2018 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS 2018), 20 October 2018, Shah Alam, Malaysia

Analysis of Implementation Control Device in Hybrid Mass Damper System

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***Abstract*—The paper present the implementation of control device to tenth storey building that refer to highrise building equipped with hybrid mass damper (HMD). Fuzzy logic control (FLC) is chosen as control strategy because of its robustness character and suitable to control nonlinearity and uncertainties system. The performance of FLC in suppressing the building vibration is proven by reduces the vibration compared to tuned mass damper and uncontrolled system. This paper also studies the placement of control device in influence the building vibration control that located at lowest, top and combines both control devices at lowest and top of the building floor. The input excitation is taken from El Centro earthquake occur in 1940. In the end, the analysis of implementation HMD on the building structure is analyzed, the design of control strategy is studied and conclusions are achieved.**

Keywords—Vibration control, earthquake, fuzzy logic control, hybrid mass damper

I. Introduction

Many high-rise building structures have been developed nowadays. However, natural disaster may cause huge impact to building structure by make it collapse and cause huge economic losses. It is essential to protect the building from damages and collapse either from earthquake or strong winds. Therefore control device are introduced to defense this structure. Structural vibration control can be divided to four categories which is passive, active, semi-active and hybrid control. Tune mass damper (TMD) is one of the examples of passive device that does not use any power supply to control vibration structure. It was introduced by McNamara in 1977 with a practical application [1]. Then TMD have been applied in many structural controls as proposed by [2]–[4].

Active control device is then introduced to overcome the problems of structural frequency specific tune in passive control device, The paper proposed by Yi *et al.* [5] had compared between passive and active device in suppressed the structural vibration in 2000 resulting active control device generate lower structural vibration compared to passive device. However, disadvantage of active control device is it used high power requirement in its operation. Among of these control device hybrid mass damper are most preferable due to its advantages that can overcome the problems cause by passive and active device and at the same time have both advanatges of robustness from passive device and high performance by active device. HMD or known as active tune mass damper applied both passive and active device in a single model that act to minimize the structural building vibration during earthquake or strong winds. HMD are found to be cost effectiveness by reduced energy requirement in their operation [6]. An extensive research has been studied in the application of control technique for this control device such as sliding mode control, FLC, PID, H∞, and etc in reducing building vibration.

Thenozhi *et al.* [7] and Guclu *et al*. [8] applied PID to structural control equipped with active device. Although the implementation of PID is simple, however this type of control technique does not achieve structural response requirement because of difficulty in tuning the parameter [9]. Linear quadratic regulator (LQR) also the most researchers studied in their paper because of practical control algorithm to reduce the structural vibration since 1970 equipped with active control device [10]. LQR are found effective in reduce structural vibration as proposed by [11]–[13].

Many more control strategies investigated by researcher in structural application control. However, this paper is focus on FLC because of its inherent robustness, the computation are simple in driving the controller, and easy implemented especially into fuzzy chip [14]. This method was firstly introduced in 1965 by Lotfi Zadeh by published his "Fuzzy Sets" to technical society [15]. Then Dimitrov stated that fuzzy logic is applied rational thinking and using the concept of "IF-THEN". The sets of fuzzy present the unique linguistic expression such as positive, zero, and negative. There are four components need to considered before generate the desired output which is firstly by fuzzifier. Then knowledge in rules and membership function. Third is by fuzzy reasoning and lastly is by defuzzifier interface [16]. Paper proposed by [15], [17], and [18] have applied FLC in their studied on structural control. FLC is one of the few algorithms free approaches to system identification and control that makes the system easier to design compared by generate an accurate mathematical model for the system with control design. Besides, FLC can solve the structure non-linearity behavior that cause by material non-linearity or by large displacement [19]. The aim of the paper is to study the performance of building structure during earthquake by implement the control device at lowest and top floor of the structure. The efficient of controlling device is determined by combine both techniques in a single structural system. Then the performances of control device are compared between the uncontrolled structure, passive, HMD and applied both techniques.

This paper is organized by derived the mathematical model for tenth storey building with HMD on the structure. The next section is by design the system and controller based on the parameter and setting used. At section 4, this paper shows the result obtain from the simulation for tenth storey

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structure without HMD and equipped with HMD and analysis the result. Finally, the conclusions have been concluded based on overall result and simulation.

II. Structural System

The system model use tenth storey building structure that represent as high-rise building equipped with active and hybrid control device at top and below building structure. The placements of control device are study to evaluate the building performance during earthquake. The implementation of active device is install at the first floor as shown in Figure1 (a) while HMD is install at the top floor is shown in Figure 1 (b) and the combination of both control device is shown in Figure 1 (c). The system with symbol *M* is represent the mass at each building structure floor, *C* is damping coefficient, *K* is stiffness, while m_d is represent as mass, c_d is damping coefficient, k_d is stiffness for TMD/HMD device.

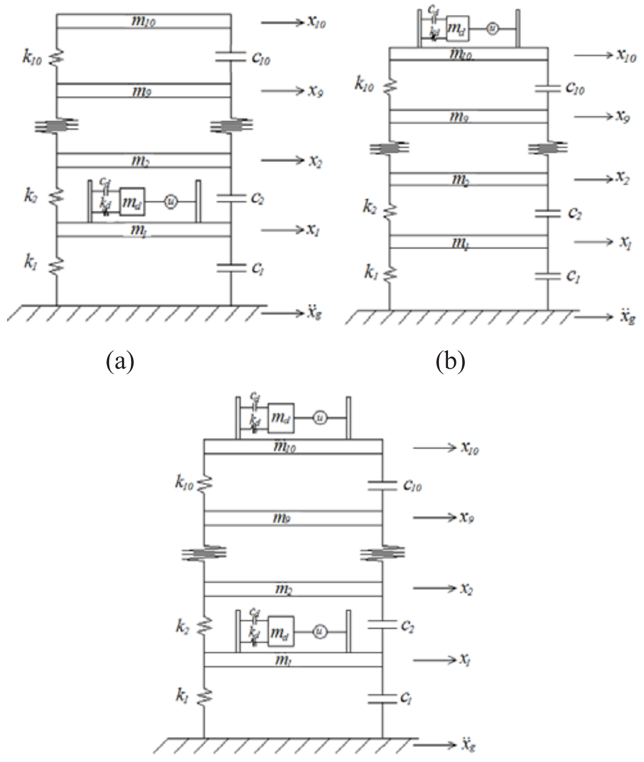


Fig. 1. Implementation of control device (a) at first floor (b) at top floor (c) at first and top floor

The mathematical model for TMD is written as in (1) where TMD is consist with mass, spring and damper that attached to the system used to attenuate any unwanted vibration. This type of classical control device is design by calculate its required natural frequency in suppressing the structure vibration. The mathematical model for HMD is written in (2). Where $\ddot{x}_g$ is ground acceleration and f_u is active control force generate by actuator. HMD implement actuator as active control device to generate external control forces to the structure. Equation (3), (4) and (5) show matrices form equation for mass, damping and stiffness for tenth storey building.

$$M\ddot{x} + C\dot{x} + Kx = -Mr\ddot{x}_g \quad (1)$$

$$M\ddot{x} + C\dot{x} + Kx = -Mr\ddot{x}_g + f_u \quad (2)$$

$$M = \begin{bmatrix} m_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & m_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & m_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & m_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & m_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & m_{10} \end{bmatrix} \quad (3)$$

$$C = \begin{bmatrix} C_1+C_2 & -C_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -C_2 & C_2+C_3 & -C_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -C_3 & C_3+C_4 & C_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -C_4 & C_4+C_5 & -C_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -C_5 & C_5+C_6 & -C_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -C_6 & C_6+C_7 & -C_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -C_7 & C_7+C_8 & -C_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -C_8 & C_8+C_9 & -C_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -C_9 & C_9+C_{10} & -C_{10} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -C_{10} & C_{10} \end{bmatrix} \quad (4)$$

$$K = \begin{bmatrix} k_1+k_2 & -k_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ -k_2 & k_2+k_3 & -k_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -k_3 & k_3+k_4 & -k_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -k_4 & k_4+k_5 & -k_5 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -k_5 & k_5+k_6 & -k_6 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -k_6 & k_6+k_7 & -k_7 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -k_7 & k_7+k_8 & -k_8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & -k_8 & k_8+k_9 & -k_9 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_9 & k_9+k_{10} & -k_{10} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -k_{10} & k_{10} \end{bmatrix} \quad (5)$$

The equation of actuator as stated in [9] is written as (6) and (7). Where *u, i, R,* K_e, and K_f are control voltage, armature coil current, resistance value, armature coil induced voltage and thrust constant.

$$Ri + K_e(\dot{x}_1 - \dot{x}_0) = u \quad (6)$$

$$F_u = K_f i \quad (7)$$

III. Methodology

In order to study the effect of control device placement and the implementation of controller to the system, the simulation is design by construct the system of tenth storey structure and design fuzzy logic controller based on described as following.

A. System Design

In designing the system, the mathematical model for tenth storey building structure is derived to obtain the relationship between mass, spring, damper, force and actuator as shown in equation (1-2). This equation is then constructed in Simulink and the system parameter is tabulated in Table 1.

TABLE 1. SYSTEM PARAMETER

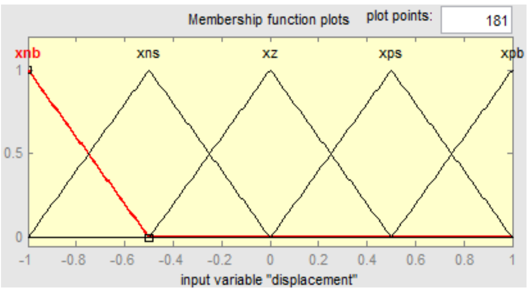
	Mass (kg)	**Stiffness (10e5N/m)**	**Damping (10e5N.s/m)**
Structure (each floor)	320000	930	15.69
Active/Passive TMD	44000	36.7	0.71

The earthquake ground motion taken from El Centro with magnitude of 7.1 *Mw* in 1940 is used as the input excitation into the structure.

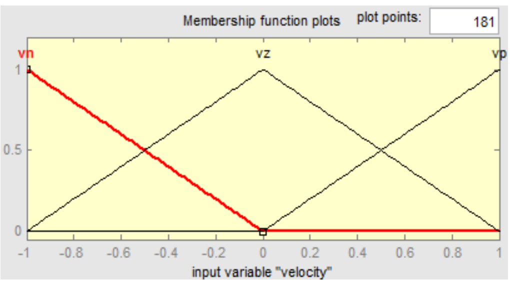
B. *Fuzzy Logic Control*

The application of FLC is simulate in Matlab/Simulink by using Fuzzy Toolbox and using Mamdani method. In structural vibration control, FLC is the best choice to reduce vibration because it can tolerates the uncertainties of the data from earthquake excitation and thus producing a controller system with robustness. Besides, having the ability to overcome large displacement that caused non-linear behavior of the structure and its rules or membership function can be modified suitable with desired output response [20].

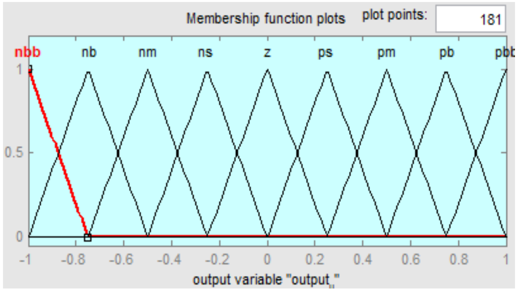
The model of FLC is consists with two inputs taken from error, *e* as the first input and its derivatives, *de/dt* as the second input while the output variables are control output, *u*. The rules used to simulate the structure system are shown as in Table 2 where P, N, Z, B, M and S are represent as Positive, Negative, Zero, Big, Medium and Small as mention in [21]. The triangular membership function are shown in Figure 2 with each membership function is set to common range between [-1 1]. The actual values for all this range is calculated by setting scaling factor at input (*Se* and *Sde*) and output (*Su*) of FLC.



(a)



(b)



(c)

Fig. 2. Membership function for FLC

TABLE 2. FLC RULES

de/dt \ e	**XNB**	**XNS**	**XZ**	**XPS**	**XPB**
VN	NB	NM	NS	Z	PS
VZ	NM	NS	Z	PS	PM
VP	NS	Z	PS	PM	PB

The closed loop diagrams of mass spring damper system with controller and actuator as shown in Figure 3. Where X_{ref} is the reference value for the system output and this value is set to *0* so that the structure will stable and remain at its position. *e(t)* is error value calculated by the desired value minus with the actual value, another input to controller is derivative error and then the controller will produce control signal value. Actuator produce force signal to the building and lastly, the system will produce the desired displacement position and at the same time reduce the overall building vibration.

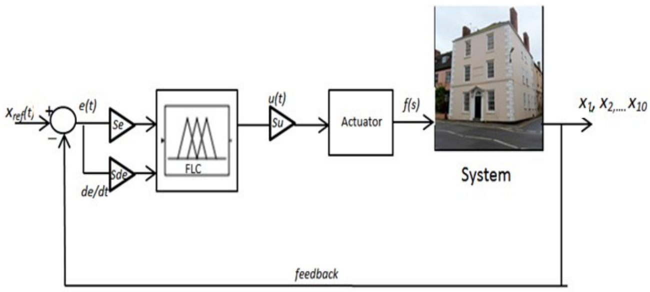


Fig. 3. Closed loop block diagram with the controller

IV. RESULT AND DISCUSSION

The building system are simulated against the earthquake excitation on 1940 at El Centro with 30s ground motion. The performance of HMD with the implementation at the top floor of the building, TMD and uncontrolled building are represent in Figure 4 which measure displacement from the response at tenth floor structure building. While Figure 5 shows the result measure from the displacement response at the first floor. This result show that HMD has reduce higher compared to TMD and uncontrolled structure. Then HMD is install at the first floor as shown in Figure 1 (a) resulting the structure vibration is higher than the implementation of HMD at the top floor as shown in Figure 6.

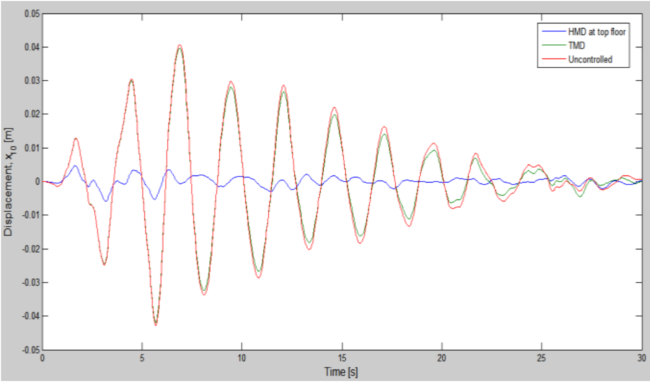


Fig. 4. Displacement response between uncontrolled, TMD and HMD measure at tenth floor building

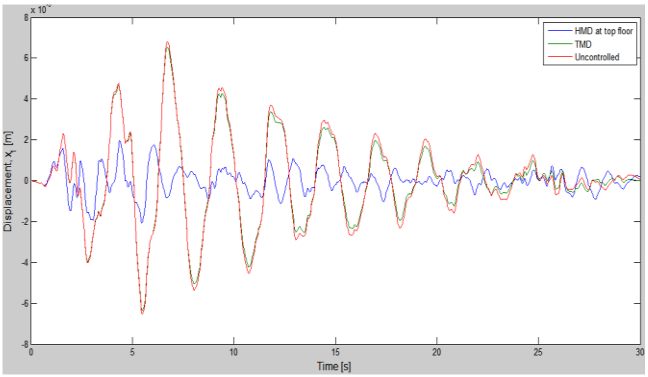


Fig. 5. Displacement response between uncontrolled, TMD and HMD measure at first floor building

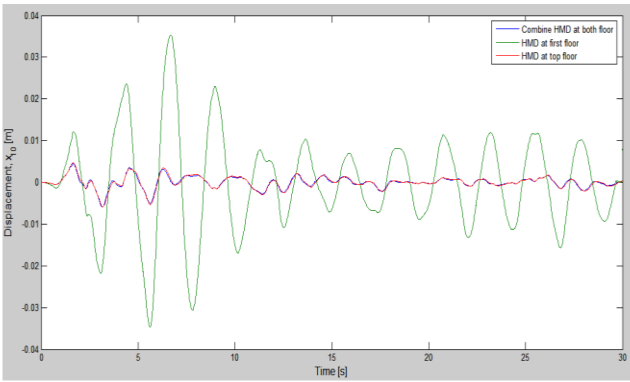


Fig. 6. Displacement response at tenth floor for three method implementation of HMD

Figure 7 shows the frequency response for tenth storey structure with various placement of HMD. Based from the result, the higher curves belong to uncontrolled system while the lowest curve is by combine both HMD in a system. However this result is close with implementation of HMD at top floor. This frequency response shows that the implementation of HMD in structural system can suppress the vibration during earthquake.

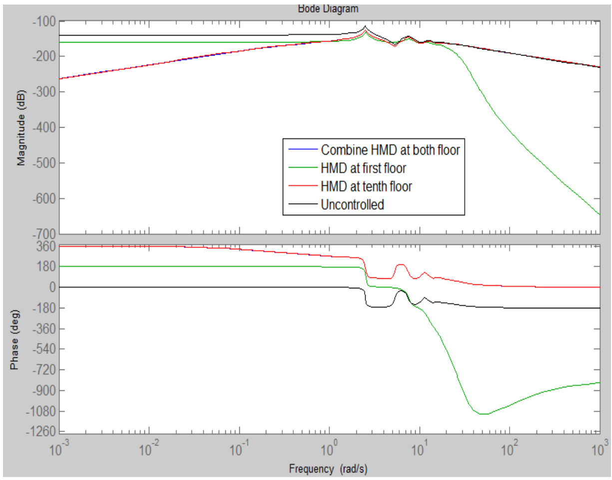


Fig. 7. Frequency response of tenth storey

The movement and comparison between applied methods can be seen clearly through the graph tabulate in Figure 8. Based from the figure, the implementation of HMD has reduces greater vibration of the structure. However the placement of HMD in a system influences the amount of vibration reduction and performance of the structure. The installation of HMD at the top floor reduces better than the installation of HMD at the lowest floor. The combination of both placement of HMD in a single system gives excellent performance. However the combination of these controlling devices in a single system may cause higher cost.

Figure 9 shows the force generates from actuator to the system in suppressing the structure vibration. The installation of HMD at the first floor generates 30kN while HMD at top floor generate 40kN in reducing the structure vibration.

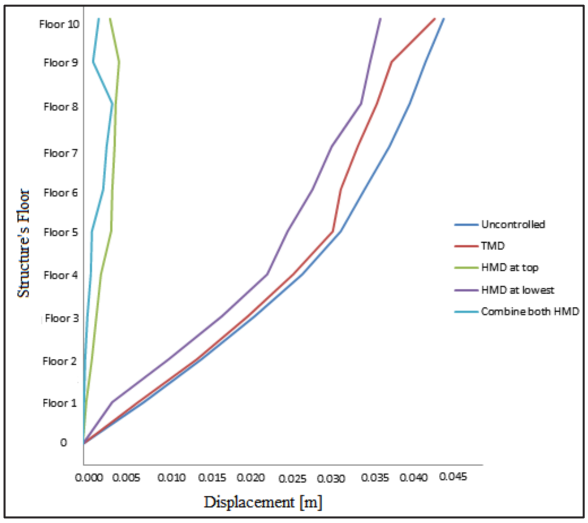
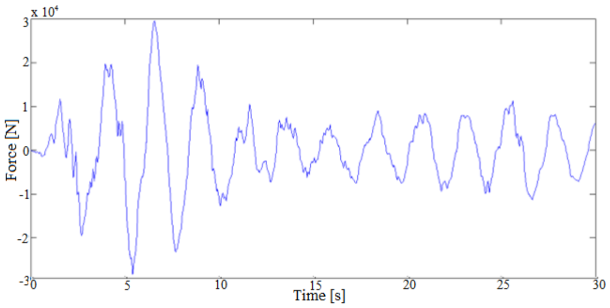
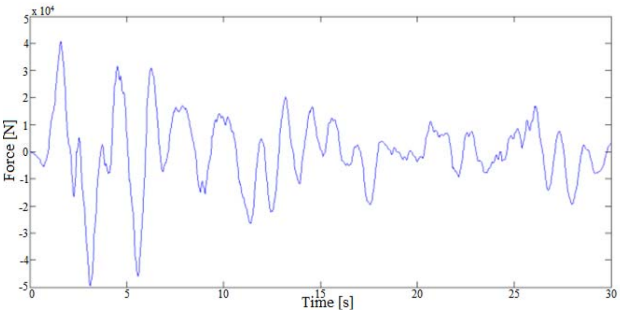


Fig. 8. Comparison uncontrolled, tune mass damper and hybrid mass damper for each storey building at 6.5s



(a)



(b)

Fig. 9. Force generate by actuator to the system (a) HMD at lowest floor (b) HMD at top floor

V. Conclusion

As conclusion, this paper presented the model, simulation and analysis of multiple DOF mass spring damper that represent as high-rise building structure system by implemented various control device placement which is at the lowest floor and the top floor. The simulation is using real seismic data as an input to mass spring damper system that obtain from El Centro earthquake that occur in 1940. FLC is used to improve the position performance of building during earthquake and increase the stability of the building. The application of FLC to tenth storey building structure equipped with HMD is compared to TMD and uncontrolled structure to evaluate the performance of HMD. The simulation result shows that the control methods are success to suppress the building vibration. Then the application of FLC to HMD is investigate by changing the location of HMD. The simulation result shows that that method influence the building response and form this result can be conclude that the implementation of HMD at top floor helps to reduce better than HMD at lowest floor. However, the combination of both control method had reduce higher vibration but this control method may cause higher cost especially in actual application.

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