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SELF-ADAPTIVE IMPACT ABSORPTION WITH A USE OF SMART PNEUMATIC ABSORBER WITH PIEZO-ELECTRIC VALVE

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Key words: self-adaptive impact absorber, adaptive control system, real-time control, pneumatic absorber, drop tests, piezo-electric valve, braking system

Abstract. Within this contribution a challenging problem of adaptive impact absorption is considered and studied in detail. The paper is focused on practical implementation of the self-adaptive system and experimental assessment of its performance. For this purpose a novel kinematics feedback control method is applied and used to adjust in real-time the opening of piezo-electric valve, which is an important part of the smart pneumatic shock-absorber developed in the Institute of Fundamental Technological Research Polish Academy of Sciences (IPPT PAN). As a result, an outstanding shock-absorbing system, capable to adaptively mitigate the impact, is obtained and decelerations acting on the amortized object are significantly reduced for varying parameters of the dynamical excitation. Within the paper the control system improvement based on proportional control of the piezo-electric valve opening is considered. This improvement may provide much better response of the system in terms of reaction force, which is transferred to the amortized object. Indeed, such control in real-time is very hard to be realized in practice. Nevertheless, the authors make an effort to develop the electronic system allowing for proportional adjustment of the valve opening and replacing the on-off control, which gives worse performance and higher control cost.

1 INTRODUCTION

Impact mitigation is a common problem in many industries, including but not limited to manufacturing and transportation. The purpose of impact absorption is to protect people and machines in order to minimize the forces and decelerations acting on them. Therefore shock-absorbers operating of the basis of various principles and techniques are being developed. Some impact mitigation techniques rely on real-time reaction force control. The developed methods include: regulation of the force between the friction elements [1], [2], regulation of the flow rate of the medium having the contribution to the absorber reaction force [3], [4], [5], [6], [7], forcing

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of the flow of magnetorheological fluid through the throttle due to absorption of the kinetic energy of the braked object [8], [9], [10], application of electrorheological fluids [11].

The topic under consideration here is minimization of the braking force of moving object by the use of controllable pneumatic absorber. The adjustment of the force is achieved by opening and closing the piezo-valve which connects two chambers of the pneumatic cylinder (Fig. 1).

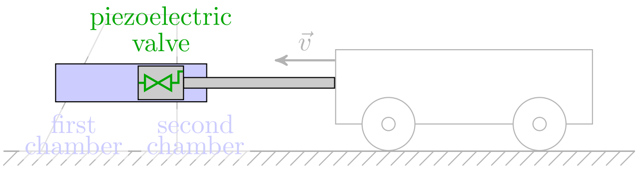

Figure 1: Concept of the kinetic energy absorber

The presented study concerns the improvement of the method of controlling the pneumatic impact absorber. In the previous stages of the investigation in question here, the techniques in which the valve full opening and closing was realized, were based on the deceleration feedback (Fig. 2). The control performed in this way leads to relatively big fluctuations in force (Fig. 4, b). Now, the research concerns the control method in which the current valve opening is compared with the computed reference level (Fig. 3). Therefore intermediate openings with relatively small fluctuations are made possible by frequently changed signals puling the valve towards fully open or complete closed. This solution makes it possible to obtain a lower maximum braking force compared to the case with two-stage valve opening control based on the force measurement alone (Fig. 4, c). The proposed mode of operation enables maintaining smaller maximum braking force than in the case of adjustment of the valve opening fixed before the impact (Fig. 4, a).

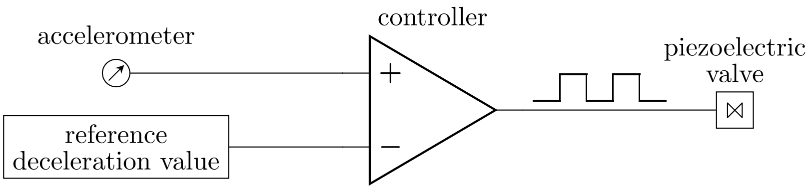

Figure 2: System without valve the opening measurement

2 FEASIBILITY STUDY OF THE VALVE CONTROL METHOD

The effective control of the valve opening requires repeatable behaviour of the system. This may be achieved when the response of the valve does not depend on its opening history. Such a situation is ensured by unique correspondence between elongation of piezo-electric stack and the displacement of the plug, which in turn, relates directly to the opening of the valve.

The method of approximating the plug displacement and valve opening engages the use of the dial gauge (Fig. 5). During the measurements the valve and the gauge were fixed to the optical bench (Fig. 6). On the plot in Fig. 7 the value indicated by this gauge is denoted by x. The extension of the piezo-electric stack, which is applied within the control process, is measured

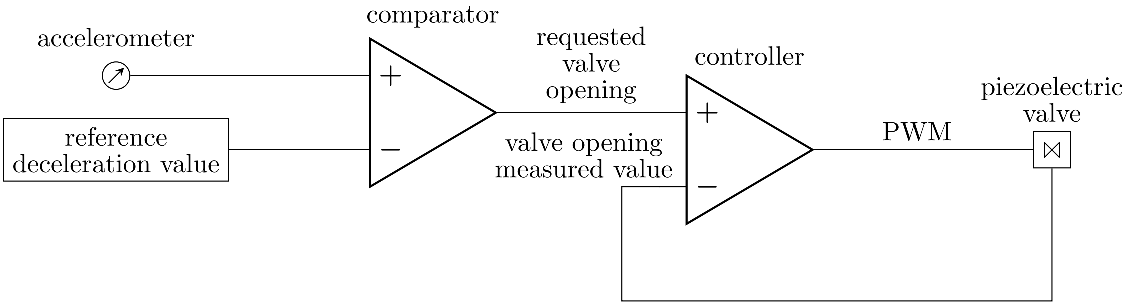

Figure 3: System with the valve opening measurement

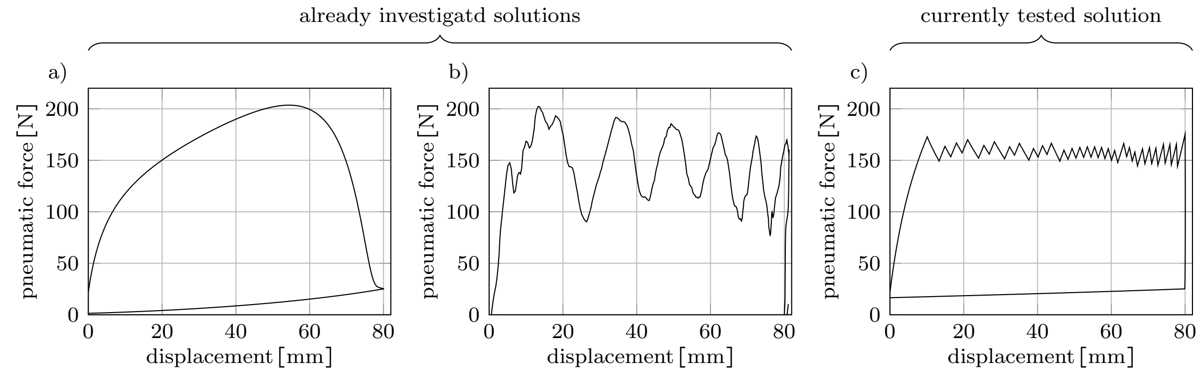

Figure 4: Schematically depicted results of the control investigated in the following stages of the research

with the use of strain rosette (Fig. 5). Strains of the piezo-electric stack, corresponding to the opening of the valve, are denoted by ε in Fig. 7.

Both of these values should be unambiguously related by a single-valued function to enable the proper valve opening control. This is not the case when the voltage supplied to the valve is gradually increased to some maximum value and then gradually decreased to zero – then a relatively wide hysteresis arises (Fig. 7). Nevertheless, the tested system is equipped with two stage controller that switches between the extreme values of the control signal (PWM) dependently on the current valve opening value. Hence the opening oscillates around the desired level (Fig. 8). Such changes of piezo-electric actuator length almost remove the hysteresis in the $x(\varepsilon)$ characteristics. This can be seen in Fig. 9 – when the selected voltage on the piezo-electric stack is reached once by rise (_┌‾┐_) and in the second case by the drop of the control signal (‾┐_┌‾), then the plug displacements are close to each other.

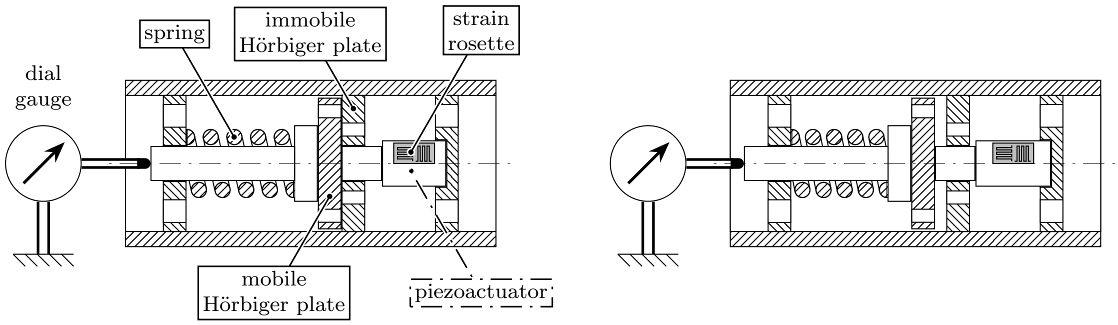

Figure 5: Closed valve (left) and open valve (right). The method of estimation of valve opening with the use of dial gauge

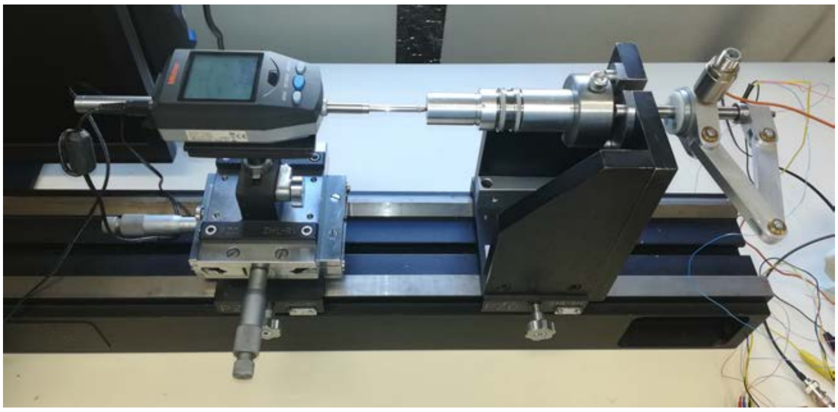

Figure 6: Valve in the piston fixed to the optical bench

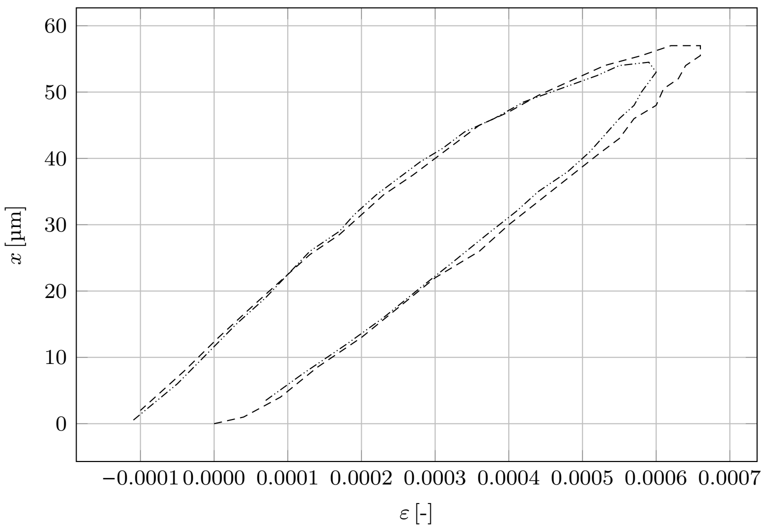

Figure 7: Two cycles of of opening and closing the valve

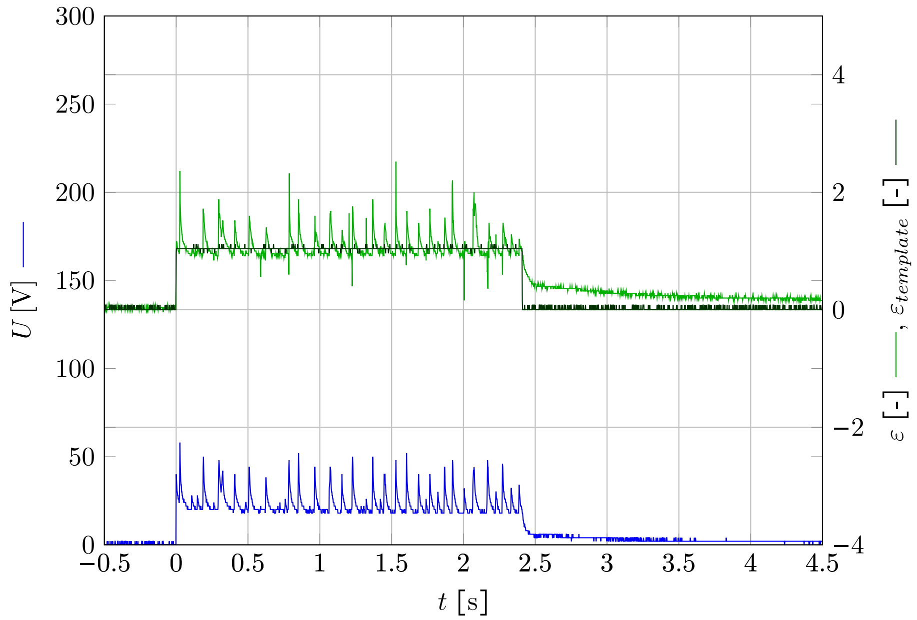

Figure 8: An exemplary voltage and strain time-dependencies while the required valve opening is given by $\varepsilon_{template}$

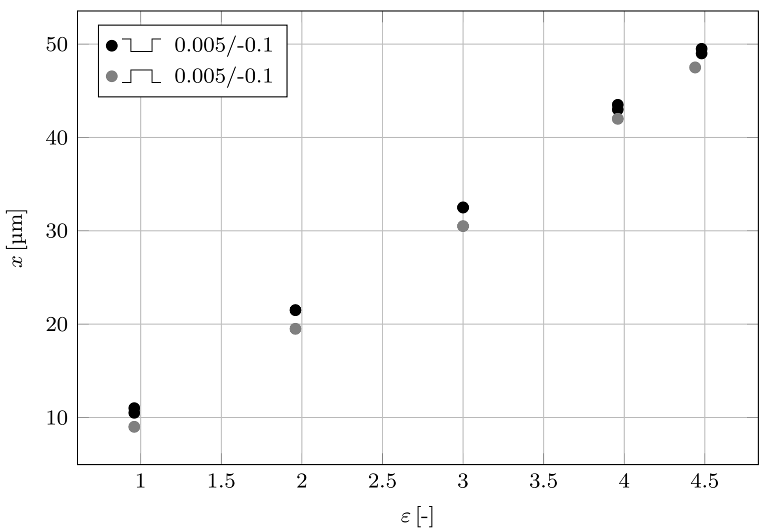

Figure 9: Valve opening at arbitrary various requested control opening

3 CONCLUSIONS

The study discussed within this paper introduced overview of the authors' research conducted currently in IPPT PAN in order to further develop the impact mitigation technique aiming at minimization of the force response. Until now, the kinematic feedback control with on-off following of the optimal path was demonstrated. In order to improve obtained performance further adjustments of the smart pneumatic shock-absorber are required. They include above all the proportional valve opening control, which allows for better resembling of the optimal impact mitigation. Specific features of the piezo-electric valve results in PWM control of the system in order to obtain intermediate valve openings. The next steps of the authors will concern application of the valve opening controller for implementation of high level control of the absorber force response and as a result, obtaining the more optimal impact mitigation performance.

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