Suppressing delay-induced vibrations via the tuned mass damper

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Time delay in control is a major cause of instability, which is relevant for many engineering systems [1]. For instance, micro- and nano-electromechanical systems can experience instabilities even when time delay is very small because of their high natural frequency [2]. Human-controlled systems are subject to time delay related to human reflex, this causes the failure of high-precision haptic interfaces and also causes dangerous speed wobble in bicycles and motorbikes [3]. Complex control algorithms require non-negligible computational time, causing instabilities in robots [4].

The tuned mass damper (TMD) is an established solution for passively mitigating undesired vibrations and improve stability in otherwise unstable systems. It is successfully adopted for the stabilization of many engineering systems, such as slender structures subject to wind induced vibrations [5] or machine tools undergoing regenerative chatter vibrations [6].

The objective of this study is to investigate the performance of the TMD for the suppression of delay-induced vibrations. Three cases are considered. Namely, a single-degree-of-freedom resonator, a simple inerter (a mass with no restoring force) and an inverted pendulum, all subject to proportional-differential position control with feedback time delay. Stability, speed of convergence and post critical behavior are analytically studied in order to understand the potentiality of the TMD for these applications.

Our results illustrate that the TMD can significantly improve stability properties of the system in all the three cases. However, the optimal tuning of the natural frequency of the absorber critically depends on the control delay. This suggest that, in order to implement it in a real engineering application, either an accurate knowledge of the time delay is required, or the TMD should encompass a sort of self-tuning mechanism, enabling it to operate efficiently. Alternatively, multiple TMD can be adopted, in order to improve system robustness.

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