지진하중을 받는 구조물의 수정된 에너지 소산 제어 시스템

Modified Energy Dissipation Control System for Seismic Response Reduction

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1. Introduction

In the filed of civil engineering, many control algorithms and devices have been proposed over the last few decades for the purpose of protecting structures and their contents from the damaging effects for environmental hazards such as earthquakes and wind loadings. Semiactive control has received a lot of attention recently because it offers great adaptability without a large power requirement. Previous research has demonstrated the effectiveness of semiactive systems in structural vibration control using viscous fluid dampers. Magneto-rheological (MR) damper is one of the semiactive devices that can provide reliable vibration control. Besides its minute power requirement, the MR damper is reliable, fail safe, and is expected to be relatively inexpensive.

The maximum energy dissipation algorithm(MEDA) for semiactive control system represents one control class which employ the Lyapunov's direct approach to stability analysis in the design of a feedback controller (Brogan 1991). The approach requires the use of a Lyapunov function that must be a positive definite function of the states of the system. According to Lyapunov stability theory, if the rate of change of the Lyapunov function is negative semi-definite, the origin is stable in the sense of Lyapunov. Thus, in developing the control law based on Lyapunov stability theory, the goal is to choose control inputs for each device that will result in making the rate of change of the Lyapunov function as negative as possible. Jansen and Dyke (2000) suggested MEDA as a variation of the decentralized bang-bang approach proposed by Mc Clamroch and Gavin (1995). It is noticeable that this control law requires only local measurements, which means MEDA is simple implemented without any design process.

In the original MEDA, the command voltage takes on the value of either zero or the maximum value. In some situations when the dominant frequencies of the system under control are low, large changes in the forces applied to the structure may result in high local acceleration values. This behavior is dependent on the time lag in the generation of the control voltage. We are proposing a modification to the original MEDA to reduce this effect.

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2. Control Algorithms

Consider a seismically excited structure controlled with *n* MR dampers. The equation of motion can be written as

$$\boldsymbol{M\ddot{x}} + \boldsymbol{C\dot{x}} + \boldsymbol{Kx} = \boldsymbol{\Lambda f} - \boldsymbol{M\Gamma}\ddot{x}_g \tag{1}$$

where $\boldsymbol{M}$, $\boldsymbol{C}$, and $\boldsymbol{K}$ are the ($n\times n$) mass, damping, and stiffness matrices, respectively; $\boldsymbol{x}$ is the *n*-dimensional vector of the displacements of the floors of the structure relative to the ground; $\boldsymbol{f}$ is the vector of measured control forces generated by *m* control devices; $\ddot{x}_g$ is ground acceleration; $\boldsymbol{\Gamma}$ is the matrix determined by the placement of control devices in the structure; $\boldsymbol{\Lambda}$ is the column vector of ones. This equation can be written in state-space form as

$$\boldsymbol{\dot{z}} = \boldsymbol{Az} + \boldsymbol{Bf} + \boldsymbol{E}\ddot{x}_g \tag{2}$$

$$\boldsymbol{y} = \boldsymbol{Cz} + \boldsymbol{Df} + \boldsymbol{v} \tag{3}$$

where z is a state vector; y is the vector of measured outputs; and v is a measurement noise vector.

2.1 Maximum Energy Dissipation Algorithm (MEDA)

This control algorithm is presented as a variation of the decentralized bang-bang approach proposed by McClamroch and Gavin (1995). Lyapunov's direct approach requires the use of a Lyapunov function, denoted V(x), which must be a positive definite function of the states of the system x. In the decentralized bang-bang approach, the Lyapunov function was chosen to represent total vibratory energy in the system. Jansen and Dyke (2000) instead consider a Lyapunov function that represents the relative vibratory energy in the structure as in

$$\boldsymbol{V} = \frac{1}{2}\boldsymbol{x}^{\mathrm{T}}\boldsymbol{Kx} + \frac{1}{2}\boldsymbol{x}^{\mathrm{T}}\boldsymbol{Mx} \tag{4}$$

According to Lyapunov stability theory, if the rate of change of the Lyapunov function $\dot{V}(x)$ is negative semi-definite, the origin is stable in the sense of Lyapunov. Using Eq. (4), the rate of change of the Lyapunov function is then

$$\dot{V} = \boldsymbol{x}^{\mathrm{T}}\boldsymbol{K\dot{x}} + \boldsymbol{x}^{\mathrm{T}}\boldsymbol{M}(-\boldsymbol{C\dot{x}} - \boldsymbol{Kx} - \boldsymbol{M\Gamma}\ddot{x}_g + \boldsymbol{\Lambda f}) \tag{5}$$

In this expression, the only way to directly effect $\dot{V}$ is through the last term containing the force vector f. To control this term and make $\dot{V}$ as large and negative as possible, the following control law is obtained

$$v_i = V_{\max} H(-\dot{x}\Lambda_i f_i) \tag{6}$$

where Λ_i is i th column of the Λ matrix; f_i is i th column of the f matrix.

Note that MEDA is very simple because only local measurements (i.e., the velocity and control force) are requires to implement this control law. In eq. (6), there is no design parameter to decide, which is essential part in other control laws.

However, in the original MEDA, the command voltage takes on the value of either zero or the maximum value. In some situations when the dominant frequencies of the system under control are low, large changes in the forces applied to the structure may result in high local acceleration values. This behavior is dependent on the time lag in the generation of the control voltage. We are proposing a modification to the original MEDA to reduce this effect.

2.2 Variable Energy Dissipation Algorithm (VEDA)

In the modified version of the control algorithm, the control voltage can be any value between 0 and V_{max}. The control voltage, denoted V_i, is determined using a linear relationship between the maximum voltage and the maximum force of MR damper. This modified variable energy dissipation algorithm is graphically represented in Fig. 1 and can be given as

$$v_i = V_i H(-\dot{x}\Delta_i f_i) \tag{7}$$

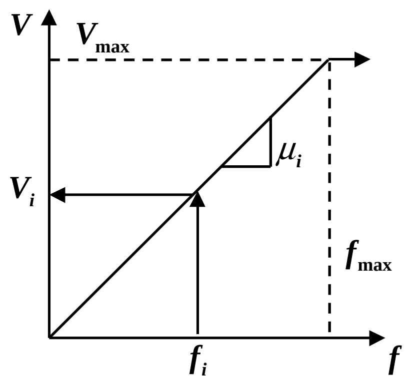

Fig. 1. Graphical representation of the variable energy dissipation algorithm

3. Numerical Example

To evaluate the performance of the proposed variable energy dissipation algorithm using MR damper, a three-story shear building structure is performed. Simulation results of the proposed control system are compared to those of an uncontrolled system, clipped-optimal system designed in [4], MEDA and VEDA. Maximum force of the MR damper is 1500 N.

The system matrices of a three-story shear building are

$$M_s = \begin{bmatrix} 98.3 & 0 & 0 \\ 0 & 98.3 & 0 \\ 0 & 0 & 98.3 \end{bmatrix} kg \qquad C_s = \begin{bmatrix} 175 & -50 & 0 \\ -50 & 100 & -50 \\ 0 & -50 & 50 \end{bmatrix} \frac{N \cdot sec}{m} \qquad K_s = \begin{bmatrix} 12.0 & -6.84 & 0 \\ -6.84 & 13.7 & -6.84 \\ 0 & -6.84 & 6.84 \end{bmatrix} \frac{N}{m}$$

This system is a simple model of the scaled, three-story, test structure, described in [4], which has been used in previous active control studies at the Structural Dynamics and Control/Earthquake Engineering Laboratory (SDC/EEL) at the University of Notre Dame. Because the MR damper is attached between the first floor and the ground, its displacement is equal to the displacement of the first floor of the structure relative to the ground.

The test structure is controlled under normal (100%), high (150%) and low (50%) excitation levels of the El Centro and Hachinohe earthquakes, and under normal (100%) and low (50%) exciteation levels of the Northridge and Kobe earthquakes. Because the system under consideration is a scaled model, the earthquake must be reproduced at five times the recorded rate. The MR damper attached three-story building is the prototype model that Dyke et al. [4] used.

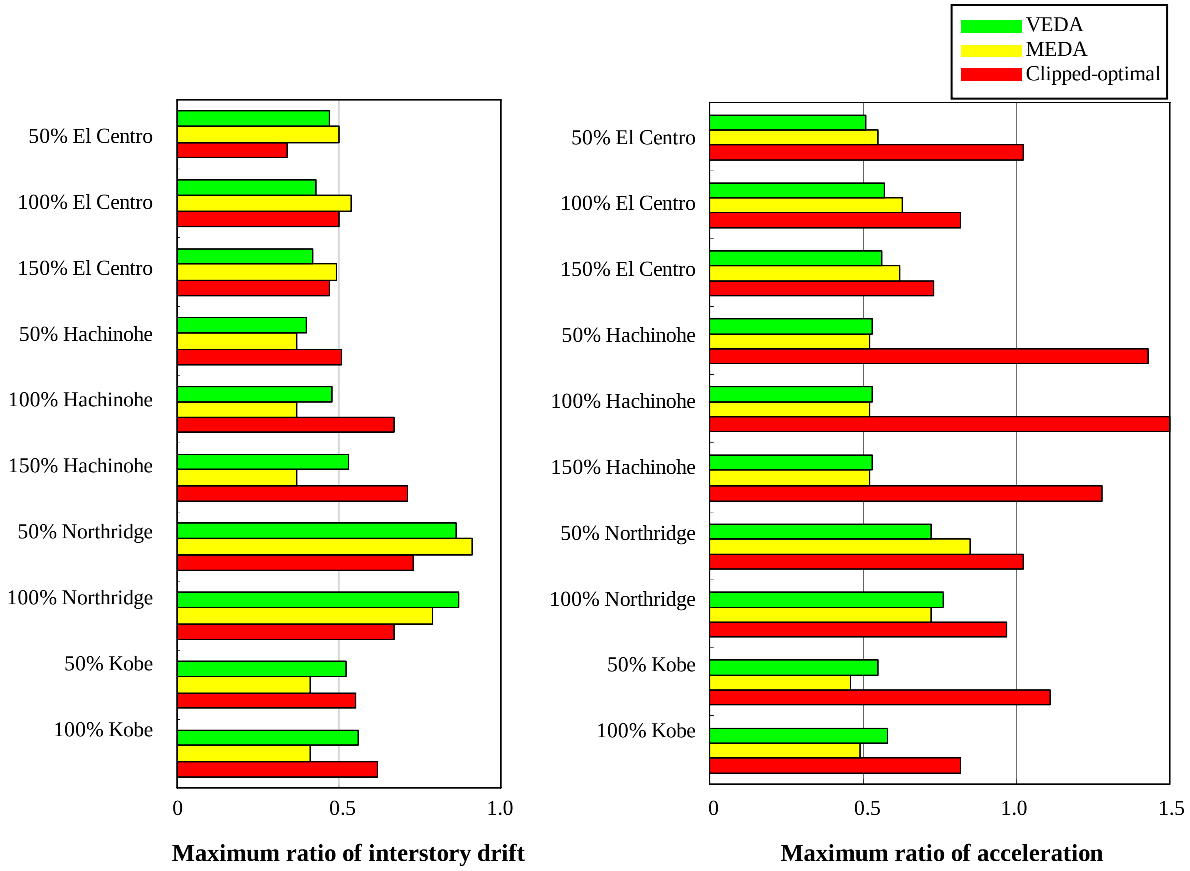

Fig. 2. Bar chart comparing the evaluation criteria for various controllers

4. Conclusions

A modified maximum energy dissipation algorithm is presented for seismic response reduction. The MR damper was controlled using MEDA, as well as a newly proposed variable energy dissipation algorithm that supplied continuously varying command voltages. It is noticeable that these control laws require only local measurements, which means MEDA is simple implemented without any design process. In comparing the two control algorithms used with the MR damper, performance of VEDA was found to be slightly better or similar to MEDA.

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