PERGAMON

Mechatronics 12 (2002) 393–413

MECHATRONICS

Delayed resonator with speed feedback – design and performance analysis

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Received 8 July 1999; accepted 8 August 2000

Abstract

In this work a tunable torsional vibration absorption mechanism, the delayed resonator (DR) is studied. The tuning feedback used is time delayed proportional control on the angular velocity of the absorber. Dynamic analysis of the absorber and its tuning features are presented. Single- and dual-frequency resonance characteristics are introduced, both of which are achieved owing to the added delay in control. Combined system stability, for such time delayed dynamics and relevant topics of relative stability and dominant pole placement are discussed. A design tool is suggested based on the property called, the degree-of-stability. Experimental results are also presented, using a torsional vibration setup involving electric motor drives. They support the theoretical findings strongly.

Keywords: Torsional vibrations; Vibration absorption; Resonator; Delayed resonator; Stability; Time-delay

1. Introduction

The paper elaborates on a recently introduced real-time tunable vibration absorption strategy, the delayed resonator (DR) [1–3]. The underlying control strategy is a partial state feedback with time delay. It has been shown that this control structure can convert the absorber into a resonator, with a tunable resonance

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PII: S0957-4158(00)00065-9

Nomenclature

$\angle$	angle
$\vert\ \vert$	absolute value (module)
$\lceil\ \rceil$	the ceiling function
$\Re$	the real part of complex number
$\Im$	the imaginary part of complex number
c, c_a	torsional stiffness
d, d_a	torsional damping
f_L, f_a	the load torque and the feedback torque
g, g_c, g^*	gain of the feedback
J_1, J_2, J_a	moments of inertia
l	root locus branch identifier (counter)
n_1, n_2, n_a	speed of rotation (r/min)
q	squared frequency ratio of two DFFDR frequencies
s	the complex variable
t	time
T_d	sampling time
v	the complex variable
τ, τ_c, τ^*	time delay of the feedback
$\varphi_1, \varphi_2, \varphi_a$	angle of rotation
ζ_a	damping coefficient
ω_a	natural frequency of passive absorber
$\omega_c, \omega_{c1}, \omega_{c2}$	resonant frequencies of DR

frequency. This resonator functions as a perfect vibration absorber against a tonal excitation even when its frequency is varying with time.

The DR absorber is studied for transverse vibration cases in the earlier efforts [1–4,7,12]. Its usage for torsional oscillations was first introduced by Filipović and Olgac [3]. This paper presents two contributions. First is on the analysis of single- and dual-frequency resonances for delayed speed feedback. It is shown that the torsional DR can be tuned to resonate at not only one but two distinct frequencies. At these settings the DR can absorb bi-tonal oscillations. These two frequencies, however, are not tunable, i.e., they are fixed for a given passive absorber. Both the direct problem (i.e., the analysis) and the indirect problem (i.e., the synthesis) of the absorber for a given pair of frequencies are presented.

Second contribution is on the stability measure of the operation. When the DR is effectively suppressing the tonal vibrations, the combined system (the primary system and the DR absorber) should remain asymptotically stable. This feature is studied from various points-of-view. The characteristic equation representing the combined system exhibits the form of a quasi-polynomial, i.e. a polynomial with exponential, $e^{-\tau s}$ delay terms where τ represents the time delay. This class of systems are not easy to analyze [5,6,8,9]. They possess infinitely many *finite characteristic roots* due to the transcendentality of the equation. The dominant (i.e., the rightmost) root dictates