Control of structure with tuned liquid column damper

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ABSTRACT

Advanced structures are long and slender and they have less damping. Hence they may undergo large oscillations when external lateral forces acts. These oscillations may produce catastrophe of the structure. Supplementary control devices are used to control these vibrations. One of a passive control device to minimize these oscillations is Tuned liquid column damper (TLCD). TLCD will shift the energy from the structure to TLCD by the motion of water in a U-shape tube fitted with an orifice opening. Therefore the oscillations will minimize. The aim of this paper is to study the potency of fuzzy logic control algorithm in TLCD structure system. The results are obtained with structure, with passive TLCD, PID and fuzzy controlled TLCD structure system. From this paper, the oscillations can be effectively suppressed with the proposed fuzzy controller.

KEY WORDS: vibrations, tuned liquid column damper, control device, state, passive, PID controller, fuzzy logic controller.

1. INTRODUCTION

Advanced structures are thin, elongate and bad damping structures. The oscillation will act on the stability of the structures. Hence the analysts focus on the structural control which weaken the oscillations by dissipating the energy. The control of structure can be executed in three ways: as passive, active and semi active. There is no need of external force in passive system, but in an active system a big amount of external force was needed for its working. A small external power source like battery is used in Semi active devices.

Tuned liquid column dampers (TLCD) are modification of a tuned liquid damper (TLD). TLCD will shift the energy from the structure to TLCD by the motion of water in a U-shape tube fitted with an orifice opening. Therefore the oscillations will minimize. Firstly the TLCD was brought into by Sakai (1989). The review of control devices is given (Housner, 1997). Hybrid liquid column damper was suggested by Haroun (1994). Yalla (2001, 2000), Hrovet (1983) etc were initiated with semi active TLCD. Abe (1996) studied the control laws for semi active TLCDs. Zeigler (2007), Soong (1991), Adeli (2008) etc were also worked with various aspects of TLCD. Xu (1992), Kareem (1994), Sun (1994) etc were studied the reaction of structures with TLCD to wind excitations. The response of structures with TLCD in earthquake loading was studied by Won (1996) Datta (2003) studied about the active control devices. Control algorithms are detailed in (Felix, 2006) and (Monica, 2012). Pourzeynali (2013) applied fuzzy control in variable stiffness device.

The nonlinear behaviour of the structure due to excitation can be accounted by fuzzy logic. Fuzzy logic has been used in semi active control to vary mechanical properties. The fuzzy theory was first introduced by Zadeh (1965). Mamdani (1974) successfully demonstrated Zadeh's theories of linguistic approach and fuzzy inference. Brown and Yao (1983), Juang and Elton (1986) etc. were applied the fuzzy set theory in civil engineering.

Smart control methods provide a method of approximate reasoning like human decision making process. Fuzzy controller is one of a smart control method. Fuzzy logic provides a formal idea for exhibiting and executing human knowledge about how to control a system. The potency of the fuzzy controlled system which is subjected to unit step force is studied.

The System: The testing system is shown in Fig 1.

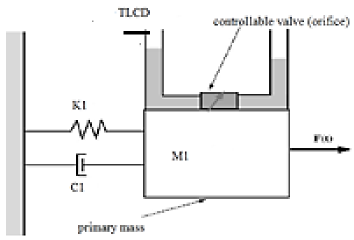


Figure.1. The system

The equation of motion of the system can be written as (Housner, 1997)

$$\begin{bmatrix} M_1 + m_d & \propto m_d \\ \propto m_d & m_d \end{bmatrix}\begin{bmatrix} \ddot{x_s} \\ \ddot{x_d} \end{bmatrix} + \begin{bmatrix} C_1 & 0 \\ 0 & 0 \end{bmatrix}\begin{bmatrix} \dot{x_s} \\ \dot{x_d} \end{bmatrix} + \begin{bmatrix} K_1 & 0 \\ 0 & k_d \end{bmatrix}\begin{bmatrix} x_s \\ x_d \end{bmatrix} = \begin{bmatrix} F(t) \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u(t) \qquad (1)$$

Where,

M_1 −structural mass

C_1 −dampingcoefficient of the structure

K_1 −structural stiffness
x_s −structural displacement
$\dot{x_s}$ −structural velocity
$\ddot{x_s}$ −acceleration of the structure
m_d −mass of the water column in the damper=(ρA*l*)
k_d −stiffness of the water column in the damper=(2ρAg)
x_d −displacement of the water in the damper
$\dot{x_d}$ −velocity of the water in the damper
$\ddot{x_d}$ −acceleration of the water in the damper
ρ _ density of water
A- area of cross section of the tube
l- total length of the water column
α-length ratio (= b/*l*)
b- horizontal length of the column
g- gravitational constant
F(*t*)- external force acting in the structure
u(*t*)- control force
In state space form Eq (1) represented as,
$M\ddot{x}(t) + C\dot{x}(t) + kx(t) = E_1W(t) + B_1u(t)$ (2)
Then the state space form,
$\dot{x}(t) = AX + Bu$ (3)
Where $X=\begin{bmatrix} x \\ \dot{x} \end{bmatrix}$
$A=\begin{bmatrix} 0 & I \\ -M^{-1}K & -M^{-1}C \end{bmatrix}$
$B=\begin{bmatrix} 0 \\ M^{-1}B_1 \end{bmatrix}$
The building response can be represented as
Y=CX+Du (4)
Where,
C=[I], D=[0]
Fuzzy control: The schematic diagram of fuzzy controller is shown below.

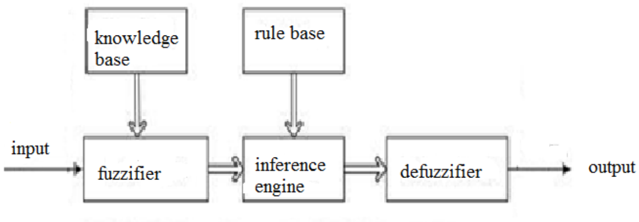


Figure.2. Fuzzy controller

Fuzzification (fuzzifier) part adapts crisp input values into fuzzy values. The knowledge base includes a database of the plant. This will provide all the required definitions for the fuzzification process. Rule base symbolize the controlling system of the network. It is exhibited as a set of if-then rules. Inference applies fuzzy reason to rule base to get the output. Defuzzification process changes fuzzy output to crisp values.

The fuzzy logic controller designed here consists of two inputs, namely error (er), change in error (cer) and an output (cf). The linguistic variables associated with inputs are ne and po. The linguistic variables associated with output are ne, ze and po. A simple rule base connecting these variables, which consists of four rules, is given in Table 1. Triangular shaped membership functions are chosen and are shown in the Figs 3 to 5. Fuzzy logic controller is executed by using Matlab Simulink fuzzy logic toolbox.

Table.1.Rule base for fuzzy controller

er / cer	ne	po
ne	ne	ze
po	ze	po

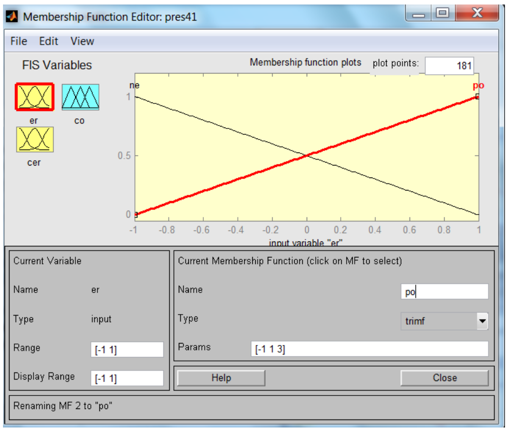


Figure.3. Membership function for input1.

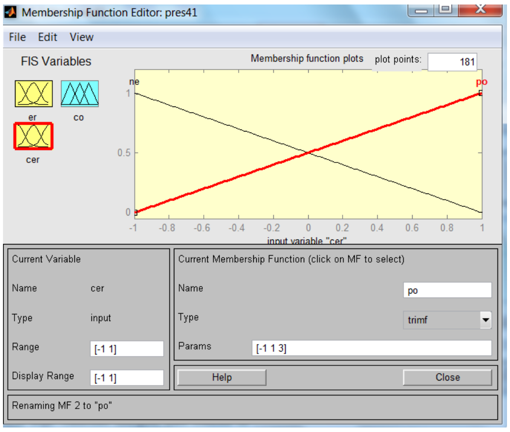


Figure.4. Membership function for input 2.

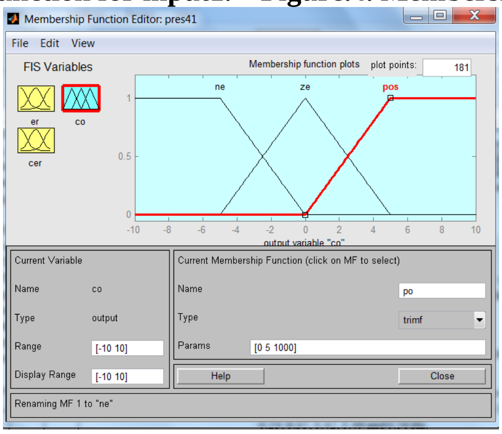


Figure.5. Membership function for output

Properties of Test system: The system is shown in Fig 6, the lumped mass on each level of the structure is 1313386 kN and the stiffness matrix K in kN/m is

$$\left(\frac{4.5}{0.0254}\right)\begin{bmatrix} 2000 & -1000 & 0 & 0 & 0 \\ -1000 & 4800 & -1400 & 0 & 0 \\ 0 & -1400 & 6000 & -1600 & 0 \\ 0 & 0 & -1600 & 6600 & -1700 \\ 0 & 0 & 0 & -1700 & 7400 \end{bmatrix}$$

The damping ratio of structure is assumed to be 3% in each mode. The natural frequencies of the structure are0.23, 0.35, 0.42, 0.49 and 0.56 Hz.

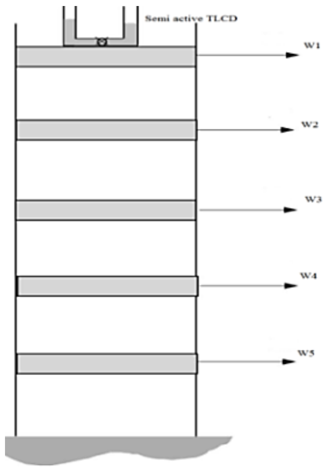


Figure.6. The test system

The TLCD is placed on the top level of the structure. The TLCD is designed as the liquid mass of TLCD is 1% of first generalized mass of structure, the length ratio α of TLCD is 0.9 and ξ_{max}=15.

The structure- TLCD system is analyses as TMD analogy system as in Fig 1 and simulation done in Matlab Simulink. This combined system converts in to two degree of system. The system identification in Matlab Simulink was done as state space form. In this paper unit step loading is used for fluctuation. The analysis was done with structure only, with passive TLCD, with PID control and fuzzy controlled system.

5. RESULTS

First the system is analysed with structure only i.e. structure without the TLCD. The block diagram of the system is shown in the Fig.7. Then the structure with TLCD system i.e. passive system is analysed which is shown in Fig.8. Again, the system is analysed with PID control with limits of proportional (P) = 1285.535, integral (I) = 0.66 and derivative (D)=0. This limits got from trial and error method. Fig.9. represents this system. At last fuzzy controller is introduced. The Matlab Simulink test model is presented in Fig 10.

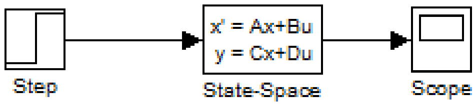


Figure.7. Structure only

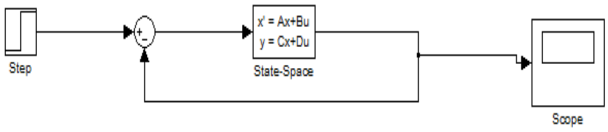


Figure.8. The system with passive control

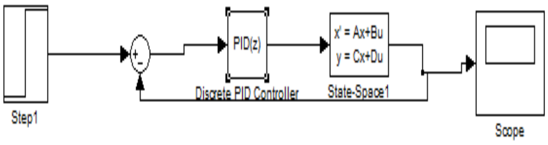


Figure.9. PID controlled system

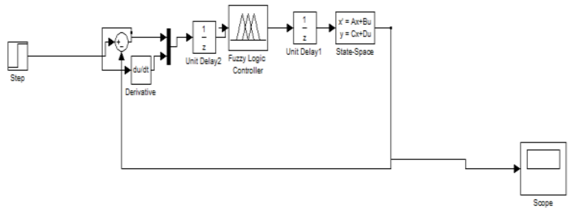
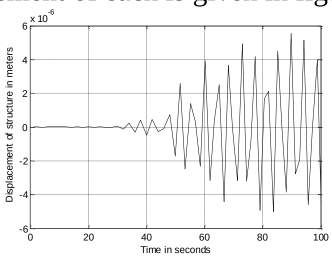


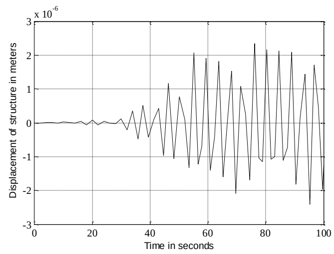
Figure.10. fuzzy controlled system.

The simulation results of each systems are shown in Figs 11, 12, 13 and 14 respectively. The absolute maximum displacement of each is given in figures.



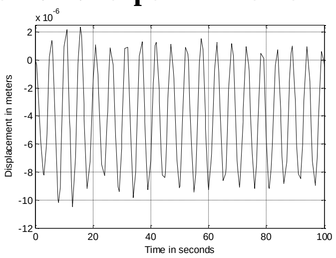
Abs.Max:5.5x10^{-6}m

Figure.11: output of structure only



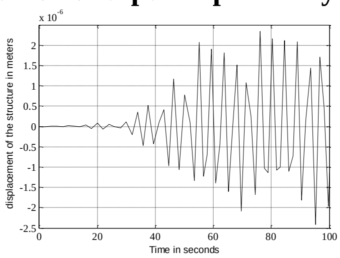
Abs.Max:2.40x10^{-6}m

Figure.12. output of passive system.



Abs.Max:2.34x10^{-6}m

Figure.13: output of PID controlled system.



Abs.Max: 2.28x10^{-6}m

Figure.14. output of fuzzy controlled system.

From the Figs11-14, the absolute maximum displacement for structure only is 5.5x10^{-6}m and that for passive control is 2.4x10^{-6}m. In PID controlled and fuzzy controlled systems the value is 2.3x10^{-6}m and 2.28x10^{-6}m. The absolute maximum displacement of fuzzy controlled systemis smaller than other systems. The percentage reduction in fuzzy controlled system is nearly 60%.The fuzzy control can minimize the fluctuations due to the loading.The displacement again can be reduced by modifying the rule base. Therefore we can conclude fuzzy control will more potent than other systems.

4. CONCLUSION

From this study, we can see that fuzzy controlled system is more adapted than other controlled systems. TLCD is also very adequate in reducing fluctuations due to the external forces. The performance of fuzzy controlled system can be further increasedby modifying the rule bases.

REFERENCES

Abe M, Kimura S, Fujino Y, Control laws for semi-active tuned liquid column damper with variable orifice opening, Paper presented at 2nd International Workshop on Structural Control, Hong Kong, December 1996.

Brown CB, Yao JTP, Fuzzy sets and structural engineering, Journal of Structural Engineering (ASCE), 109, 1983, 1211–1225.

Datta T.K, A state-of-the-art review on active control of structures, Journal of Earthquake Technology, 40 (1), 2003, 1-17.

Felix Weber, GlaucoFeltrin, and Olaf Huth,Guidelines for Structural Control, SAMCO Final Report 2006.

Haroun MA, Pires JA, Active orifice control in hybrid liquid column dampers. In, Proceedings of the First World Conference on Structural Control, Los Angeles, FA1. USA, IASC, 1, 1994,69–78.

Hojjat Adeli, Smart structures and building automation in the 21st century, The 25th International symposium in automation and Robotics in construction, 2008, 26-29.

Housner GW, Bergman LA, Caughey TK, Chassiakos AG, Claus RO, Masri SF, Structural control, past, present, and future.J Eng Mech, 123 (9), 1997, 897–971.

Hrovat D, Barak P, Rabins M, Semi-active versus passive or active tuned mass dampers for structural control, J Eng. Mech, ASCE, 109 (3), 1983, 691–705.

Juang C, Elton DJ, Fuzzy logic for estimation of earthquake intensity based on building damage records, Civil Engineering Systems, 3, 1986, 187–191.

Kareem A, The next generation of tuned liquid dampers. In, Proceedings of the First World Conference on Structural Control, vol I, Los Angeles, FB5. USA, IASC, 1994, 19–28.

Mamdani EH, Application of fuzzy algorithms for control of simple dynamic plants. Proceedings of the IEE, 121, 1974, 1585–1588.

Monica Patrascu1, Ioan Dumitrache2, Petre Patruţ3, A comparative study for advanced seismic vibration control algorithms, U.P.B. Sci. Bull, Series C, 74 (4), 2012.

Nikos G, Pnevmatikos, New strategy for controlling structures collapse against earthquakes, Natural Science, 4, 2012, 667-676.

Pourzeynali S, Jooeib P, Semi-active Control of Building Structures using Variable Stiffness Device and Fuzzy Logic, IJE Transactions A, Basics, 26 (10), 2013, 1169-1182.

Sakai F, Takaeda S, Tamaki T,Tuned liquid column damper- new type device for suppression of building vibrations,In, Proceedings of international conference on high rise buildings, 1989, 926-931.

Soong TT, Active structural control - theory and practice, London and New York, Longman and Wiley, 1991.

Sun L, Goto Y, Application of fuzzy theory to variable dampers for bridge vibration control. In, Proceedings of the First World Conference on Structural Control, Los Angeles, CA. USA, IASC, 1994, 31–40.

Won AYJ, Pires JA, Haroun MA, Stochastic seismic performance evaluation of tuned liquid column dampers. Earthquake Eng Struct Dyn, 25, 1996, 1259–74.

Xu Y L, Samali B, Kwok KCS, Control of along-wind response of structures by mass and liquid dampers. J Eng Mech, 118 (1), 1992, 20–39.

Yalla S.K, Kareem A, Kantor J.C, Semi-active tuned liquid column dampers for vibration control of structures, Eng. Structures, 23, 2001, 1469-1479.

Yalla S.K, Kareem A, Optimum absorber parameters for tuned liquid column dampers, J. Structural Eng, 126, 2000, 906-915.

Zadeh LA, Fuzzy set, Information and Control 8, 1965, 338–353.

Ziegler F, The tuned liquid column damper as the cost - effective alternative of the mechanical damper in civil engineering structures, Int J Acoustics Vib, 12 (1), 2007, 25-39.