A review on optimization of design of tuned mass dampers

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Abstract. Tuned mass dampers (TMDs) are applied in various high rise buildings to reduce wind induced and seismic vibration response of the structures. This paper reviews various techniques to optimize design variables of TMDs i.e. damping ratio, period and mass. The optimization problem of TMD deals with TMD frequency tuning to different frequency modes of vibration of structures. The application of novel optimization approaches such as genetic algorithm and modified bat algorithms are reviewed in this paper.

1. Introduction
The high rise buildings, tall and slender towers, long span bridges experience vibrations significantly under earthquakes and high velocity winds which hampers the safety of buildings as well as the comfort of occupants. The traditional structure design addresses this issue but the complexity of structure increases when the stiffness is increased in this process. The tuned mass dampers (TMD) consist of elastic elements and dampers, mass blocks reduces wind induced and earthquake vibration response of the structures. There are several structures in the world in which TMDs are installed.

TMDs were generated by modifying the vibration absorber device invented by Frahm with damping elements to damp random vibrations. Often, in an iterative manner, the optimized TMD parameters are found in the tuning process of TMDs. A TMD efficiently reduces the dynamic response of linear system to the narrow input band range. The applicability of TMD for reducing responses of in single degree of freedom systems as well as in multi degree of systems have been investigated by the researchers.

TMD system is one of the passive control devices, use no external power source. The TMD system consist of mass - spring - dashpot system.

To install TMD system at optimum position and also to finding optimum values of mass, stiffness and damping are the most important problems and are extensively investigated in the seismic design of controlled building.

Nam Haong et al [1] derived simple formulas of optimized TMD parameters. The TMD studied in this paper is applied for reducing seismic force of a long span truss bridge. They studied the interrelationship between optimal parameters of large TMD and mass ratio. They found that the increase in mass ratio results into higher damping ratio and lower tuning frequency of optimal TMD. The primary structure response is effectively minimized by TMD if the mass ratio is large. The formulae are proposed for smaller ground frequency ratio.
Mohtasham Mohebbi et al [2] presents an effective method to design optimal MTMDs for mitigation of seismic response of the structures. Considering parameters of TMDs as variables, it defines an optimization problem with the objective of minimization of maximum structural response. The genetic algorithm is used for optimization problem of a ten storey linear shear frame for which optimal MTMDs are to be designed. It is observed that MTMD performance is based upon configuration of TMD and mass ratio. For smaller range of values of mass ratio, the TMDs mass ratio improves the performance of MTMDs.

Agathoklis Giaralis et al[3] applies a standard numerical optimization search to optimally design tuned mass damper inerter (TMDIs) for damping, stiffness and inerter constant parameters. The TMDI is designed optimally for a range of prespecified mass values of TMDI. In this paper, the optimal damping and stiffness is derived to improve efficiency of TMDI. For fixed inertance values and at increasing mass, the frequency and damping ratio parameters of optimal TMDI are equally effective as the parameters of classical TMD. To connect primary structure with inerter terminals, the range of peak inerter force can be effectively managed.

Zhan Shu et al [4] presents the performance of Pendulum Type Tuned Mass Damper System (PTMD) for power plant structure under seismic effect inside which non-structural coal buckets are suspended. To minimize the inter storey drifts under seismic excitations, the mechanism developed in this research optimally designs the PTMD system. Reductions in most of the structural responses are observed depicted by the derived optimal ranges for PMTD variables. For the mass varying system, a conceptual length adaptive PTMD design is proposed. The understory drifts are significantly reduced by optimal implementation of PTMD. This study considers the uncertainties in system nonlinearities, earthquake input and other structural complexities.

O. Lavan [5] presents a multi objective formulation of a TMD optimization problem for either an external load or for a base excitation. Objective of the optimization process is to minimize TMD stroke, TMD mass and structural responses. First approach considers TMD equations and the second approach approximately decomposes multimodal responses of the structure to its modal contributions.

Gebrail Bekdas et al [6] presents a novel optimization approach which employs modified bat algorithm for tuned mass damper optimization problem. The proposed method considers different earthquakes records to optimize design variables such as damping ratio, period and mass of tuned mass of damper. The results of this method is compared with other methods such as particle swarm optimization, genetic algorithms and harmony search. The proposed method proves to be more efficient and feasible as compared to other methods when applied to ten-storey civil structure.

Khatibinia M et al [7] proposes improved gravitational search algorithm to find optimal TMD parameter values. This method proves to be a better method when compared with other algorithms. When TMD system is optimized with this method, it can predict seismic occurrence probability.

Sinan Melih Nigdeli et al [8] investigates the optimization of TMD using flower pollination algorithm which is a metaheuristic algorithm. The TMD is optimized for near fault excitations. The process of optimization is carried out with impulse motions. This study explores the possibility of replacing a TMD with heavy mass with smaller TMDs at multiple positions. The Runge Kutta method is used for structural dynamic analysis using Simulink and MATLAB.

R. Kamgar et al [9] considers soil structure interaction (SSI) in a high rise building and optimum TMD system by comparing different criteria of optimization. Using a number of distinct TMD optimization criteria, optimal design for a 40 storey shear building is performed. The objective is based on the minimization of the displacement and acceleration for the structural displacement subjected to a design constraint which includes the scaled stroke of TMD. To optimize the TMD system parameters, the whale optimization algorithm (WOA) is used in this study.
Takeshi Nakai et al [10] has developed a large TMD to counteract the seismic effects in existing high rise buildings. The oil dampers and suspended weights increase the damping coefficient prevents outstroke when predetermined value of TMD is reached during large earthquakes. The TMD stroke is controlled by this system with minimally affecting its performance.

Gino B. Colherinhas et al [11] presents study of optimal parameters of pendulum tuned mass damper (PTMD). Genetic algorithm is used to find the mass ratio, pendulum length and flexural stiffness/damping. These are optimal parameters of PTMD. It is searched by the chosen fitness function for which verification of time history and parametric analysis is performed.

A. Batou et al [12] considers a TMD with viscoelastic properties which is generalized as the TMDs which are viscously damped. They use the of viscoelasticity model of Biot in which the stiffness and time constant parameters are compared with those of an undamped TMD. In this paper TMD’s viscoelastic optimized parameters are generalized by using the fixed points theory. When vibration amplitude of three fixed points are controlled, two stiffness are obtained. If symmetry of amplitude function is controlled in relation with the fixed central point, the damping coefficient is obtained. A better vibration mitigation can be reached by viscoelastic optimal TMD which also gives greater flexibility as compared to classical viscously damped TMD.

Luciara Silva Vellar et al [13] propose a new methodology for optimization of multiple tuned mass damper (MTMD) parameters and positions in buildings under seismic effects. The methodology of optimization aims to obtain a robust design considering uncertainties in dynamic loading condition, the structural parameters and in the MTMD design. The sensitivity of design of MTMD to the variation in the structural dynamic behaviour is considered in the optimization process. The methodology proposed here can be an effective tool for MTMD design as it is tested for a 10 story building. Proposed methodology effectively reduces maximum inter storey drift of the building.

Anhui Liu et al [14] depicts an optimization method for designing TMD. Genetic algorithm is used to optimize the control effect of TMD. The constraint condition is stroke of TMD in frequency range. The parameters of TMD design were obtained by numerical optimization method. The optimal design method is used to design a TMD with an eddy current damper. The TMD performance is evaluated by performing shaking table tests upon seven story scaled down structural model. Performance of the proposed method is compared with the design by Den Hartog’s formula. Authors found that effectiveness offered by numerical simulation method is similar as that by proposed method in comparison to the solution of Den Hartog’s formula.

2. Conclusion
The article reviewed literature which is done for optimization of tuned mass dampers. The optimization approach focuses on damping ratio, tuning frequency and mass ratio. It is clear from the study that – increase in mass ratio results into higher damping ratio and lower tuning frequency of optimal TMD. There is a lot of research which investigated Multiple Tuned Mass Damper (MTMD), Pendulum Tuned Mass Damper (PTMD) and Tuned Mass Damper Inerter (TMDI). The TMDs are optimized using various methods such as numerical optimization methods, genetic algorithms, flower pollination algorithms and modified bat algorithms.

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