigation;
(9) Energy harvesting using electromagnetic double pendulum configurations.

The topic of the project was chosen due to its potential cognitive and purely scientific values, but also due to possible applications in industry. The development of science and technology requires alignment and mutual feedback between both fields to guarantee a high standard of living for our civilization. Nowadays, the complexity of the dynamic behavior of real systems and processes still requires novel methodological approaches involving interdisciplinary exchange of ideas and dedicated techniques, and technologies aimed at in-depth, high-level modeling of process dynamics. The review of existing scientific research and its results devoted to the problems covered by this project indicates the need for a critical review of existing methods and to expand knowledge with the research proposed in the project.