Model-based Adaptive Predictive Control of Semi-active Fluid Dampers Subjected to Unknown Impact Loading

Application of fluid-based (hydraulic and pneumatic) dampers serving for absorption and dissipation of impact energy is required in many branches of contemporary engineering including transportation, aviation, machine industry and civil engineering. The most common examples of dampers applications are automotive shock absorbers, aircraft landing gears and large-scale elements of anti-seismic protection of high-rise building and long-span bridges. In each above case the optimal absorption of impact energy constitutes fundamental problem from the point of view of safety and economy. Application of incorrect or non-optimal solutions results in the possibility of damages, high material costs and even threat to human health or life.

The standard fluid damper has been designed as a passive device, whose mechanical response is predetermined by initial pressure of the fluid and shaping of the orifices providing its transfer between chambers located on the opposite sides of the piston. However, the recent progress in the field of functional materials has enabled construction of controllable fast-operating valves, which can be applied in fluid dampers to semi-actively control actual flow of the fluid and reaction force generated during the short period of impact. Dampers equipped with flow-control valves have the potential of wide adjustment of mechanical characteristics and adaptation to actual dynamic loading. The main obstacle in their widespread application is the lack of advanced control strategies providing efficient response for various loading conditions.

The objective of the project is development, numerical testing and experimental verification of control strategies which provide efficient and reliable dissipation of impact energy in case of unknown impact loading, limitations of valve operation speed, occurrence of process disturbances and sudden changes of system parameters. The conducted research will concern two types of fluid dampers:

- semi-active hydraulic (or hydro-pneumatic) dampers utilizing controlled flow of viscous fluid,
- semi-active pneumatic dampers utilizing controlled flow of compressible fluid.

The strategies for optimal impact absorption will be based on the methods of modern control theory. The first part of the project will be focused on application of optimal control methods which allow to determine time-dependent valve opening providing optimal dissipation of the impact energy when complete information about external loading is available, but significant limitations of valve operation speed exist. The second part will be aimed at development of predictive control methods, which operate efficiently in case of unknown loading and system disturbances due to sequential computation of the control signal using conducted measurements and numerical model of the damper. In turn, the third part will be oriented towards elaboration of control methods which can identify unknown parameters (e.g. impacting object mass), detect current changes of other system parameters and adjust the control strategy accordingly. Finally, the fourth part will be aimed at development of the most universal adaptive predictive control methods which respond to all above mentioned challenges by combining the advantages of previously developed control systems.

The ultimate result of the project will be control strategies providing efficient and robust damper operation in case of unknown impact loading and incomplete knowledge about the system. The prototype of adaptive damper with fast-operating piezoelectric valve will be equipped with hardware controller with implemented control strategies. The experimental testing will be performed with the use of kinematic excitation and impact excitation at experimental drop testing stand. The conducted tests will provide ultimate evaluation of effectiveness and robustness of the proposed control strategies in application to mitigation of unknown impact loadings.