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Tuning and shaping semi-active tuned mass dampers for use on high-rise wind excited structures

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Introduction
Semi-active tuned mass dampers (STMD) are control devices that can be used to enhance the vibration mitigation capacity of structures subjected to dynamic loading such as earthquakes and strong winds enhancing structural safety and occupant comfort. Such devices operate on the basis of altering their damping and/or stiffness properties for maximum energy dissipation. The manner that these parameters change depends explicitly on the chosen control algorithm which is in a sense the brain of the control system. In this regard, the selection of an appropriate control algorithm becomes an integral part of the control system design process and can undoubtedly affect to a great extend the vibration attenuation performance of the control system. To date, a large volume of advanced control algorithms has been developed and reviewed for the case of semi-active control (Liedes, 2009), however, a comparison of different control algorithms is not available for the case of STMD, and the problem specific (high-rise structure) case has yet to be considered.

In this paper, the most famous feedback controllers, namely proportional-integral-derivative (PID), ground-coupled (pot) displacement based (DRG) and velocity based (VRG) and linear-quadratic regulator (LQR) are examined for the case of wind excited high-rise structures comprising a variable damping STMD. It is assumed that both quantitatively and qualitatively the gains of the use of each control algorithm is compared. It is believed that such an investigation is important so as to direct future research efforts in the most promising directions by providing a frame of reference to both practicing engineers and researchers interested in the area of STMD control of high-rise structures.

Methodology
To illustrate the effectiveness of different controllers in alleviating structural response, the 78-storey wind-excited benchmark structure proposed by Yang et al. (2004) was considered. Three alternative control strategies: passive, semi-active, and active controlled structures that comprise a tuned mass damper (TMD), an STMD and an active mass damper (AMD) respectively were used for the investigation of the relative performance gains of the semi-active controlled system at different control algorithm configurations (figure 1). For the fairness of the comparison, particular emphasis was given on the tuning of the damping ratios of the TMD so as to optimize its performance while at the same time not exceed strict device limitation such as maximum stroke etc. On the contrary, the optimum minimum and maximum achievable damping ratio by the STMD were found using the cumulative energy dissipated by the auxiliary device at different damping (min/max) configurations.

Concluding remarks
Through the numerical analyses it was shown that the choice of a control algorithm has considerable effects on the performance of the STMD controlled structure. It is evident by the fact that only two of the semi-active control algorithms managed to bring the system’s acceleration response within the allowable limit (<15gms) (Yang et al. 2004). Yet, regardless of the choice of algorithm, the STMD as expected is shown to outperform the purely passive system, achieving behaviour similar to the actively controlled one (figure 2). Some additional interesting findings from the analysis include:

- DRG compared to VBG by default yield a better control on attenuation performance for a given min/max damping ratio, however the latter algorithms can attain similar performance to the first when the maximum damping ratio of the device is reduced and the mass of the damper is allowed to move further (without exceeding the maximum stroke). Similar observation can be made for the case of PID controlled STMD.

- LQR controllers although being more complex to design (i.e. need of observers, full state feedback) by default yield a better performance compared to the other algorithms. Additionally LQR controllers allow the designer to choose the states to minimise, which implies that more control is obtained in terms of stroke minimization and vibration attenuation at certain locations.

References

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Figure 1. Structural configurations of the 76-storey building (a) TMD, (b) AMD, (c) VD-STMC.

Figure 2. Peak and RMS responses of the STMD equipped structure using different algorithms.