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Control Algorithms for Evaluating Seismic Performance of Structures

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Abstract - *Passive control refers to systems that do not require an external power source. To enhance the performance of passive control systems, active control systems are developed. In active control system, sensors measure the motions of the structure and actuators and a feedback control strategy exert counteracting forces to compensate for the effect of external excitations. In this paper three different control algorithms namely LQR control algorithm, a filtered x-LMS algorithm and a hybrid feedback LMS control algorithm are studied and their performance in seismic control of structures are also reviewed. LQR is a feedback control algorithm and filtered-x LMS is an adaptive control whereas the hybrid feedback LMS is a combination of feedback and adaptive control algorithms. A brief idea about ATMD and different types of control algorithms are briefly explained..*

Key Words: Active Tuned Mass Damper, Active Control Algorithm, LQR feedback control, LMS control, filtered-x LMS control.

1. INTRODUCTION

An active control system can be defined as a system that requires a large power source for the operation of electrohydraulic or electromechanical actuator. These actuators increase the stiffness or damping of the structure. The active control system uses sensors for measuring the ground excitation and structural responses, and actuators for controlling the unwanted vibrations. The working principle of the active control system is that, based on the measured structural response the control algorithm will generate control signal required to attenuate the vibration. With the help of this control signal, the actuators placed at different locations of the structure generate a secondary vibrational response which in turn reduces the overall structural response. The power requirements of these actuators vary from kilowatts to several megawatts with respect to the size of the structure.

There are many active control devices designed for structural control applications. Some of them are active tuned mass damper (ATMD), active tendons, active brace systems, pulse generation systems, etc. Some of the control algorithms are feedback control, adaptive control and hybrid control.

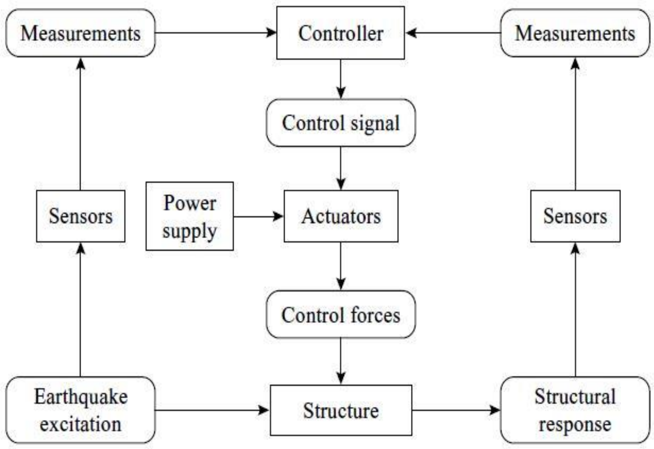

Fig -1: Active Control System

2. ACTIVE TUNED MASS DAMPER

Active Tuned Mass Damper (ATMD) is evolved from Tuned Mass Damper (TMD) with the addition of an active control mechanism. TMDs are only effective for structural response control when the first mode is dominant. Development of AMDs focuses on seeking control of structural seismic response with a wide frequency band. For ATMD one actuator is installed between the primary (i.e., structure) and the auxiliary (i.e., TMD) systems. The actuator controls the motion of the auxiliary system to increase the control effectiveness. Many analytical studies have been done to find how to operate the actuator to subdue response of the primary system most effectively with optimum control law and to find the appropriate feedback gain of the ATMD in order to obtain optimum control input. ATMDs have an economic advantage in full-scale structures because far less control force and a much smaller actuator are required than for other active systems.

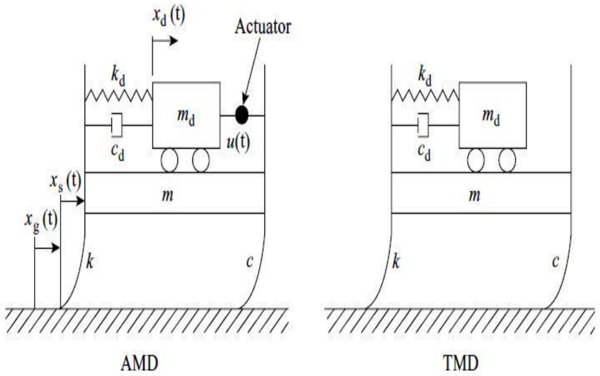

Fig -2: Active Mass Damper (AMD) and Tuned Mass Damper (TMD)

3. DIFFERENT CONTROL ALGORITHMS

An automatic controller compares a process measurement to a desired set point value and produces a controller output in response. The first step in most algorithm is a comparator which calculates an error. This error is used to calculate a compensating change in the controller output, which when transmitted to the control element changes the manipulator to adjust the process. The goal of the controller is thus to reduce the error to zero in an appropriate fashion. A number of control algorithms have been used for structural problems which can be broadly grouped under feedback control, adaptive control and hybrid-control algorithms. The Linear Quadratic Gaussian (LQG) algorithm and the Linear Quadratic Regulator (LQR) control algorithm are the widely used feedback control algorithms. It is mainly due to their simplicity and ease of implementation. These algorithms can supress the vibrations effectively when frequency of the external disturbance is in the vicinity of the natural frequency of the structure. But in case of seismic signals with frequencies widely different from the natural frequency of the structure then, theses algorithms are not much useful. To overcome these disadvantages adaptive control algorithms were developed. The most commonly used is the adaptive LMS filter algorithm. In this system input signal i.e., the seismic ground excitation signal is fed into both the unknown system and the filter, and the outputs of unknown system and filter are subtracted to find the error signal. The aim of adaptive algorithm is to adapt the filter coefficients such that the error sequence is as close to zero. In the adaptive LMS filter, the coefficient vector is adapted by using the LMS algorithm to minimise the error. But these adaptive filters are not effective for short transient vibrations because it requires adaptation time. Hence hybrid algorithms are introduced to minimize vibrations for both steady state and transient state by combining feedback control together with an adaptive algorithm.

4. LITERATURE REVIEW

Various literature reviewed on base isolation techniques is presented in this section. A number of works have been performed on base isolation using different types of isolators and their combined action. A review of literatures is presented in brief summarizing the work done by different scholars and researchers on the seismic response of multi-story structures using these techniques.

C.C.Chang (1995) proposed a closed loop feedback control algorithm for the vibration control of structures. The model used for this study is a SDOF system having an ATMD. It is assumed that this SDOF system is under the action of a stationary Gaussian white noise ground excitation. The displacement, velocity and acceleration responses of the SDOF system and the ATMD are used for calculating the control force required for suppressing the vibrations. In this study the control efficiency of ATMD with optimal and non-optimal parameters, and velocity feedback and complete feedback are compared. It is found that the control forces are effective either by using velocity feedback on an ATMD with non-optimal parameters or by using complete feedback on an ATMD with optimal parameters.

B.Samali, J.N.Yang, And S.C.Liu (1985) this paper studies the application and effectiveness of active tendon and active mass damper as control systems for buildings excited by strong earthquakes. The reduction in coupled lateral-torsional motions is taken as a measure to find the effectiveness of both control systems. The earthquake ground acceleration is modeled as a uniformly modulated non-stationary random process. Results show that larger the control forces better will be the reduction in building response. It is also concluded that under strong earthquake excitations both the above control systems are effective in response reduction.

Haichen Zhao, Shaolu Hu, Linhua Li, Xiaobo Wan (2013) This article presents a FIR filter design method which utilizes the NLMS (Normalized Least Mean Square) adaptive algorithm's system identification abilities. Adaptive filters have the abilities of system identification, obtaining the unknown systems' linear characteristic. In this study FIR structured adaptive filters are used because of their high performance and easy availability. LMS (Least Mean Square) adaptive algorithm is a converging algorithm based on the norm of MMSE (Minimum Mean Square Error) in Wiener filter theory and uses a steepest descent method to achieve it. NLMS algorithm adds normalization to the LMS algorithm, its converging process behave more stable than the counterpart. The output of the NLMS adaptive filter is

$$y(n)=\sum_{k=0}^{N-1} b(k)x(n-k) = \mathbf{b}^T\mathbf{x}$$

y(n) and the desired signal d(n) make the error signal e(n)

$$e(n)=d(n)-y(n)$$

The parameter b(n) is updated automatically by the feedbacks of error signal e(n).

R.A.Burdiso, L.E. Suarez (1994) In this paper an experimental investigation is carried out to assess the feasibility of the adaptive feed forward control approach for the response reduction of structures excited by seismic ground motions. A critical factor for the control of structures under environmental loads is the high degree of uncertainty in the dynamic properties obtained from analysis. These uncertainties in the structural parameters may affect the effectiveness of any control system. The adaptive feedback control algorithm overcomes these potential difficulties through the use of adaptive filters.

Fahim Sadek and Bijan Mohraz (1998) This study investigates the effectiveness of variable dampers in reducing the response of structures to earthquake loading. Performance of three semi-active control algorithms (1. LQR algorithm, 2. LQR algorithm with a penalty imposed on the acceleration response and 3. A displacement-acceleration domain algorithm) are compared. It is found that variable dampers are effective in reducing the acceleration responses of flexible buildings but are not effective for rigid structures. The LQR algorithm with a penalty imposed on acceleration response is more efficient than the other two in reducing the responses.

Hojjat Adeli and Hongjin Kim (2004) the filtered x-LMS algorithm requires a large number of filter coefficients and thus it takes significant amount of computational time. This makes the real time implementation impractical. In order to overcome the shortcomings a low-pass filter is integrated with the filtered-x LMS adaptive system. This low pass filter allows all lower frequencies from zero to the specified filter cutoff frequency and eliminate all other incoming higher frequencies. This makes the adaptation more stable and computationally much faster. In this paper, a wavelet based low-pass filtering is proposed. In wavelet transform, the original signal is broken down into a series of basic functions that are localizes in both time and frequency. Thus it provides an effective way of processing time-varying non-stationary signals like earthquake waves.

Moshe Tarrab and Arie Feuer (1988) in this the advantages of normalized least mean square (NLMS) algorithm over the LMS algorithm is presented. It is found that the convergence rate of NLMS algorithm is independent of environmental changes. But its steady-state performance is considerably worse. Compared to the LMS performance there is significant improvement in speed of convergence for the NLMS algorithm.

A.A.Golafshani And H.R.Mirdamadi (2002) In this paper a semi-active controller is designed using NLMS algorithm. The mechanism consists of a piston connecting chevron bracings on one end to a cylinder on other end. This is applied on a three storied framed structure model. The displacement response of the top floor for two different algorithms i.e., LMS and filtered-x LMS are compared. The result shows that the filtered-x LMS is more optimized and efficient in response reduction.

S.J. Dyke, B.F.Spencer (1996) this paper demonstrates experimentally the efficiency of acceleration-feedback-based active mass driver (AMD) system in reducing the response of seismically excited structures. A three-storey, single-bay scale model steel frame building was the test structure. The AMD system consisted of a high-pressure hydraulic actuator with steel masses attached to each end of the piston rod. Accelerometers positioned on each floor measured the absolute acceleration of the model and that located on the base measured the ground excitation. LQG optimal control strategies were employed in the study. Analysis was done on this control-structure models and the results indicate that AMD systems employing acceleration-feedback strategies are effective for reduction of structural responses (approximately 80% reduction in rms acceleration response) during seismic activity and that response reduction can be achieved in all three modes of the structural system.

S.K.Rasouli and M.Yahyai (2002) in this paper performance of TMD and ATMD systems are investigated and compared. A 25 storied building is modelled and designed and real earthquake excitations are applied. The earthquakes chosen are El Centro and Taba earthquakes. For the active damper a feedback control strategy is adopted. It is concluded that by increasing the mass ratio of TMD to building, the damping of the building can be increased linearly. Considering different positions for TMD, the most effective position for maximum response reduction is on the top floor. It is also inferred that ATMD are powerful in response reduction over conventional TMD, but its only disadvantage is the requirement for an external power source.

5. CONCLUSIONS

Active control algorithms for evaluating seismic performance of structures has been reviewed and presented. A brief idea about ATMD is also included.

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