Active Vibration Absorber for an Oscillating Structure Using Nonlinear Control

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The paper addresses the attenuation problem of harmonic vibrations affecting an oscillatory mechanical system using passive and active vibration control methods based on nonlinear control techniques. The methodology starts from a proper design of a passive vibration absorber, which by the addition of an actuated degree of freedom is transformed into an active vibration absorber described by a nonlinear model. The active vibration control scheme employs the measurement of the excitation frequency and the open-loop frequency response to compute an optimal attenuation condition, which is achieved with the application of a nonlinear controller (partial feedback linearisation or output regulation control techniques). The active vibration absorber can attenuate harmonic vibrations with varying excitation frequency as well as parameter variations on the system.

1. INTRODUCTION

Vibration control in mechanical systems is an important tool by means of which undesirable vibrations are suppressed or at least attenuated. This problem appears in many applications with beams, frames, mechanisms, structures, cranes, etc.[1-4]

There are three fundamental methodologies which are normally denoted as passive, semi-active and active vibration control. Passive vibration control relies on the addition of mass, stiffness and/or damping to the system to reduce the primary response and can be used for a narrow band of excitation frequency and stable operating conditions, but it is not recommended for variable forcing frequencies and uncertain system parameters.[3,5] Semi-active vibration control deals with adaptive spring or damper characteristics, which are tuned according to the operating conditions.[2] Active vibration control achieves better performance by adding actuators or actuated degrees of freedom to the system and controlling them according to feedback and feedforward information obtained from sensors on the system.[6-8]

Most of the research on mechanical vibration absorbers is devoted to minimise the system response in the presence of vibrations.[3] Sometimes this is performed by changing the structure, adding extra degrees of freedom, considering nonlinear stiffness or damping elements,[9] using active/smart materials or applying actuators.[2,7,10] Active vibration control has been rapidly gaining some well-deserved popularity in the field of mechatronics because of many technological advances, enabling the analysis and real time applications of passive and active vibration absorbers for complex mechanical systems. In general, the addition of extra degrees of freedom leads to highly nonlinear and coupled dynamics. In the case of nonlinear systems the application of appropriate nonlinear control schemes is then recommended to achieve satisfactory operation.[3,11]

This paper considers a mechanical structure, consisting of an oscillating rigid bar coupled to a classical passive absorber, which is able to attenuate harmonic vibrations only at a nominal excitation frequency. The study is motivated by applications to several engineering systems. For a variable excitation frequency a third degree of freedom is added to the original system, including a proper controller to automatically place the passive absorber along the rigid bar, for each measured frequency. The resulting dynamical system is underactuated and strongly nonlinear, hence, nonlinear control techniques are applied. Since the output to be controlled is not controllable about the set of equilibria then, an indirect controller based on nonlinear control laws combined with optimal attenuation, is proposed. Thus, the active vibration control methodology starts from the measurement of the excitation frequency, which serves to compute the position of the passive absorber. This leads to optimal attenuation and then, the desired behaviour is asymptotically achieved by a nonlinear controller. Two control strategies are analysed, 1) a partial feedback linearisation technique and 2) an output regulation technique. They both use feedback and feedforward information of the overall system to get a robust performance.

2. SYSTEM DESCRIPTION

The equivalent system to be considered is motivated by engineering applications such as beam structures, jib cranes, civil structures, swing-axle suspension of vehicles, etc. A schematic diagram of the mechanical system is shown in Fig. 1. The *primary* system consists of a rigid bar of inertia J and length $L = 2l$ attached to a linear spring k_1. The oscillations are consequence of the torque $\tau(t) = Q\cos(\Omega t)$. The *secondary* system (passive vibration absorber) is composed