DSTA 2021
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16th INTERNATIONAL CONFERENCE
Dynamical Systems – Theory and Applications
December 6-9, 2021, On-line

Predictive Control of Semi-active Fluid-based Dampers Under Impact Excitation

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Abstract: The contribution presents recent progress in development of the control systems for semi-active fluid-based dampers equipped with fast-operating valves. The attention is focused on the case when the damper is subjected to impact of mass moving with initial velocity and additional excitation force acting during the process. The objective of the corresponding control problem is to find the change of valve opening which provides absorption of the entire impact energy with minimal value of generated reaction force. The contribution presents two different approaches to solution of the challenging control problem with unknown excitations and disturbance forces, which are based on the concept of Model Predictive Control.

Keywords: fluid-based dampers, semi-active dampers, Hybrid Prediction Control, Identification-based Predictive Control

1. Introduction

Semi-active fluid-based dampers consist of two chambers filled with hydraulic or pneumatic fluid and connected by the orifice, which is equipped with fast-operating valve controlling the actual rate of fluid flow. The most often used types of fluid-based shock-absorbers are semi-active dampers with fast electromagnetic or piezoelectric valves. These devices can be used in both vibration suppression problems and impact mitigation problems. Although many control strategies have been successfully developed for protection against vibration, the problem of optimal impact absorption has not gained sufficient attention of researchers and has not been completely solved so far.

2. Results and discussion

In the considered impact absorption problem the damper is subjected to the impact of a rigid object of mass M moving with initial velocity $\mathrm{v_0}$ and external force $\mathrm{F_{ext}(t)}$, as shown in Fig. 1a. The objective of the control problem is to find the change of valve opening in time $\mathrm{A}_v(\mathrm{t})$, which provides absorption and dissipation of the entire impact energy with minimal value of total discrepancy between force generated by the absorber $\mathrm{F_{abs}}$ and its theoretical optimal value $\mathrm{F_{abs}^{opt}}$, see Fig. 1b (black and red lines, respectively).

The direct mathematical formulation of the impact mitigation problem, which has been studied in detail by the authors reads:

$$\text{Minimize: } \int_0^T \left(\mathrm{F_{abs}}(\mathrm{A}_v(\mathrm{t}),\mathrm{t}) - \mathrm{F_{abs}^{opt}}\right)^2 \mathrm{dt} \tag{1a}$$

$$\text{With respect to: } \mathrm{A}_v(\mathrm{t}) \geq 0 \tag{1b}$$

$$\text{Subject to: } \int_d \vec{\mathrm{F}}_{\mathrm{abs}} \mathrm{d}\vec{\mathrm{s}} = \mathrm{E_{imp}^0} + \mathrm{E_{imp}^{ext}} = \tfrac{1}{2}\mathrm{M}\mathrm{v_0^2} + \int_d \vec{\mathrm{F}}_{\mathrm{ext}} \mathrm{d}\vec{\mathrm{s}} \tag{1c}$$

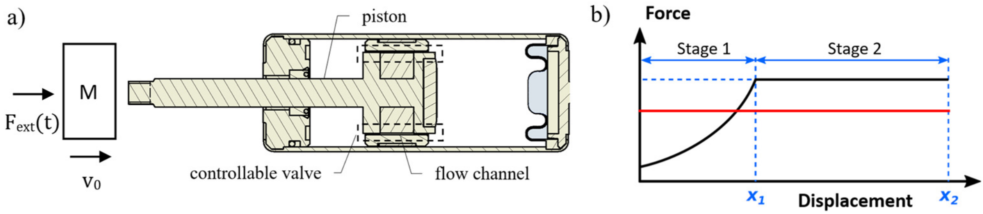

Fig. 1. a) The problem considered: damper subjected to the impact excitation, b) force-displacement characteristics: red – theoretical optimal force, black – schematic optimal change of force obtained using pneumatic damper

The solution of the above control problem is straightforward (and for pneumatic damper assumes form shown in Fig. 1b) only in a special case when no limitations on valve operation are considered, impact excitation is a priori known and theoretical value of optimal force can be directly calculated. In the opposite situation, the impact mitigation problem requires reformulation and application of advanced methods of control theory.

In particular, when external excitation is not a priori known the problem has to be reformulated into its kinematic version, the so called *state-dependent path-tracking*, based on minimization of the actual and currently optimal value of deceleration, which is continuously updated during the process:

$$\text{Minimize: } \int_0^T \left[\ddot{u}(A_v(t),t) + \frac{\dot{u}(t)^2}{2(d-u(t))}\right]^2 dt \tag{2a}$$

$$\text{With respect to: } A_v(t) \text{ such that } A_v(t) \in \langle A_v^{min}, A_v^{max}\rangle \text{ and } \frac{dA_v(t)}{dt} \leq V_v^{max} \tag{2b}$$

$$\text{Subject to: condition of entire energy absorption (1c)} \tag{2c}$$

In such a case, the efficient approach is application of the Model Predictive Control, which assumes repetitive solution of the control problems defined at finite time horizon Δt of arbitrary length:

$$\text{Minimize: } \int_{t_i}^{t_i+\Delta t} \left[\ddot{u}(A_v(t),t) + \frac{\dot{u}(t_i)^2}{2(d-u(t_i))}\right]^2 dt \tag{3}$$

The approximate solution can based on the proposed by the authors methods including Hybrid Prediction Control (HPC) [1] and Identification-based Predictive Control (IPC) [2]. The HPC provides efficient impact mitigation using system kinematics measurements, prediction of valve operation mode and prediction of required change of valve opening. In turn, the IPC additionally utilizes repetitive identification of selected system parameters in order to improve system performance at each control step.

3. Final remarks

Within this contribution the impact mitigation problem has been reformulated into kinematic version and two dedicated control methods (HPC, IPC) have been proposed. Both methods are proved to provide efficient mitigation of dynamic response of the system subjected to unknown impact excitation.

Acknowledgment: The financial support of the National Science Centre, Poland, granted under agreement DEC-2018/31/D/ST8/03178, is gratefully acknowledged. RF is supported by the Foundation for Polish Science (FNP) under the START scholarship.

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