DESIGN AND IMPLEMENTATION OF AN AMD SLIDING MODE CONTROLLER BASED ONA REDUCED MODEL

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ABSTRACT

Active structural control has attracted considerable interest in recent years, as structures are getting taller yet more flexible (Soong, 1998). Active mass dampers (ADMs) are one of the efficient solutions presented for mitigating destructive effects of seismic and wind loads. However, design of model-based active structural control systems is such a hardship, as the available models for the control design are contaminated with parametric uncertainties and unmodeled dynamics. Robust control is agoodsolutionfor active control of uncertain structural systems (Zhao et al, 2000). In this research, design and implementation of a new robust sliding mode controller for tackling seismic excitations in the presence of parametric uncertainty is presented. For this purpose, a shear frame model developed based on a reduced model of a high rise building is built in laboratory scale. The structure is then equipped with a laboratory scale AMD system and the proposed controller is implemented in the system. Finally, effectiveness of the proposed controller is evaluated via shake table tests. The test results prove success of the proposed controller in suppressing inter-story drift and base shear responses in the presence of structural uncertainty.

INTRODUCTION

Nowadays preserving building performance against natural phenomenon such as earthquake and wind is one of most controversial subjects between engineers. It would be more necessary if we notice that the rate of construction is going up especially in areas with high level of seismic activity. Therefore, this subject has attracted many researches in recent years(Somali et al,2004,Lu et al,2003).

Dynamic response control of a structure may be performed via passive, semi-active, or active systems. Among them, the passive structural control systems have attracted more interests in recent years because of their simplicity, low cost, andzero energy consumption (Housner et al,1997, Park et al,2002, Somali et al,2003, Choi et al,2005,Guclu R, Yazi et al,2008, Mohan et al, 2008, Tani et al,2008, Li et al, 2010, Bitaraf, et al,2012). Nevertheless, performance of the passive systems is restricted as they are usually tuned for a certain frequency range, most of the time the first structural mode. Therefore, they are not able to adopt themselves with different disturbances. Due to uncertain nature of seismic disturbances, this maybeconsidered as a serious drawback of the passive structural control systems (Yang et al,1996 and

Adhikari et al, 1998).

In the active structural control systems it is aimed to control dynamic behavior of the structure via applying a control forces. The control force is determined based on the feedback signals and according to the control strategy(Qiu et al., 2004).

Several works have been done on active control design of civil structures e.g. (Ceriwa and Isiowa, 1987, Soong et al,1991).Due to inherent uncertainties in the structural models used for control design, robust control approach is a proper match for control purpose of these systems (yang et al., 1996). Sliding mode control, as a robust nonlinear controller, has also been employed for active structural controlapplications (Adhikari et al., 1997).

Design and implementation of a new sliding mode controller is presented in this paper. For this purpose, a real steel shear frame has been built based on a reduced 2 degree of freedom model extracted from a real ten story building. Furthermore, the structure is equipped with an AMD system at its top story. The AMD system consists of an electric motor and a mechanical transmission system through with the control force is applied to the structure. A two-loop controller is proposed for calculating the control force. The outer loop estimates the required motor torque for minimizing the top story displacement. The inner loop, on the other hand, calculates the electric motor current using a PI controller. The control inputs i.e. displacement and velocity of the top story are provided via image processing technique. The effectiveness of the proposed controller is examined through shake table tests.

STRUCTURAL MODEL

A ten story building is considered in this study. A FEM model is built for this structure. The FEM model is then reduced to a 2 DOF model using model order reduction techniques. Figure 1 depicts the building model. In this model, mass of each floor is modeled as a lumped mass. Moreover, the frame has ten floors with 3 meters height each, and 3 gates (entrances)with equal 6 meters width. Furthermore, the model was loaded in mass centers by a 100(kg/m)×3×6=1800(kg) continuous load

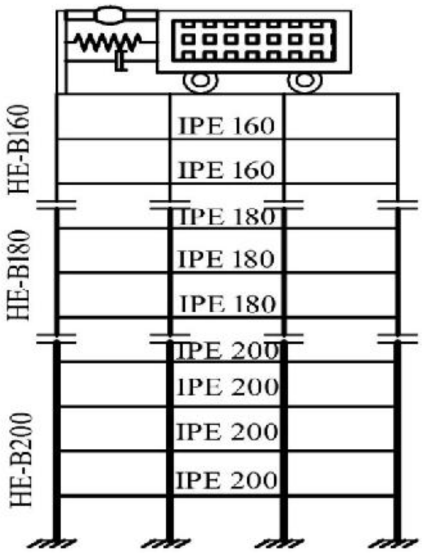


Figure 1.Ten story shear frame model

AMD DESIGN

The AMD system contains an electric motor and its driver, a rack and pinion mechanism as the transmission system, limit sensors in order to confine displacement, a data acquisition card and a personal computer. A permanent magnet 12 volt DC motor with planetary gear was chosen as the system driver. Moreover, a MOFSET IR3710driver in conjunction with two ir2014 amplifiers is employed for torque control of the electric motor. Figure 2depicts a schematic diagram for the AMD control system.

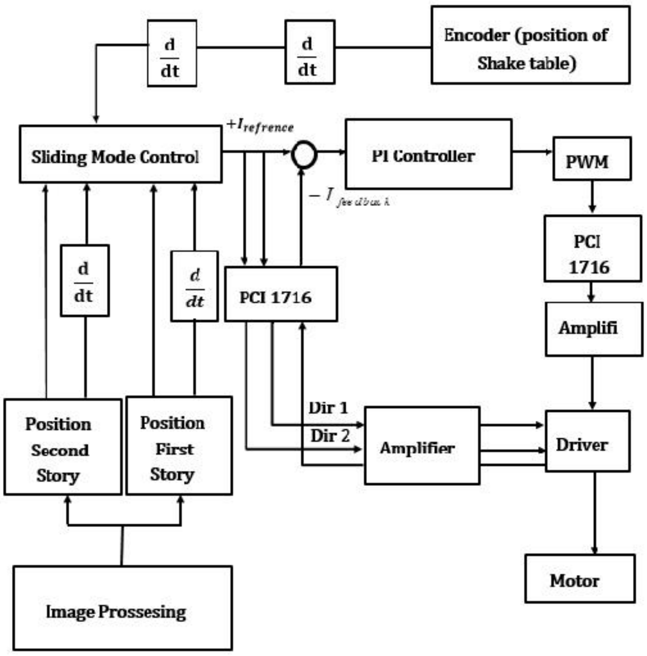


Figure 2.Schematic diagram for the control system

Figure 3also shows the 2 DOF structure with AMD system mounted on the shake table.

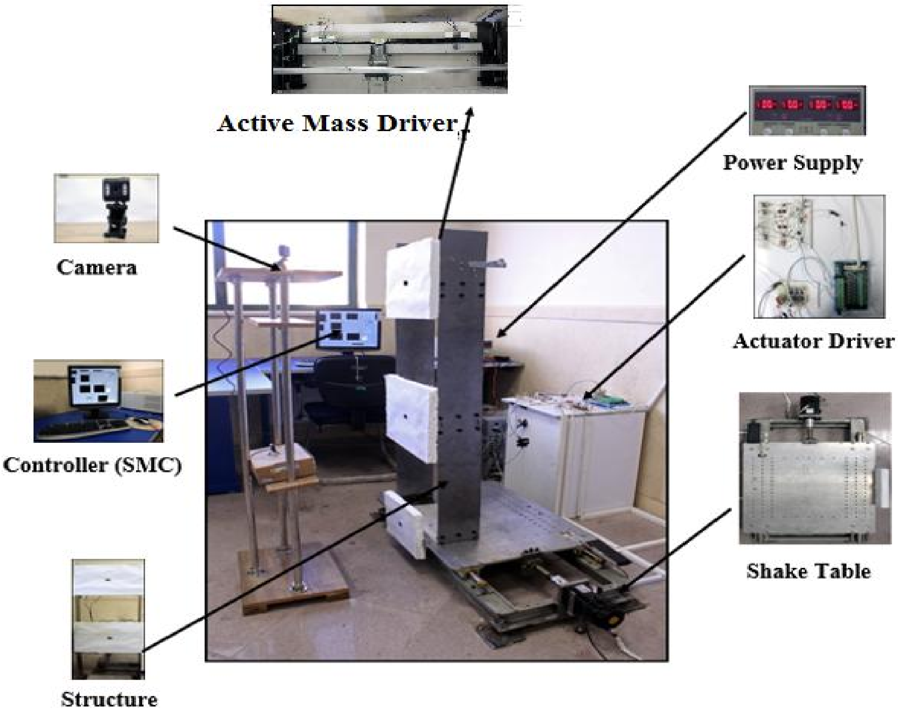


Figure 3.Structure and AMD system on the shake table.

CONTROL DESIGN

A two loop controller is proposed for calculating the control force. The outer loop estimates the required motor torque for minimizing the top story displacement. The inner loop, on the other hand, calculates the electric motor current using a PI controller. The control inputs i.e. displacement and velocity of the top story are provided via image processing technique.

In the sliding mode control strategy it is aimed to track a reference trajectory, here the zero displacement of top story. We call this reference signalx_d. In order to achieve this goal, a first order sliding surface is defined and the control input is calculated such that the system response reaches the sliding surface in a finite time. Equations 1 and 2 depict the governing dynamic equations of motion for the system in the state space form.

$$\dot{X} = AX + BU \tag{1}$$

$$Y = CX \tag{2}$$

Where Ais the physical characteristics matrix, Bis input matrix, and C is the output matrix.

$$U = \left[f \quad \ddot{x}_g \right]' \text{ , } X = \left[x_1 \quad x_2 \quad \dot{x}_1 \quad \dot{x}_2 \right]' \tag{3}$$

Moreover, U is the inputs vector. $\ddot{x}_g$ is ground acceleration, here the shake table acceleration, and f is the AMD control force.

Equation 4shows the sliding surface.

$$s = \left(\mathrm{a} + \frac{d}{dt} \right)^{2-1} \hat{x} = \mathrm{a}\,\hat{x} + \dot{\hat{x}} \tag{4}$$

Inthis equation $\hat{x}$ is the tracking error vector and a is a positiveintegerconstant.Applying the sliding condition, the control input is calculated as bellow.

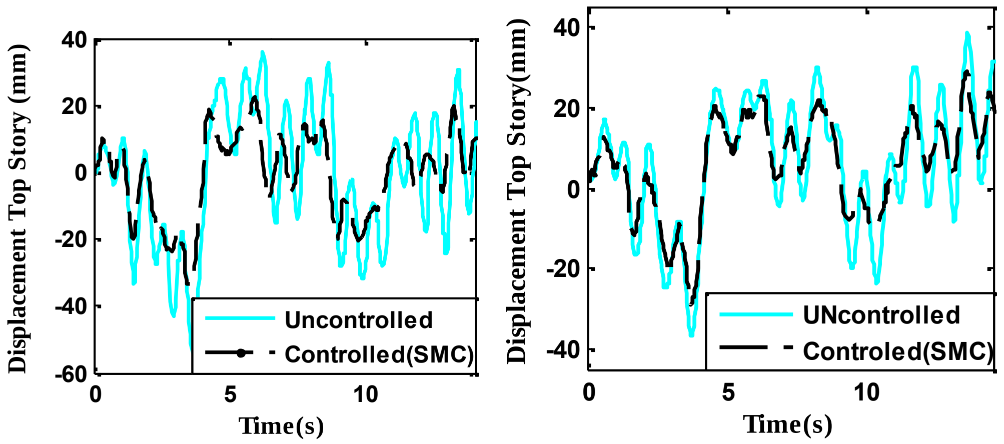
$$u = -5\dot{x}_2 - 86.89x_1 + 69.01x_2 - 0.47\dot{x}_1 + 0.47\dot{x}_2 - ksat(\frac{\mathrm{a}\,x_2 + \dot{x}_2}{\text{¤}}) \tag{5}$$

EXPERIENTIAL RESULTS ANDANALYSIS

The proposed sliding controller is implemented in the AMD system and its performance is assessed during a shake table test. A scaled version of Chalfont earthquake is employed as the seismic disturbance and is simulated by the shake table.

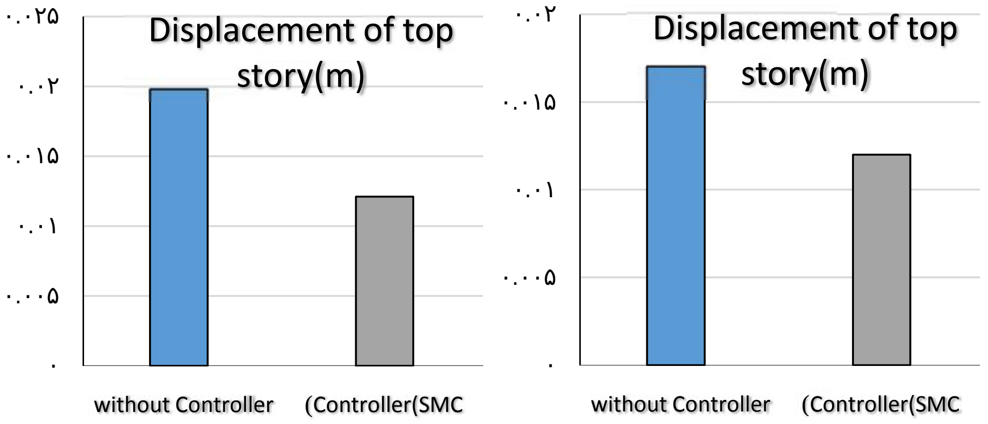
In order to have an objective measure of the response histories, the root mean square (RMS) criterion is employed and RMS of the top story displacement and the base shear are calculated for the structure with and without AMD system. Besides, in order to have an estimate of the system failure as a result of large displacements, inter-story drift response histories are also compared. Furthermore, in order to check robustness of the system, a 20 percent mass uncertainty has been considered in the control law calculations.

Figure 8 illustrates base shear for both controlled and uncontrolled system. Moreover, figure 4 shows the response histories for the top stories with and without uncertainty. As it is seen in this figure, the sliding controller could successfully decrease the amplitude of the transmitted displacements up to an acceptable level, even in the presence of uncertainties, implying robustness of the controller in tackling parametric uncertainty.



(a) (b)

Figure4. Top story displacement a)without uncertainty b)with uncertainty

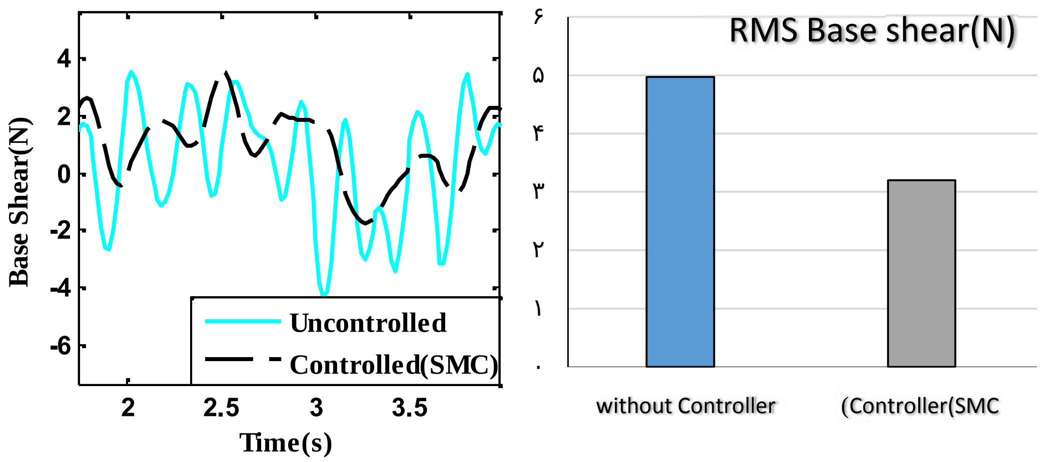


(a) **(b)**

Figure 5.RMS of top story displacement (a) without uncertainty (b) with uncertainty

Figure 5 also summarizes the same results as RMS criterion. As it is seen in this figure, a considerable drop in the top story displacement is reported for both cases.

Figure 6 compares the base shears with and without the AMD system. According to the obtained results, a substantial decrease in the base shear is calculated as a result of the AMD system application.



(a) **(b)**

Figure6. Base shear response a)response history b)RMS of responses

Finally figure7 illustrates the maximum inter-story response history for the structure with and without the AMD system. As it is seen in this figure, the AMD system causes a considerable decrease in the inter-story drift. This result is in agreement with the top story displacement results.

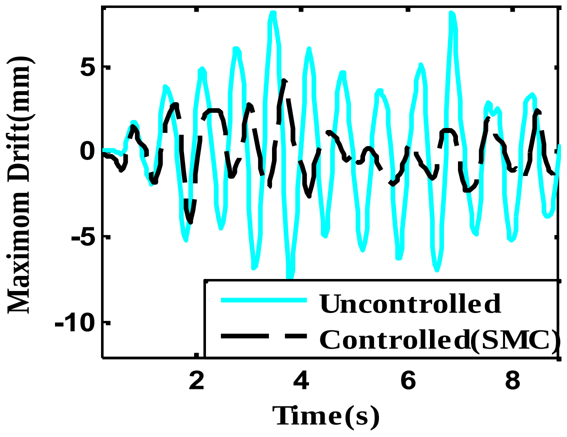


Figure7. Maximum drift response history

CONCLUSION

Design and implementation of a sliding mode controller for a laboratory-scale structure developed based on a reduced model of a high-rise building was presented in this paper. The AMD system comprises an electric motor and a mechanical mechanism as the transmission system. The proposed controller is a two loop one with a sliding controller as the main loop and a PI controller for controlling the electric motor current. The controller was implemented in the AMD system and its performance was evaluated via shake table test in the presence of mass uncertainty. The test results proved the effectiveness and robustness of the proposed controller in suppressing inter-story drift and base shear responses in the presence of uncertainties.

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