Design of Experiments for MR Damper Modelling

Jorge Lozoya-Santos, Ruben Morales-Menendez and Ricardo Ramirez-Mendoza

Abstract— An approach to find out the training inputs for identification of a Magneto-Rheological (MR) damper is proposed. Reduction of overuse of the damper, number of experiments and configurations of training inputs are main features of this approach. Experimental validation with a commercial MR damper was carried out. Main results show inputs configuration with modulated frequency at fixed amplitude displacement, and random amplitude step with fixed period generate key information. A feed-forward neural network was selected as model emulator. Modelling results showed an error-to-signal ratio lower than milli-thousands.

I. INTRODUCTION

A Magneto-Rheological (MR) fluid is a smart material that changes its rheological properties when a magnetic field is applied. A MR damper is an example of a commercial application of this type of fluids. A control system based on a MR damper presents high nonlinear behavior. A precise model of this damper is a research challenge in order to get better control performance (i.e., semi-active suspension in automotive industry). Even there are several important contributions in this domain [1]; there are still several needs.

There are two key steps in order to get a precise MR damper model. First, the design of the experimental training inputs. Second, the definition of the model structure. A contribution in is given in the first step mentioned above.

The paper is organized as follows. Section II reviews the state of the art. Section III describes the experimental setup. Design of experiments is proposed in IV. Training inputs configuration approach is described in section V. Results are discussed in section VI. Finally, section VII concludes the paper.

II. STATE OF THE ART

The problem of developing a best model that predicts the response of a MR damper does not have a unique solution. Several modelling approaches have been proposed since the Bouc-Wen modified model [2]. Each approach presents a different DoE. Hysteretic behavior is an inherent MR damper feature, no matter where the field is applied. Its characterization is not a trivial task. The chosen model and DoE impact the nonlinear identification process. Results recommend a division of the testing and modelling steps [3], [4], [5]. Following, subsection II-A outlines the state of the art of training inputs configurations; and subsection II-B describes a validation step. In subsection II-C, modelling approaches are discussed.

A. Training inputs

A review of the most representative Training Inputs Configuration (TIC) is presented. The TIC review is oriented but not restricted to automotive field. TIC is defined as those input behaviors used to perform experiment and obtain damping force in order to use it as fitting patterns. Better TIC richness imply better dynamical characterization, consequently better realistic model. It is well-known that the design of training inputs is a key step in order to identify the full spectrum of possible behaviors. According to the displacement signal, training inputs are:

1) Pure Sine Sweep (SSS). They are fixed tests with an amplitude and frequency. Each test is stopped in order to increase frequency, then recorded data has no transitory information between these changes. It does not guarantee uniform temperature in fluid.
2) Road Profiles (RP). These signals are based in [6].
3) Seismic displacement records (XSP). Signals coming from seismic records where frequency bandwidth white noise are less than 5 Hz.
4) Bandwidth White Noise (BWN) are Gaussian noises filtered to interest frequencies. Maximum amplitude and BW are for specific application.
5) Sinusoidal simple signal (S) with an amplitude and fixed frequency.
6) Sine-On-Sine (SoS) is a popular industrial laboratory test that validates structural designs. Sometimes actuators have low bandwidth for high displacement. Then a carrier sine wave (high amplitude) gives a ride to other higher frequency sine waves (low amplitudes).
7) Increased Clock Period Signal (ICPS) or random walk whose amplitude varies randomly each constant period defined by the application constraints [7].
8) Triangular wave (Tr). Signal with constant amplitude. It is used to extract relations between force and excitation input.

Input excitation to MR damper also has many variants. The most representative are:

1) Constant current (C) where values are set manually. item BWN. Same as defined for displacement.
2) Ramp signal (R) is useful for determination of ratio changes. MR damper force and current have non-linear relationship. It can be explored an exponential ratio.
3) Sinusoidal signal (S), applied for modelling testing.
4) Amplitude Pseudo-Random Binary Signal (APRBS). The minimum amplitude period must be greater than settlement time of transfer function.
5) Sine Sweep Signal (SSS) does not offer identification.