PERFORMANCE COMPARISON OF INTELLIGENT TUNING METHODS USING PID-AFCGA AND PID-AFCPSO IN ATTENUATING THE VIBRATION OF THE SUSPENDED HANDLE MODEL

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by

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DECLARATION

I hereby declare that this thesis, which I submit to Universiti Sains Malaysia as part of the requirement for the award of degree, is based on my personal effort, except other sources where such work has been cited and acknowledged within text. The results embodied in this thesis have not been submitted to other institution or universities for the award of any degree or diploma. I hereby authorize Universiti Sains Malaysia to make the thesis available outside organization for purpose of scholarly research.

Signed…………………………………………………………………….CHOO KINN

Date…………………………………………………………………………...25/6/2021

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

LIST OF SYMBOLS

Symbol	Description
c	Damping
e	Error difference between actual output and reference input
E	Error between desired and system outputs
ET	Sum of track error of each generation
f_{GA}	Fitness score
f_{PSO}	Function value
F	Disturbance force
F^*	Estimated disturbance force
F_a	Actuator force
F_{in}	Internal disturbance
F_{eA}	External disturbance A
F_{eB}	External disturbance B
k	Stiffness
K_D	Derivative term
K_I	Integral term
K_P	Proportional term
m	Mass
IN	Inertia matrix value
Q	Stiffness of actuator
S	Number of samples
t	Time
T_d	Disturbance torque
u	Control variable to adjust actuator force
x	Displacement

$\dot{x}$	Velocity
$\ddot{x}$	Acceleration

LIST OF ABBREVIATIONS

Abbreviation	Description
ABC	Artificial Bee Colony
AFC	Active Force Control
ANN	Artificial Neural Network
AVC	Active Vibration Control
CA	Crude Approximation
DOSH	Department of Occupational Safety and Health
DVA	Dynamic Vibration Absorber
EM	Estimated Mass
FFT	Fast Fourier Transform
GA	Genetic Algorithm
HAVS	Hand-Arm Vibration Syndrome
IL	Iterative Learning
LQR	Linear Quadratic Regulator
MOHR	Ministry of Human Resources
PI	Physik Instrumente
PID	Proportional-Integral-Derivative
PSO	Particle Swarm Optimization
RMS	Root Mean Square
SDOF	Single Degree of Freedom
SOCSO	Social Security Organization
TLV	Threshold Limit Value
USM	Ultimate Sensitivity Method
VWF	Vibration White Finger

LIST OF APPENDICES

ABSTRAK

Dalam kajian ini, prestasi yang dihasilkan oleh pelbagai jenis skim kawalan dalam mengurangkan getaran daripada pemegang tergantung telah dikaji. Pendedahan yang berpanjangan kepada getaran daripada alat kuasa akan mengancam kesihatan pekerja dan mengakibatkan penyakit seperti sindrom getaran lengan tangan (HAVS). Oleh itu, sistem kawalan getaran yang efektif memainkan peranan yang amat penting dalam mengurangkan getaran tersebut dan salah satu kaedah yang dibukti berkesan dalam mengawalkan getaran ialah kawalan daya aktif (AFC). Namun, kaedah AFC memerlukan proses penalaan yang sesuai untuk berfungsi secara optimum. Oleh yang demikian, beberapa langkah penalaan seperti penganggaran kasar (CA), algoritma genetik (GA) dan pengoptimuman kelompok zarah (PSO) telah diguna dan dibanding berdasarkan prestasi pemegang tergantung yang terpengaruh oleh getaran yang berbeza. Berteraskan hasil kajian, kaedah AFC dapat mengurangkan getaran secara lebih efektik berbanding dengan sistem pasif dan pengunaan pengawal berkardar-kamiran-kebezaan (PID). Daripada semua skim AFC, langkah penalaan dengan PSO telah menghasilkan prestasi yang terbaik walaupun di bawah pengaruh gangguan yang berbeza. Kombinasi AFC dengan langkah penalaan yang pintar merupakan satu pendekatan yang mempunyai harapan cerah bagi pengawalan getaran terutamanya dalam aplikasi alat kuasa.

ABSTRACT

In this study, the performance of different control schemes in attenuating the vibration of the suspended handle model is investigated. Prolonged exposure to the undesirable vibration of the power tools can cause detrimental effect to the worker health and resulted in sickness like hand-arm vibration syndrome (HAVS). An effective vibration control system is necessary to suppress the vibration of the power tools, whereby vibration control through active force control (AFC) is proven to be a feasible method from the previous research. However, AFC requires proper tuning process to optimally attenuate the vibration. Thus, several tuning methods such as crude approximation (CA), genetic algorithm (GA) and particle swarm optimization (PSO) are implemented and compared based on the performance of the suspended handle model under different vibration. From the results, the AFC schemes are very effective in attenuating the vibration compared to passive system and proportional-integral-derivative (PID) controller. Among the AFC schemes, PSO tuning method has the best performance even though under the influence of different disturbances. AFC with intelligent tuning method is a promising solution for the vibration control especially in power tool application.

CHAPTER 1

INTRODUCTION

1.1 Background Study

Vibration is a mechanical phenomenon whereby oscillations occur about an equilibrium point. Vibration in some cases is desirable which involving tuning fork, mobile phone or loudspeaker as the triggered oscillations are significant to ensure their correct functioning. However, vibration is more often undesirable because it creates problem to various kinds of mechanical system including energy wastage, generation of noise, structural damage, and performance reduction.

Undesirable vibration also brings harmful effects to the health of workers when operating the vibrating tools such as chain saw, jackhammer and power drill. Prolonged exposure to vibration induced by power tools can cause damage to blood vessel, nerves and joints of the worker's hand which results in a condition called white finger disease, Raynaud's syndrome, or hand-arm vibration syndrome (HAVS). Workers affected by HAVS tend to experience loss of sensation in fingers, loss of grip strength, and even pain. Hence, it is vital to implement vibration control methods to attenuate the vibration generated by power tools.

To date, various passive and active vibration control (AVC) techniques have been introduced for reducing the vibration. For passive vibration control, dynamic vibration absorber (DVA) or isolator in the form of anti-vibration gloves have often been used. However, most commercial anti-vibration gloves fail to attenuate the vibration lower than 100 Hz and only effective for reducing high frequency vibration (Sampson and Niekerk, 2003). Besides, the anti-vibration gloves also been reported to affect the dexterity of fingers, restrict blood circulation, and reduce performance rate (Brown, 1990). On other hand, DVA is effective when it is tuned to match the operating frequency of power tools (Hao *et al.*, 2011), but its effectiveness drops at other frequencies. In overall, passive vibration control become ineffective and less functional when dynamics of system and frequencies of disturbance vary with time.

AVC is comparably more effective as it reacts dynamically to the incoming vibration. This technique involves an active application of force in an equal but opposite manner to the forces induced by the vibration, so that it can be cancelled out. Normally, AVC consists of sensor, actuator, and controller. Sensor converts the vibration energy into electronic signals which are then transmitted to the controller. Controller will process the signals using preset control algorithm and transmit the cancellation signal to the actuator. Finally, actuator generates an equal but out of phase vibration to attenuate the incoming vibration.

In this project, an available active suspended handle model (Mazlan & Ripin, 2017) is used to simulate the effectiveness of AVC system in attenuating the vibration from power tools. The sources of vibration can be classified into two types which are internal and external disturbances. Both disturbances can be existed at a single time which makes the tuning process of the AVC system becomes more difficult. AVC usually involves either proportional-integral-derivative (PID) controller, active force control (AFC) method or integration of both. AFC method can be tuned with several tuning methods. In this project, intelligent tuning methods such as Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are utilized to study their efficiency in suppressing the vibration.

The model is constructed using MATLAB/Simulink software and is then simulated to investigate the effectiveness of AVC system in attenuating the vibration of the suspended handle generated from the power tool. Several control schemes such as PID controller, PID controller with AFC using Crude Approximation Tuning Method

(PID-AFCCA), PID controller with AFC using GA Tuning Method (PID-AFCGA) and PID controller with AFC using PSO Tuning Method (PID-AFCPSO) are used and compared the vibration attenuation performance of the suspended handle model.

1.2 Problem Statement

Prolonged exposure to the vibration of power tools can cause detrimental effect to the worker health and resulted in sickness like HAVS. Hence, it is vital to build an effective vibration control system to attenuate the vibration of power tools. Vibration control through AFC can be one of the solutions. However, AFC requires proper tuning process to effectively attenuate the vibration. To improve the performance of AFC, different intelligent tuning methods such as GA and PSO are studied and compared in suppressing the vibration on suspended handle model.

1.3 Objectives

The objectives of this study are listed as follows:

- To construct the suspended handle models with AVC system using MATLAB/Simulink software
- To compare the performance of AFC scheme with different intelligent tuning methods such as GA and PSO in attenuating vibration of suspended handle model

1.4 Scope of Work

In this project, MATLAB/Simulink software is used to carry out the simulation of suspended handle model with AVC system. Different control schemes such as PID and AFC are used in this model and by varying the intelligent tuning methods such as GA and PSO, the performance of suspended handle model under different vibration is investigated. The results of various control schemes are studied and compared under similar input parameter.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this chapter, the cause and effect of the vibration of power tools and HAVS are discussed. Besides, AFC using tuning methods such as CA, GA and PSO are explained in terms of working principal and their effectiveness in vibration suppression based on the reported work by other researchers.

2.2 High Vibration of Power Tools

Power tools are devices that operated by power source and motor. These tools are commonly used for construction job and others such as in production, assembly, packaging, and maintenance. Power tools are grouped into two main categories which are portable and stationary. Portable power tools can travel from one place to another easily because of their light weight, while stationary power tools are large machines that are tightly fastened to enable them to function properly. However, power tools often vibrate during operation and this vibration can be transmitted to the worker's hands and arms. Regular and frequent exposure to this mechanical hand-arm vibration will eventually lead to permanent health effects known as HAVS.

To protect the safety and health of worker, the Department of Occupational Safety and Health (DOSH) under the Ministry of Human Resources (MOHR) of Malaysia has provided the recommended vibration limits known as Threshold Limit Values (TLVs) for the hand-arm vibration exposure (DOSH, 2003). These TLVs are shown in Table 2.1 which refer to the maximum permitted vibration acceleration level and duration of exposure. These values can be used as guideline in controlling the hand-arm vibration exposure.

Table 2.1 Threshold limit values (TLVs) for hand-arm vibration exposure

Total Daily Exposure Duration (hours)	**Maximum Root Mean Square (RMS) Acceleration (m/s^2)**
4 – 8	4
2 – 4	6
1 – 2	8
0 – 1	12

The total daily exposure duration is counted as the total time of vibration transmits to the worker's hand per day whether continuously or intermittently, while the maximum RMS acceleration denotes the permitted acceleration level that should not be exceeded. In addition, worker is prohibited to operate the vibrating power tools more than 8 hours per day.

2.3 Hand-Arm Vibration Syndrome (HAVS)

Based on the 2010 Malaysia National Labor Force Statistics Report, it is estimated that more than four million workers in Malaysia are exposed to the hand-arm vibration (Qamruddin *et al.*, 2018). Besides, the number of cases reported to Social Security Organization, Malaysia (SOCSO) under the category of diseases caused by vibration, which is the disorders of muscles, tendons, bones, joints, peripheral blood vessels, or peripheral nerves have increased from 34 in 2010 to 89 in 2016. Based on the reported cases to SOCSO, HAVS has become the second most common disease caused by physical agent after noise-induced hearing loss. However, the actual number of cases might be higher since there will be some cases that are not reported (SOCSO, 2010), (SOCSO, 2016). HAVS is a disease that causes a change in sensation of fingers which can lead to permanent numbness of fingers, muscle weakness, short periods of vibration white finger (VWF) and pain of hands, wrists, forearms, and elbows. An example of VWF disease is shown in Figure 2.1.

Figure 2.1 Vibration white finger (Voelter-Mahlknecht *et al.*, 2012)

In order to secure the health of workers that readily expose to hand-arm vibration due to frequent use of vibrating tools, there is a need to introduce an effective vibration control method in attenuating the vibration generated from the power tools to allow safer usage of tools by the workers.

2.4 Active Force Control (AFC)

One potential approach to avoid HAVS is the use of suspended handle implemented with AVC system. This AVC system tends to generate an actuating force to the suspended handle to suppress the vibration generated from the power tool. The generated force is equal in amplitude but in opposite manner relative to the forces induced by the vibration, whereby the actuating force will cancel out the vibration force. However, AVC system using AFC method requires proper tuning process and by employing intelligent tuning methods such as GA and PSO, the implementation of AVC system on the suspended handle in attenuating vibration from power tools becomes more effective. Before introducing intelligent tuning methods in AFC, CA is once proven to be a feasible tuning method as shown in the following examples. However, CA has low efficiency in vibration attenuation because it takes plenty of time to approximate the best parameter to suppress the vibration.

A control strategy involving AFC using CA and PID controller has been carried out by (Mohebbi *et al.*, 2016) to reduce the vibration of short length drive shaft. Based on the results, it is noticeable that the undesirable offsets are produced by PID controller when short drive shaft is rotating at given loading and operating conditions. Besides, by using PID controller alone, the short drive shaft vibrates at relatively high frequency although there is attenuation in vibration magnitude towards the end. PID controller is very sensitive, and its performance can be adversely affected with slight changes in system. Hence, it is not robust against disturbances as fixed PID controller gains could not adapt to changes in disturbances. However, when AFC scheme is introduced and worked with PID controller, the performance of vibration attenuation is greatly enhanced with offsets being eliminated and vibration magnitude and frequency being largely reduced as shown in Figure 2.2.

Controller (direction)	Amplitude	Frequency (Hz)
Without (x)	2.0 mm	122
Without (y)	3.0 mm	77
Without (θ)	0.035 rad	850
PID (x)	1.5 mm	122
PID (y)	2.2 mm	77
PID (θ)	0.025 rad	850
PID+AFC (x)	0.2 mm	below 0.5
PID+AFC (y)	0.3 mm	below 0.5
PID+AFC (θ)	0.004 rad	below 0.5

Figure 2.2 AFC performance for short length drive shaft (Mohebbi *et al.*, 2016)

A five-link biped robot installed with PD controller and AFC using CA and iterative learning (IL) method are investigated by (Kwek *et al.*, 2003). The average tracking error generated by joints of robot during motion is used to evaluate the overall performance of various control schemes. As in result, the overall performance of AFC scheme outperforms the PD scheme, with and without the external disturbances. The proposed AFC schemes show high degree of accuracy and robustness even with the presence of disturbances. It should be noted that CA method is used only when the dynamic model of robot is known whereby it is impractical in most of the cases whereas IL method does not require any prior knowledge of the robot dynamic model. Hence, AFC using IL method is better as it can provide a simpler and automatic way to obtain the suitable inertia matrix of robot used in disturbance elimination.

2.5 Genetic Algorithm (GA)

GA is a method for solving both constrained and unconstrained optimization problem based on natural selection where the fittest individuals are selected for reproduction to produce offspring of the next generation. This process keeps on repeating until a generation with the fittest individuals is found. In general, there are five phases in GA which are initial population, fitness function, selection, crossover, and mutation. GA begins with a set of individuals called population where each individual is a solution for the optimization problem. Fitness function then determines the fitness of each individual by giving fitness score where individual is selected based on it. Individuals with high fitness have higher probability to be selected for reproduction. In crossover phase, two selected individuals called parents are combined to create offspring of the next generation. Besides, mutation also occurs where random changes are applied to individual parent to form offspring of the next generation. Mutation is vital as it maintains diversity within population and prevents premature convergence. Finally, GA terminates when the produced offspring does not have any significant difference from the previous generation and hence solution is found for the optimization problem (The Mathworks, 2021).

In research done by (Min Yee *et al.*, 2002), it shows that an AFC scheme using GA is able to display a high degree of robustness and accuracy in controlling a rigid two-link horizontal planar robotic arm. When the disturbance torque, T_d is introduced to robotic arm, the performance of control scheme will generally decrease. However, the performance of GA is found to be minimally affected because it can adapt to the increasing disturbance torque, T_d satisfactorily. Based on the results shown in Figure 2.3, it is observable that the GA technique can adapt the inertia matrix value, IN effectively to the changing working condition caused by increasing disturbance torque, T_d. The estimated inertia matrix, IN of robotic arm is appropriately identified and adapted to the imposed condition. Therefore, it can be said that AFC scheme using GA can adapt to disturbances effectively without lowering the performance of system.

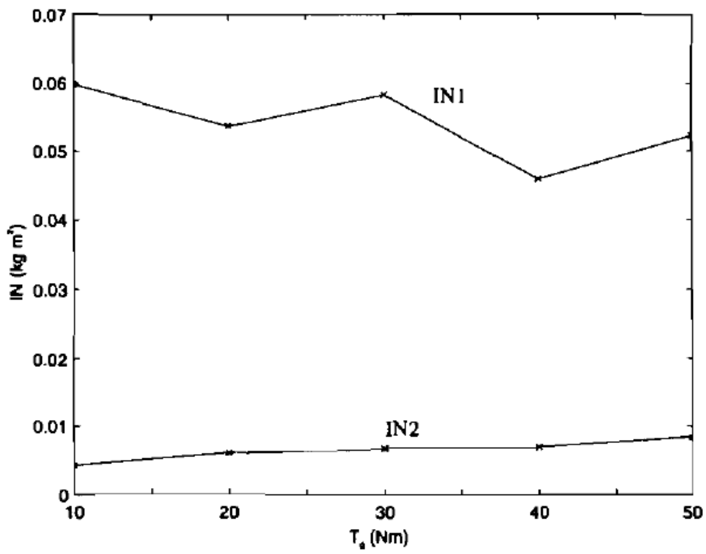

Figure 2.3 AFC-GA performance for controlling a rigid two-link horizontal planar robotic arm (Min Yee *et al.*, 2002)

Active vibration control device is commonly used in structures that are built in seismic zone to control the vibration due to earthquakes for the safety and human comfort. In the study carried out by (Hadi and Arfiadi, 2001), GA procedure is utilized to discover the optimal control force to be applied in active control device to solve structural control problem. Performance indices such as linear quadratic regulator

(LQR) and H_2 norm of the transfer function from the disturbance to the regulated output are chosen and will be minimized by GA to obtain the optimal control force. Based on the results, it is shown that the use of GA in finding the optimal control force is successfully applied for the structural control problem and the optimization procedure involving the performance indices is highly simplified with the application of GA.

2.6 Particle Swarm Optimization (PSO)

PSO is a population-based stochastic optimization technique that is inspired by the social behavior of the animal groups like flocks of birds or schools of fish. PSO begins by creating a group of particles called swarm and these particles are the potential solutions of an objective function to be optimized. The particles are defined by their locations in the search space and initial velocities are assigned to these particles. PSO evaluates the objective function at each particle location and determines the best function value and the best location. Then, new random velocity is assigned to each particle based on the current velocity, its own best location, and the best location of the entire swarm. Again, PSO evaluates the objective function at each new particle location and discovers the best function value and the best location. The process is then repeated until a stopping criterion is satisfied in which an optimal solution is found (The Mathworks, 2021).

A PID controller using PSO has been designed by (Yatim and Mat Darus, 2014) in controlling the flexible manipulator system. This intelligent PID controller tuned by PSO enables flexible body motion of the system because intelligent PID control can suppress the undesirable vibration at the endpoint of flexible link. The controller gains tuned by PSO are optimized by setting the minimization of mean square error as its objective function. By referring to the results in Figure 2.4, it is shown that the