Mechanical Systems and Signal Processing 24 (2010) 4–18

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/jnlabr/ymssp

Black-box model identification for a continuously variable, electro-hydraulic semi-active damper

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ARTICLE INFO

Article history:
Received 25 November 2008
Received in revised form
20 March 2009
Accepted 27 March 2009
Available online 10 April 2009

Keywords:
Semi-active damper
Vehicle suspension
Identification
Experiment design
Nonlinear system
Neural network model

ABSTRACT

This paper discusses the black-box identification of a continuously variable, electro-hydraulic semi-active damper for a passenger car. A neural network based output error (NNOE) model structure is selected to describe the complex nonlinear damper dynamics. This model structure is able to accurately and efficiently describe the dynamic damper behaviour, and is appropriate for full vehicle simulation. The identification procedure includes optimal experiment design, regression vector selection and model parameter estimation. The damper excitation signals are optimized multisines that yield uniform coverage of the achievable working range of the damper. A state of the art iterative procedure is used to concurrently estimate the model parameters and select an optimal set regression vector elements. Experimental validation of the proposed procedure shows that models identified from the data measured using the optimized excitations are considerably more accurate than those identified from data obtained using conventional random phase multisine excitations.

1. Introduction

Nowadays, most luxury cars are equipped with semi-active suspension systems and more recently they become also available for mid class vehicles. It is expected that their market share will continue to grow rapidly and their performance will improve too [1]. Two types of semi-active dampers are currently applied in car suspensions: magneto-rheological (MR) dampers and continuously variable, electro-hydraulic semi-active dampers (*CVEHSA*). When a magnetic field is applied to a magneto-rheological oil, the micron-sized, polarizable particles suspended in the fluid tend to form chain-like structures, which modifies the yield stress of the fluid. In the piston of a MR-damper, a solenoid is mounted that allows to apply a magnetic field over the orifice through which the oil flows when the damper is moving. Hence, the damping characteristic can be altered by controlling the current applied to the solenoid. The *CVEHSA*-damper is equipped with a servo-valve that allows to vary continuously the orifice through which the oil flows when the damper is moving.

Semi-active dampers exhibit one major inconvenience: their inherent nonlinear dynamic behaviour which complicates the design of a controller for the suspension system. Swevers et al. [3] have developed a parameterized, model-free control structure for a passenger car equipped with an electro-hydraulic semi-active suspension system, that can be tuned based on the directions of a test-pilot. However, the road tests required to tune the controller are time consuming and costly. A reliable full vehicle simulation model would allow the car manufacturers to overcome this drawback. This requires a

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doi:10.1016/j.ymssp.2009.03.013

model for the semi-active damper dynamics that accurately describes the damper force as a function of the rattle velocity and current in the frequency band up to about 30 Hz [2].

In the past, a lot of effort has been invested in developing models and experimental identification methods for passive hydraulic dampers and magneto-rheological dampers, ranging from complicated physical models [4] to nonlinear black-box models [5–7]. These black-box techniques have shown to yield the most accurate descriptions of the damper dynamics. Black-box models use general mathematical approximating functions to describe the systems input–output relations. Hence, the most important advantages of these modelling techniques are the computational efficiency, both in model identification as in simulation, and the limited physical insights required to develop the model. However, there remain two challenging steps in the identification of black-box models for highly nonlinear systems:

- the selection of the most suitable set of regression variables,
- the design of excitation signals that yield experimental data that uniformly covers the entire working range of the system.

The identification procedure presented in this paper uses a state of the art technique based on simulation error minimization [8] to select an optimal set of regression variables. The authors have shown in previous work [9] that this method works well for the identification of a neural network based output error model for an electro-hydraulic semi-active damper. With respect to this earlier work the procedure is extended with an optimal experiment design method that selects the phases of a multisine excitation such that the total working range of the damper is uniformly covered. In addition, this papers presents an elaborate experimental validation of the effectiveness of the experiment design method and the regression vector selection procedure.

The paper is organized as follows. Section 2 describes the considered semi-active damper and reviews briefly some literature on the modelling of passive and magneto-rheological dampers. Section 3 gives a short overview of the used concepts of black-box modelling: it introduces the considered model structure, followed by a discussion on the identification procedure that includes the model structure selection algorithm and the parameter estimation method. Section 4 describes the test setup and the optimal experiment design procedure. In Section 5 the effectiveness of the presented methods is experimentally verified by identifying and validating a simulation model for a semi-active damper. Section 6 presents the conclusions and gives some suggestions for improvements.

2. Semi-active damper characteristics

The first part of this section discusses the structure of *CVEHSA*-dampers by comparing it to classical passive dampers, from which the design has been derived. The next part shows the characteristics of the damper and illustrates the highly nonlinear dynamic behaviour, while the last part reviews some models of passive and magneto-rheological dampers. These dampers exhibit a dynamic behaviour similar to that of the *CVEHSA*-damper. Hence, these models are useful background information for the development of a model for the *CVEHSA*-dampers.

2.1. Working principle

A classic passive damper consists of a cylinder filled with oil and a rod connected to a piston which contains a calibrated restriction called the piston valve (see Fig. 1 left). The change in volume caused by the rod moving in or out of the cylinder is compensated for by oil flowing in or out of the accumulator (accu) through the base valve. The pressure drop over both the base valve and the piston valve results in a damping force acting on the piston.

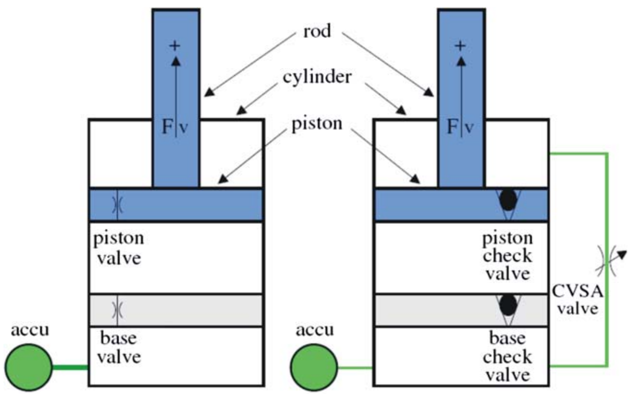

Fig. 1. Working principle of a passive and a semi-active damper.