Journal of Sound and Vibration 413 (2018) 308–331

Contents lists available at ScienceDirect

Journal of Sound and Vibration

journal homepage: www.elsevier.com/locate/jsvi

Twin rotor damper for the damping of stochastically forced vibrations using a power-efficient control algorithm

Richard Bäumer [a,*], Richard Terrill [a], Simon Wollnack [b], Herbert Werner [b], Uwe Starossek [a]

[a] *Structural Analysis Institute, Hamburg University of Technology, Denickestraße 17, 21073 Hamburg, Germany*
[b] *Institute of Control Systems, Hamburg University of Technology, Eißendorfer Straße 40, 21073 Hamburg, Germany*

A R T I C L E   I N F O

Article history:
Received 9 March 2017
Received in revised form 21 September 2017
Accepted 4 October 2017

Keywords:
Active damping
Twin rotor damper
Stochastic excitation force
Translational oscillator with rotational actuator
Phase-locked loop filter
Linear-quadratic-Gaussian regulator

A B S T R A C T

The twin rotor damper (TRD), an active mass damper, uses the centrifugal forces of two eccentrically rotating control masses. In the continuous rotation mode, the preferred mode of operation, the two eccentric control masses rotate with a constant angular velocity about two parallel axes, creating, under further operational constraints, a harmonic control force in a single direction. In previous theoretical work, it was shown that this mode of operation is effective for the damping of large, harmonic vibrations of a single degree of freedom (SDOF) oscillator. In this paper, the SDOF oscillator is assumed to be affected by a stochastic excitation force and consequently responds with several frequencies. Therefore, the TRD must deviate from the continuous rotation mode to ensure the anti-phasing between the harmonic control force of the TRD and the velocity of the SDOF oscillator. It is found that the required deviation from the continuous rotation mode increases with lower vibration amplitude. Therefore, an operation of the TRD in the continuous rotation mode is no longer efficient below a specific vibration-amplitude threshold. To additionally dampen vibrations below this threshold, the TRD can switch to another, more energy-consuming mode of operation, the swinging mode in which both control masses oscillate about certain angular positions. A power-efficient control algorithm is presented which uses the continuous rotation mode for large vibrations and the swinging mode for small vibrations. To validate the control algorithm, numerical and experimental investigations are performed for a single degree of freedom oscillator under stochastic excitation. Using both modes of operation, it is shown that the control algorithm is effective for the cases of free and stochastically forced vibrations of arbitrary amplitude.

1. Introduction

Engineers are often confronted with vibration related problems. Such problems include, for instance, human discomfort due to noise or engine vibrations as well as reduced material lifetime in structures or machinery parts. To suppress or isolate vibrations from other machinery parts or humans, damping devices are often utilized [1]. There are three classifications of damping devices: passive, adaptive and active [2]. The implementation of passive damping devices in structures, e.g. in

---

* Corresponding author.
E-mail address: richard.baeumer@tuhh.de (R. Bäumer).

https://doi.org/10.1016/j.jsv.2017.10.007

bridges, is quite common, see Refs. [3–8]. If the environmental or operating conditions of the system to be damped change, passive devices may become untuned and lose their effectiveness [2]. In such cases, adaptive devices can be more effective. By remotely controlling or adjusting specific parameters, their behavior can be varied during operation. Advances concerning this have led to a variety of adaptive tuned mass dampers and associated control strategies; see Refs. [2,9–14]. Regarding active devices, the greatest advantages over passive and adaptive devices include a broader band of effective frequencies and higher control authority [2,15,16]. According to the authors' knowledge, first reports concerning the active control of real structures using active mass dampers are given in Refs. [17–19]. The use of semi-active and active devices has recently been shown to be a promising application for the suppression of wind turbine tower vibrations, see e.g. Refs. [20,21]. Further findings concerning active devices and corresponding control algorithms can be found in Refs. [22–25].

In Ref. [26], the twin rotor damper (TRD), which implements the centrifugal forces of eccentrically rotating masses, was presented. The basic layout consists of two eccentric control masses which rotate in a preferred mode of operation, the continuous rotation mode, about two parallel axes. The resulting centrifugal forces are used for the vibration control of a single degree of freedom (SDOF) oscillator. The nearly constant angular velocity results in a power advantage in comparison to conventional active mass dampers. In Ref. [27], the research of [26] was further pursued; an algorithm ensuring the anti-phasing between the harmonic control force of the TRD and harmonic vibrations is presented.

In this paper, research done in Ref. [27] is further investigated and augmented for the control of stochastically forced vibrations. In chapter 2, the TRD and two corresponding modes of operation, the continuous rotation mode and the swinging mode, are introduced. This information summarizes previous publications, see Refs. [26,27]. In chapter 3, the algorithm of [27] for the continuous rotation mode is augmented, allowing for a straightforward tuning of the continuous rotation mode for stochastically forced vibrations. Based on open-loop studies, it is shown that the continuous rotation mode is ineffective below a specific vibration-amplitude threshold. In chapter 4, the test setup, which was presented before in Ref. [27], is introduced including a stochastic example loading scenario, which is used for a design example. To additionally damp small vibrations below the critical vibration-amplitude threshold, an additional newly developed control algorithm for the more power demanding swinging mode is proposed. For the design example, a tuning procedure to operate the TRD in the continuous rotation mode for large vibrations and in the swinging mode for small vibrations is developed. The power demand required for the continuous rotation mode is chosen as an upper bound for the power demand in the swinging mode. To validate the tuning procedure including both control algorithms, controlled free vibrations are performed using both modes of operation. At the end of chapter 4, numerical simulations and experiments are presented and main findings are discussed.

2. TRD for SDOF oscillator

As shown in Fig. 1, the TRD consists of two eccentric control masses $m_c/2$ driven by two actuators creating the moment $M(t)$ [26,27]. The control masses are hinged by two massless rods with the length r to two parallel axes. The angular position, $\varphi(t)$, describes the motion of both rotors (control mass with massless rod) and the displacement coordinate, $x(t)$, the motion of the SDOF oscillator, where (t) indicates the time dependency. The dot operator indicates differentiation with respect to time. As shown in Ref. [27], the differential equation describing the motion of the SDOF oscillator is as given by

$$(m+m_c)\ddot{x}(t)+c\dot{x}(t)+kx(t)=f_T(t)+f_e(t) \tag{1}$$

in which $m+m_c$ is the total mass of the SDOF oscillator, c the damping coefficient, k the stiffness, $f_e(t)$ the excitation force and $f_T(t)$ the force of the TRD given by

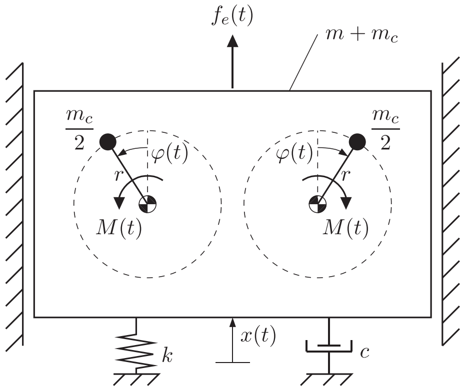

Fig. 1. TRD for SDOF oscillator [27].