Suppression of Building Vibrations Using PD+PI Type Fuzzy Logic Controller

Yuksel Hacioglu
Department of Mechanical Engineering, Istanbul University, Avcilar, Istanbul, Turkey

Keywords: Building Vibrations, Fuzzy Logic Control, Earthquake Excitation.

Abstract: In order to bring the useful properties of PD and PI type fuzzy logic controllers together, a PD+PI type fuzzy logic controller for vibration suppression of a building was presented in this study. The building has nine storeys and an active tuned mass damper was placed on the top floor. The building model was excited with a real earthquake ground motion. The results have shown that designed controller attenuated the building vibrations successfully.

1 INTRODUCTION

During the last decades developing technology gave rise to construction of high and slender buildings and those tall buildings are more susceptible to dangerous effects of earthquakes. This is why the control of building vibrations is essential. In fact suppressing the vibrations will result in increased safety and comfort of occupants. The tuned mass damper (TMD), which is an auxiliary mass connected to the main body via a spring and a damper, has been widely used (Ahlawat and Ramaswamy, 2003). In recent years active tuned mass dampers (ATMD) were also presented where an actuator is placed generally parallel to the spring and damper. Various control strategies have been proposed with ATMD equipped buildings such as LQR control (Fujita, 1994), fuzzy logic control (Guclu and Yazici, 2008), H_∞ control (Poncela et al., 2007) and backstepping control (Hacioglu and Yagiz, 2012).

Fuzzy logic control, which is based on fuzzy set theory presented by Zadeh (Zadeh, 1965), has become popular within automatic control community during the last years. This is mainly due to the fact that it do not require the exact mathematical model of the system and make possible to use the knowledge in linguistic form coming from the experts. Fuzzy logic control has found different application areas such as active vehicle suspension control (Yagiz et al., 2008), robotic manipulator control (Yagiz and Hacioglu), power systems control (Yesil et al., 2004) etc.

It is well known that classical fuzzy logic controller namely PD type fuzzy controller can give rise to steady state errors. On the other hand using PI type fuzzy logic can solve this problem but with possible poor transient performance. Therefore in this study a PD+PI type fuzzy logic controller is designed for the ATMD controlled nine storey building model.

2 BUILDING MODEL

A nine storey building model as seen in Figure 1 is used in this study. The ATMD is placed on top floor. Here, m_i, k_i, b_i, and y_i ($i=1,\ldots,9$) denote the mass, stiffness, damping and lateral absolute displacement of the related storey, respectively. Additionally, m_{10}, k_{10}, b_{10} and y_{10} stand for the mass, stiffness, damping and lateral absolute displacement of the ATMD, respectively; u is the control force generated by the actuator; y_0 is the earthquake ground motion input to the building.

The equations of motion of the building model are given below.

It should be noted that, in equations (1) – (10) if $u=0$, then the equations of motion for the building model with TMD is obtained. If in addition, $m_{10}=0$, $k_{10}=0$ and $b_{10}=0$ are set then, the equations of motion for the building model without any auxiliary mass are obtained.

Hacioglu Y..
Suppression of Building Vibrations Using PD+PI Type Fuzzy Logic Controller.
DOI: 10.5220/0005129101530157
In *Proceedings of the International Conference on Fuzzy Computation Theory and Applications* (FCTA-2014), pages 153-157
ISBN: 978-989-758-053-6

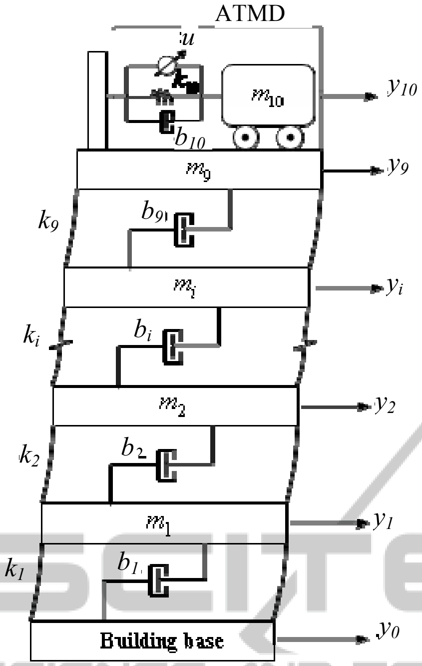

Figure 1: The building model.

$$m_1\ddot{y}_1 + b_1(\dot{y}_1-\dot{y}_0) - b_2(\dot{y}_2-\dot{y}_1) + k_1(y_1-y_0) - k_2(y_2-y_1) = 0 \quad (1)$$

$$m_2\ddot{y}_2 + b_2(\dot{y}_2-\dot{y}_1) - b_3(\dot{y}_3-\dot{y}_2) + k_2(y_2-y_1) - k_3(y_3-y_2) = 0 \quad (2)$$

$$m_3\ddot{y}_3 + b_3(\dot{y}_3-\dot{y}_2) - b_4(\dot{y}_4-\dot{y}_3) + k_3(y_3-y_2) - k_4(y_4-y_3) = 0 \quad (3)$$

$$m_4\ddot{y}_4 + b_4(\dot{y}_4-\dot{y}_3) - b_5(\dot{y}_5-\dot{y}_4) + k_4(y_4-y_3) - k_5(y_5-y_4) = 0 \quad (4)$$

$$m_5\ddot{y}_5 + b_5(\dot{y}_5-\dot{y}_4) - b_6(\dot{y}_6-\dot{y}_5) + k_5(y_5-y_4) - k_6(y_6-y_5) = 0 \quad (5)$$

$$m_6\ddot{y}_6 + b_6(\dot{y}_6-\dot{y}_5) - b_7(\dot{y}_7-\dot{y}_6) + k_6(y_6-y_5) - k_7(y_7-y_6) = 0 \quad (6)$$

$$m_7\ddot{y}_7 + b_7(\dot{y}_7-\dot{y}_6) - b_8(\dot{y}_8-\dot{y}_7) + k_7(y_7-y_6) - k_8(y_8-y_7) = 0 \quad (7)$$

$$m_8\ddot{y}_8 + b_8(\dot{y}_8-\dot{y}_7) - b_9(\dot{y}_9-\dot{y}_8) + k_8(y_8-y_7) - k_9(y_9-y_8) = 0 \quad (8)$$

$$m_9\ddot{y}_9 + b_9(\dot{y}_9-\dot{y}_8) - b_{10}(\dot{y}_{10}-\dot{y}_9) + k_9(y_9-y_8) - k_{10}(y_{10}-y_9) = u \quad (9)$$

$$m_{10}\ddot{y}_{10} + b_{10}(\dot{y}_{10}-\dot{y}_9) + k_{10}(y_{10}-y_9) = -u \quad (10)$$

3 CONTROLLER DESIGN

The PD+PI type fuzzy logic controller is presented in this section. It consists of two parts as seen in Figure 2, namely the PD and PI parts. The fuzzy logic controllers use the error e_N and its derivative $\dot{e}_N$ as inputs. The output of the PD-type fuzzy controller is the control signal u_N and the output of the PI-type fuzzy logic controller is the incremental change in control signal Δu_N. Then the resultant control law for the designed PD+PI controller is given as

$$u(t)_{PD+PI} = u(t)_{PD} + \Delta u(t)_{PI} + u(t-\delta t)_{PI} \quad (11)$$

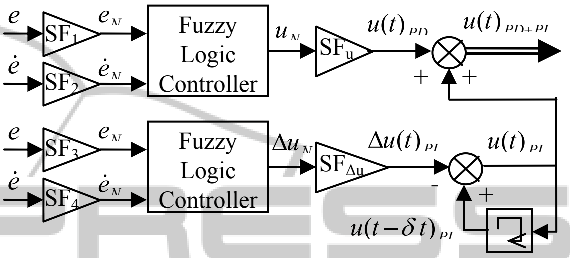

Figure 2: Structure of the controller.

As presented in Figure 3, Gaussian membership functions all defined on the [-1,1] closed interval are used for the input and output variables. Therefore scaling factors (SF_i: input scaling factors; SF_u and $SF_{(\Delta u)}$: output scaling factors) are used in order to map the crisp variables to their fuzzy counterparts. For the membership functions used, NB, NM, NS, Z, PS, PM and PB denote negative big, negative medium, negative small, zero, positive small, positive medium and positive big, respectively.

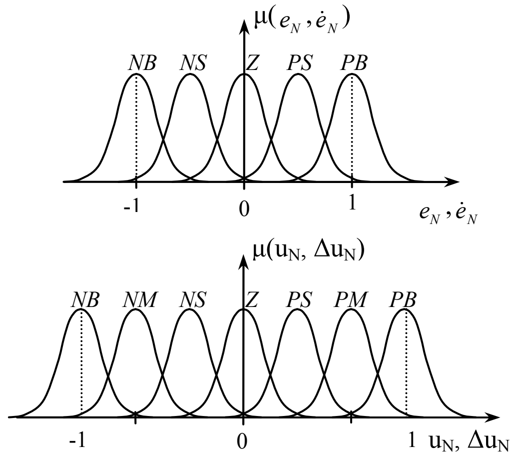

Figure 3: Membership functions for the input and output variables.

The fuzzy rules are presented in Table 1 and they were arranged in such a manner that the input variables are forced to be zero. For example if error is positive big (*e*=PB) and derivative of error is zero ($\dot{e}$=Z) the control output variables are selected to be positive medium (u_N=PM and Δu_N=PM). Similarly if both inputs are zero, which is the desired case, then the control outputs are selected to be zero (u_N=Z and Δu_N=Z).

Table 1: Fuzzy rule table for u_N and Δu_N.

$\dot{e}_N$ e_N	***NB***	***NS***	***Z***	***PS***	***PB***
NB	*NB*	*NB*	*NM*	*NS*	*Z*
NS	*NB*	*NM*	*NS*	*Z*	*PS*
Z	*NM*	*NS*	*Z*	*PS*	*PM*
PS	*NS*	*Z*	*PS*	*PM*	*PB*
PB	*Z*	*PS*	*PM*	*PB*	*PB*

4 NUMERICAL RESULTS

The numerical results for the nine storey building model with PD+PI type fuzzy logic controlled ATMD is presented in this section. The ground motion in East-West direction of the Kocaeli Earthquake in Turkey, which occurred on 17 August 1999, was applied to the base of the building model as shown in Figure 4. The data used was recorded during the main shock of that earthquake by the station located in Besiktas, Istanbul, Turkey (Acceleration data is available at the website of the National Strong Motion Observation Network of Turkey). Active and passive modes are introduced for the ATMD. For small vibrations of the building, the controller is inactive thus ATMD becomes TMD and for large vibrations of the building the controller is active thus TMD becomes ATMD. The average of the absolute value of the top floor displacement calculated over last Δt=2 s time period was used for switching criterion.

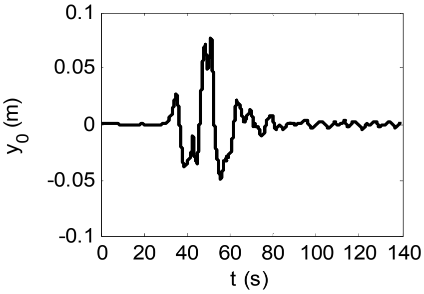

Figure 4: Earthquake ground motion.

The displacements and accelerations of the top floor are presented in Figure 5 and Figure 6 for the building model without TMD or ATMD (which is called Passive), with TMD and with designed fuzzy logic controlled ATMD. It is observed from those figures that both TMD and ATMD reduced the building vibrations, and it is obvious that the fuzzy logic controlled ATMD achieved better vibration isolation than the TMD case.

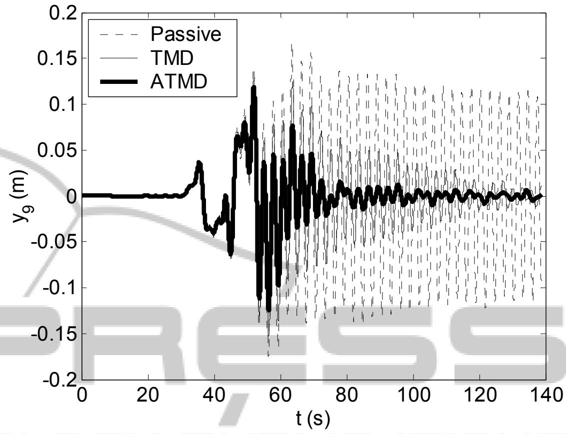

Figure 5: Displacement of the top floor.

The displacements of the TMD and ATMD are shown in Figure 7. It is seen that the ATMD moves much more than the TMD while being in reasonable ranges. Controller force for the ATMD case is also given in Figure 8.

Finally, the RMS values of the displacements and accelerations of the building floors are calculated and presented in Figure 9 and Figure 10 for the passive, TMD and ATMD cases. It is clear from those figures that the designed PD+PI type fuzzy logic controlled ATMD reduced those RMS values for displacements and accelerations much more than the TMD case, which confirmed the superior performance of the designed controller.

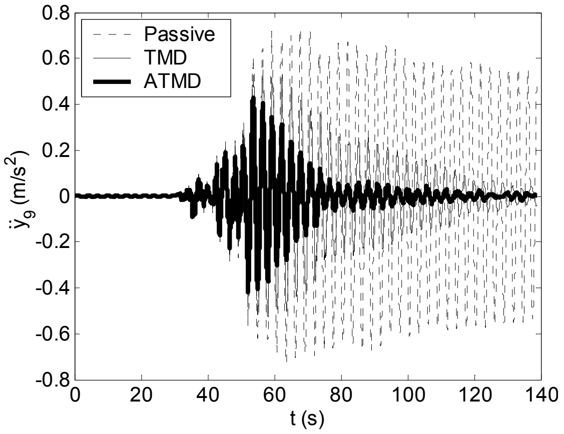

Figure 6: Accelerations of the top floor.

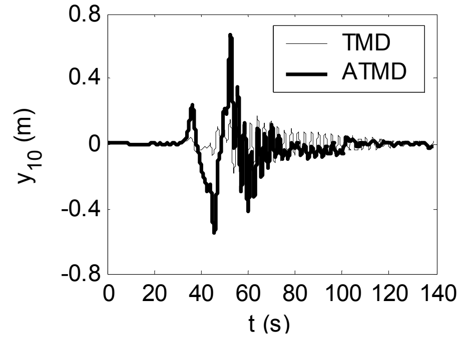

Figure 7: Displacements of the TMD and ATMD.

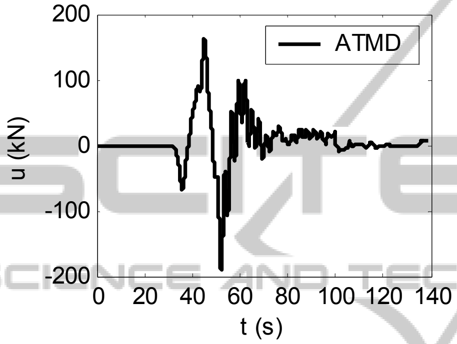

Figure 8: The controller force.

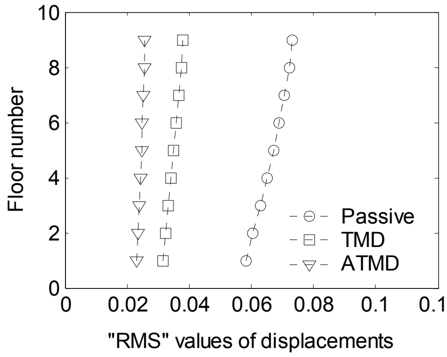

Figure 9: RMS values for the displacements of the all floors.

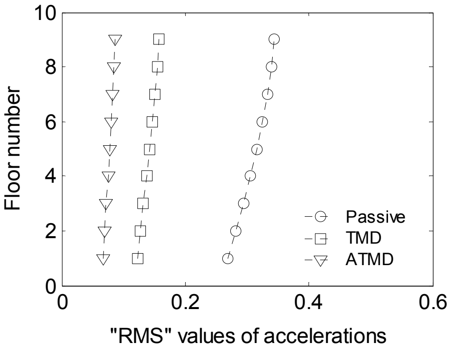

Figure 10: RMS values for the accelerations of the all floors.

5 CONCLUSIONS

In order to suppress the earthquake induced vibrations of a nine storey building, a PD+PI fuzzy logic controller was designed. The controller was applied through an active tuned mass damper installed on the top floor of the building. The results indicated that the designed controller has attenuated the vibrations of the building floors to a certain degree.

REFERENCES

Ahlawat, A.S. and Ramaswamy A, 2003. Multiobjective optimal absorber system for torsionally coupled seismically excited structures. *Engineering Structures* 25(7), 941-950.

Fujita, T., 1994. Application of hybrid mass damper with convertible active and passive modes using hydraulic actuator to high-rise building. *Proceedings of the American Control Conference, Baltimore, Maryland,* June 29 - July 1, Vol. 1, 1067-1072.

Guclu, R. and Yazici, H., 2008. Vibration control of a structure with ATMD against earthquake using fuzzy logic controllers. *Journal of Sound and Vibration* 318(1-2), 36-49.

Hacioglu, Y., Yagiz, N., 2012. Adaptive backstepping control with estimation for the vibration isolation of buildings, *Journal of Vibration and Control*, 18(13), 1996-2005.

National Strong Motion Observation Network of Turkey. Available at: http://kyh.deprem.gov.tr

Poncela A., Casado C., Baeyens E. and Peran J.R., 2007. Design of devices for protecting civil structures using fixed-order control. *Structural Control and Health Monitoring* 14(2), 239-260.

Yagiz, N., Hacioglu, Y., 2005. Fuzzy sliding modes with moving surface for the robust control of a planar robot, *Journal of Vibration and Control*, 11(7), 903-922.

Yagiz, N., Hacioglu, Y., Taskin, Y., 2008. Fuzzy sliding-mode control of active suspensions, *IEEE Transactions on Industrial Electronics*, 55(11), 3883-3890.

Yesil, E., Guzelkaya, M., Eksin, I., 2004. Self tuning fuzzy PID type load and frequency controller, *Energy Conversion and Management*, 45, 377-390.

Zadeh, L.A. 1965. Fuzzy Sets, *Information and Control*, 8, 338-353.

APPENDIX

Table A1: Numerical values of the parameters of the building model.

Parameter	Value $\times 10^3$ kg
m_1	450
m_2	345
m_3	345
m_4	345
m_5	345
m_6	345
m_7	345
m_8	345
m_9	345
m_{10}	69

Parameter	Value $\times 10^6$ N/m
k_1	18.05
k_2	340
k_3	326
k_4	285
k_5	269
k_6	243
k_7	207
k_8	169
k_9	137
k_{10}	0.3365

Parameter	Value $\times 10^3$ N s/m
b_1	26.17
b_2	490
b_3	467
b_4	410
b_5	386
b_6	348
b_7	298
b_8	243
b_9	196
b_{10}	152.39

Table A2: Numerical values of the parameters of the controller.

Parameter	Value
SF_1	1.5
SF_2	1
SF_3	1.5
SF_4	1
SF_u	200000
$SF_{\Delta u}$	4000