Modelling and Control of Smart Structures Embedded with Magnetorheological Dampers

Minh Tam Nguyen

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Faculty of Engineering and Information Technology
University of Technology, Sydney, Australia

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CERTIFICATE OF AUTHORSHIP/ORIGINALITY

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

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Minh Tam Nguyen

Abstract

Civil structures are designed with certain stiffness and damping to withstand certain loads. As a result of inadequate damping, earthquakes or strong winds may cause damage or even collapse to civil structures. Structural control devices have therefore been developed and installed in structures to help mitigate such extreme seismic vibrations. There are three types of structural control devices, namely passive, active and semi-active devices according to their energy consumption.

The magnetorheological (MR) dampers are considered to be semi-active devices and increasingly employed in structural control applications owing to many feasible advantages. The forces generated by MR dampers can be adjusted by applying an external magnetic field to the MR dampers. They can operate in a passive mode and their power consumption in active mode is very small compared to that of active control devices. However, a major drawback hindering their application exists due to their non-linear force/displacement and hysteretic force/velocity characteristics.

The modelling and control of MR dampers embedded in civil structures to mitigate seismic responses constitute the objective of this research. With regard to structural control, it is crucial that a tractable model of the MR damper is available before any realisable controller can be designed. There are several models for MR dampers in the literature, such as the Bingham, Bouc-Wen, phenomenological models, among others. In refining the modelling of MR dampers to be used in certain aspects of the control design and analysis, this thesis proposes some new models, namely the non-symmetric hysteresis Bouc-Wen model, the static hysteretic model and the polynomial fitting model. The non-symmetric hysteresis Bouc-Wen model is based on the original Bouc-Wen model but takes into account the effect of non-symmetrical hysteresis of the force/velocity relationship. The static hysteretic model makes use of a hyperbolic tangent function to represent the hysteresis, and linear functions to represent the damping and stiffness. The polynomial fitting model is based on the curve fitting approach, whereby the hysteretic behaviour of the MR damper is represented by a mixture of a sigmoid function and a Gaussian function.

There are several control strategies developed in literature such as a well-known clipped-optimal control, Lyapunov-based control, sliding mode control (SMC), and so on. In these strategies the currents supplied to MR dampers are determined indirectly from the desirable MR damper forces obtained from the controllers. In this research, a Lyapunov-based controller and a Linear Quadratic Regulator (LQR) controller that can directly control the currents supplied to MR dampers are developed with the aim of improving the control performance. Furthermore, the dampers are configured in a differential mode to counteract the force-offset problem from the use of a single damper.

The effectiveness of the proposed controllers is verified in both intensive simulations using a multi-storey building model subject to quake-like excitations, and experiment, in part using a physical building model excited by quake-like vibrations from the shaking table at the University of Technology Sydney (UTS).

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