Cairo University

TUNING OF PASSIVE AND ADAPTIVE DYNAMIC VIBRATION ABSORBER USING MINIMAX OPTIMIZATION AND AUTOMATIC CONTROLLERS

By

Mohamed Ahmed Abdel Hafiz Mohamed

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
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In
MECHANICAL DESIGN AND PRODUCTION ENGINEERING

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Under the Supervision of

Prof. Dr. Galal Ali Hassaan

Department of Mechanical Design &
Production
Faculty of Engineering, Cairo University

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Approved by the
Examining Committee

____
Prof. Dr. Saber Mahmoud Abdrabbo, External Examiner
(Faculty of Engineering at Shoubra, Benha University)

____
Prof. Dr. Ibrahim fawzy Abdelwahed , Internal Examiner

____
Prof. Dr. Galal Ali Hassaan, Thesis Advisor

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2017

Engineer:	Mohamed Ahmed Abdel Hafiz Mohamed
Date of Birth:	11/7/1989.
Nationality:	Egyptian
E-mail:	Abdelhafiz2011@gmail.com
Phone:	01283266528
Address:	Faculty of Engineering, Cairo University

Registration Date:	1/10/2011.
Awarding Date:	…./…./2017
Degree:	Master of Science
Department:	Mechanical Design & Production Engineering
Supervisors:	Prof. Galal Ali Hassaan
Examiners:	Prof. Saber Mahmoud Abdrabbo (External Examiner) (Faculty of Engineering at Shoubra, Benha University) Prof. Ibrahim fawzy Abdelwahed, (Internal examiner) Prof. Galal Ali Hassaan (Thesis advisor)
Title of Thesis:	**Tuning of passive and adaptive dynamic vibration absorber using minimax optimization and automatic controllers**
Key Words:	Adaptive Vibration Absorber, Minimax optimization, PIDF and PI-PDF controllers

Summary

A tuned vibration absorber (TVA) is realized using different tuning conditions. The main objective in adaptive tuned vibration absorber is maximizing the vibration attenuation of main system vibration by optimizing the tuning condition, which is used to track the excitation frequency. An adaptive pendulum absorber is built experimentally to test the vibration suppression of the vibrating table. The vibrating table is excited with an unbalanced rotor. Full control loop with two feedback signals is constructed to find out the benefit of using adaptive absorber. Finally, proportional-integral-derivative with first order filter (PIDF) and proportional-integral plus proportional-derivative with first order filter (PI-PDF) automatic controllers are used to adapt the pendulum absorber analytically using Simulink in MATLAB program. The PI-PDF controller gives better performance than PIDF one specially around the resonance.

Acknowledgments

I would like to thank Prof. Galal Ali Hassaan for his support and guidance throughout my thesis work.

I owe sincere and earnest thankfulness to my family: my parents and my brothers.

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Nomenclature

B	Rayleigh dissipation energy	Joule
c_a	Absorber damping	Ns/m
c_p	Primary system damping	Ns/m
f	Tuning factor	-
$f(t)$	Excitation force	N
F	Excitation force amplitude	N
k_a	Absorber stiffness	N/m
k_p	Primary system stiffness	N/m
K_{pi}	Proportional feed forward gain	-
K_i	Integral gain	s^{-1}
K_{pd}	Proportional feedback gain	-
K_d	Derivative gain	s
N	Filter coefficient	s^{-1}
l	Pendulum absorber length	m
m_a	Absorber mass	kg
m_p	Primary system mass	kg
q	Generalized coordinate of motion	m
Q	External force	N
T	frequency ratio	-
T_e	Kinetic energy	Joule
V	Potential energy	Joule
ω_a	Uncoupled natural frequency of absorber	s^{-1}
ω_p	Uncoupled natural frequency of primary system	s^{-1}
Ω	Normalized excitation frequency	-
γ	Normalized vibration amplitude of absorber	-
ζ_a	Damping ratio of absorber	-
ζ_p	Damping ratio of primary system	-
μ	Mass ratio	-

Abbreviations

ATVA	Adaptive tuned vibration absorber
DAQ	Data acquisition
DVA	Dynamic vibration absorber
FRC	Frequency response curve
MDC	Motor driver circuit
PCB	Printed circuit board
PDVA	Pendulum Dynamic vibration absorber
PIDF	proportional-integral-derivative with first order filter
PI-PDF	proportional-integral plus proportional-derivative with first order filter
SDOF	Single degree of freedom
TF3p1z	Transfer function three pole 1 zeros
TRC	Time response curve

Abstract

This work exploits mechanical vibration absorption of a single and dual pendulum absorber mounted on single degree of freedom primary system. In the first study, the main purpose is finding the optimum absorber parameters, Mini-Max optimization technique is developed for that purpose. The optimum parameters can minimize the primary system vibration amplitude and decrease the sensitivity of the primary system response to uncertainties of excitation frequency. Three types of pendulum absorber are investigated: classical pendulum, pendulum with torsional spring and dual pendulum.

In the second part of study, adaptive absorber is tuned in which its parameters are adapted according to excitation frequency and other system characteristics. A tuned vibration absorber (TVA) is realized using different tuning conditions. The main objective in adaptive tuned vibration absorber is maximizing the vibration attenuation of main system vibration by optimizing the tuning condition, which is used to track the excitation frequency. The frequency response curve (FRC) can be reduced by 10% due to optimum tuning condition. This enhancement percentage is dependent on system parameters in addition to excitation frequency.

An adaptive pendulum absorber is built experimentally to test the vibration suppression of the vibrating table. The vibrating table is excited with an unbalanced rotor. Full control loop with two feedback signals is constructed to find out the benefit of using adaptive absorber. Finally, proportional-integral-derivative with first order filter (PIDF) and proportional-integral plus proportional-derivative with first order filter (PI-PDF) automatic controllers are used to adapt the pendulum absorber analytically using Simulink in MATLAB program. The PI-PDF controller gives better performance than PIDF one specially around the resonance.

Chapter 1 : Introduction

1.1. General

Vibration is a mechanical behavior taking a form of oscillations around equilibrium configuration of elastic bodies. The response of the system passes through two stages: transient response and steady state response. Vibration takes place in many different fields such as mechanical system, civil and buildings structures and acoustical instruments. The performance of mechanical equipment is deteriorated due to increase of vibration amplitude. In some cases, unrestrained vibrations may cause structural failure due to excessive deformation or fatigue failure as result of repetitive stresses.

1.2. Dynamic excitation force

Some of vibration causes in machinery components are: misalignment, unbalanced rotating parts, loose of mountings and shaft whirling. The excitation force is classified into four main types: 1- harmonic 2- periodic (non-harmonic) 3- transient 4- impulsive as shown in Figure 1-1

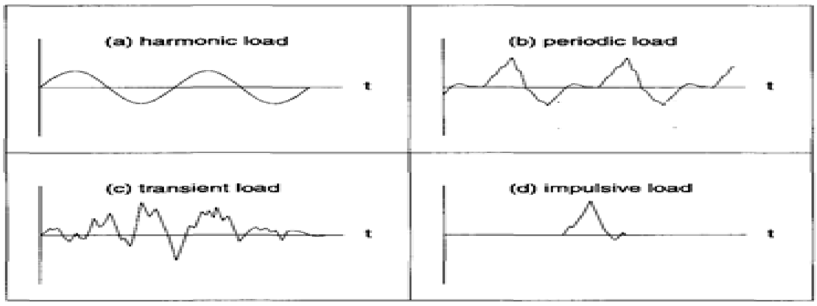

Figure 1-1: Types of excitation load [1]

1.3. Vibration control

The amplitude and frequency of structural vibrations can be manipulated by changing in system characteristics like mass, stiffness or damping. Another method of structural vibration control is adding a dynamic vibration absorber (DVA). Dynamic vibration absorber (DVA) is a mechanical system which consists of mass, damping and stiffness. Many configurations of vibration absorber are used all over the world in different applications. There are three main types of DVA: passive DVA, adaptive DVA and active DVA.

Passive DVA is a passive system that considers the most basic type of the DVA system. It is modeled with its mass, stiffness and damping. passive DVA characteristics are natural frequency, damping ratio and mass ratio , they must be tuned to optimize the maximum energy absorption from main system. Taipei 101 in Taiwan is recorded as second tallest building in the world with 509m height. It is standing on worst horizon of ground vibration, strong wind and typhoon. Consequently, civil and mechanical engineers decided to implement three pendulum DVAs as shown in Figure 1-2. One of them is the largest DVA in the world which has pendulum lamped mass 660 tones suspended by heavy cables [2]

Figure 1-2: Taipei 101 tower with PDVA [2].

The passive DVA has a big trouble in which any change in excitation load deteriorates its performance. In contrast, the adaptive DVA has the ability of online tuning. The natural frequency of adaptive DVA should be tuned such that it coincides with the frequency of excitation load.

1.4. Thesis layout

The thesis is organized as follows:

Chapter 1 provides a review of dynamic excitation loads, vibration control techniques and scope of the thesis work.

Chapter 2 offers a literature review of history and optimization techniques of vibration then it describes some of researchers attempt in adaptive DVA. Finally, it presents a different control algorithm using adaptive DVA.

Chapters 3 provides mathematical equations for 2 DOF and 3 DOF system (main system and pendulum absorbers) with linearized equations and develops new constraint equations for both single and dual pendulum optimization.

Chapter 4 presents and simulates vibration attenuation performance of adaptive pendulum vibration absorber PDVA with adjustable pendulum mass position at wide range of excitation frequencies.

Chapter 5 presents the physical prototype with the definitions of each part of testing apparatus, then completes close loop control system

Chapter 6 analyzes and observes the performance of PDVA at different kinds of tuning algorithm.

Chapter 7 discusses the thesis outlines and demonstrates the conclusion and recommendations for future work.