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.
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 $Ne$ 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 $\Delta u_N$. Then the resultant control law for the designed PD+PI controller is given as

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

(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$_{\Delta u}$: 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

$$m_N\ddot{y}_i + b_N(\dot{y}_i - \dot{\bar{y}}_i) - b_i(\bar{y}_i - \bar{\bar{y}}_i) + k_i(y_i - y_0)$$

(1)

$$-k_i(y_i - y_0) = 0$$

(2)

$$m_N\ddot{y}_i + b_N(\dot{y}_i - \dot{\bar{y}}_i) - b_i(\bar{y}_i - \bar{\bar{y}}_i) + k_i(y_i - y_0)$$

(3)

$$-k_i(y_i - y_0) = 0$$

(4)

$$m_N\ddot{y}_i + b_N(\dot{y}_i - \dot{\bar{y}}_i) - b_i(\bar{y}_i - \bar{\bar{y}}_i) + k_i(y_i - y_0)$$

(5)

$$-k_i(y_i - y_0) = 0$$

(6)

$$m_N\ddot{y}_i + b_N(\dot{y}_i - \dot{\bar{y}}_i) - b_i(\bar{y}_i - \bar{\bar{y}}_i) + k_i(y_i - y_0)$$

(7)

$$-k_i(y_i - y_0) = 0$$

(8)

$$m_N\ddot{y}_i + b_N(\dot{y}_i - \dot{\bar{y}}_i) - b_i(\bar{y}_i - \bar{\bar{y}}_i) + k_i(y_i - y_0)$$

(9)

$$-k_i(y_i - y_0) = u$$

(10)
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 $\Delta u_N=PM$). Similarly if both inputs are zero, which is the desired case, then the control outputs are selected to be zero ($u_N=Z$ and $\Delta u_N=Z$).

### Table 1: Fuzzy rule table for $u_N$ and $\Delta u_N$.

<table>
<thead>
<tr>
<th>$\dot{e}_N$</th>
<th>$e_N$</th>
<th>NB</th>
<th>NS</th>
<th>Z</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>NB</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td></td>
</tr>
<tr>
<td>NS</td>
<td>NB</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>NM</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>NS</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
<td></td>
</tr>
<tr>
<td>PB</td>
<td>Z</td>
<td>PS</td>
<td>PM</td>
<td>PB</td>
<td>PB</td>
<td></td>
</tr>
</tbody>
</table>

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 $\Delta t=2$ s time period was used for switching criterion.

![Figure 4: Earthquake ground motion.](image)

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.](image)

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.](image)
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


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


### APPENDIX

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\times 10^3$ kg</td>
</tr>
<tr>
<td>$m_1$</td>
<td>450</td>
</tr>
<tr>
<td>$m_2$</td>
<td>345</td>
</tr>
<tr>
<td>$m_3$</td>
<td>345</td>
</tr>
<tr>
<td>$m_4$</td>
<td>345</td>
</tr>
<tr>
<td>$m_5$</td>
<td>345</td>
</tr>
<tr>
<td>$m_6$</td>
<td>345</td>
</tr>
<tr>
<td>$m_7$</td>
<td>345</td>
</tr>
<tr>
<td>$m_8$</td>
<td>345</td>
</tr>
<tr>
<td>$m_9$</td>
<td>345</td>
</tr>
<tr>
<td>$m_{10}$</td>
<td>69</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$\times 10^{-3}$ N s/m</td>
</tr>
<tr>
<td>$b_1$</td>
<td>26.17</td>
</tr>
<tr>
<td>$b_2$</td>
<td>490</td>
</tr>
<tr>
<td>$b_3$</td>
<td>467</td>
</tr>
<tr>
<td>$b_4$</td>
<td>410</td>
</tr>
<tr>
<td>$b_5$</td>
<td>386</td>
</tr>
<tr>
<td>$b_6$</td>
<td>348</td>
</tr>
<tr>
<td>$b_7$</td>
<td>298</td>
</tr>
<tr>
<td>$b_8$</td>
<td>243</td>
</tr>
<tr>
<td>$b_9$</td>
<td>196</td>
</tr>
<tr>
<td>$b_{10}$</td>
<td>152.39</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF1</td>
<td>1.5</td>
</tr>
<tr>
<td>SF2</td>
<td>1</td>
</tr>
<tr>
<td>SF3</td>
<td>1.5</td>
</tr>
<tr>
<td>SF4</td>
<td>1</td>
</tr>
<tr>
<td>SFu</td>
<td>200000</td>
</tr>
<tr>
<td>SF_{40}</td>
<td>4000</td>
</tr>
</tbody>
</table>