Faculty of Mechanical Engineering

DEVELOPMENT OF A NOVEL ELECTRONICALLY CONTROLLED WEDGE BRAKING SYSTEM

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DECLARATION

I declare that this thesis entitle "Development of A Novel Electronically Controlled Wedge Braking System" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : .....

Date : .....

APPROVAL

I hereby declare that I have read this thesis and in my opinion, this thesis is sufficient in terms of scope and quality for the award of Master of Science in Mechanical Engineering.

Signature : .....

Supervisor Name : .....

Date : .....

DEDICATION

To my beloved mother and father, my wife, my brothers, my sisters, and all my supportive friends.

ABSTRACT

Most automotive vehicles in use today utilize hydraulic system for actuating braking mechanism and producing brake torque to the wheels. Besides being disadvantageous in terms of weight, space and system complexity, hydraulic brakes require relatively high energy to operate the brake piston. Leakage in the hydraulic line and vaporization of hydraulic fluid at high temperature are the main problems that degrade the overall braking performance of the hydraulic brake system. This thesis presents a new design of the Electronic Wedge Brake (EWB) caliper prototype and is part of the effort to replace and to overcome the shortcomings of the conventional hydraulic brake system. The proposed EWB caliper consists of piston, wedge mechanism, worm gear and an electric motor. The rotational motion of the worm gear is driven by the electric motor which will activate the wedge mechanism causing the piston to displace linearly. Linear displacement of the piston will generate clamping force between brake pads and the disk and also produce brake torque if the wheel is rotating. In this study, the electronic wedge brake system is developed and its behavior is investigated using a brake test rig. The mathematical model of the proposed EWB system was constructed. The parameters for the model were obtained experimentally. The model was validated by comparing the response time against experimental rig. The controller was implemented to control the behavior of electronic wedge brake in term of gaping mode and brake torque. A hardware-in-the-loop system was developed to test the controllability of the control structure. As a result, the prototype of EWB caliper can be modeled mathematically to follow its behavior and the implementation shows that the EWB prototype can be adequately controlled in an active safety system.

ABSTRAK

Kebanyakan kenderaan automotif yang digunakan pada masa kini menggunakan sistem hidraulik untuk menggerakkan mekanisme pembrekan dan menghasilkan daya kilas brek pada roda. Selain mempunyai kelemahan dari segi berat, ruang yang diperlukan dan kerumitan sistem, brek hidraulik memerlukan tenaga yang tinggi secara relatifnya bagi mengalirkan bendalir brek untuk menekan omboh. Kebocoran pada perpaipan hidraulik dan pengewapan bendalir hidraulik pada suhu tinggi merupakan masalah utama yang mengurangkan keseluruhan prestasi pembrekan sistem brek hidraulik. Laporan tesis ini membentangkan rekaan baru sistem brek baji elektronik dan merupakan salah satu usaha untuk menggantikan dan untuk mengatasi kelemahan sistem brek hidraulik konvensional. Sistem brek baji elektronik yang dicadangkan terdiri daripada omboh, mekanisme baji, gear ulir dan motor elektrik. Gerakan putaran gear ulir yang dipandu oleh motor elektrik akan mengaktifkan mekanisme baji dan menyebabkan omboh menyesar secara lurus. Sesaran lurus omboh akan menjana daya pengapitan antara pelapik brek dan cakera dan juga menghasilkan daya kilas brek jika roda berputar. Dalam kajian ini, sistem brek baji elektronik dibangunkan dengan menggunakan pelantar ujian brek. Sistem brek baji elektronik yang dicadangkan dimodelkan secara matematik. Parameter untuk model diperolehi secara eksperimen. Model telah disahkan dengan membandingkan gerakbalas model dengan pelantar eksperimen. Pengawal telah dibangunkan untuk mengawal kelakuan brek baji elektronik dari segi mod ngangaan dan daya kilas brek. Sistem perkakas-dalam-lingkaran telah digunakan untuk menguji kebolehkawalan struktur kawalan.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

psi	-	Pound per square inch
kPa	-	Kilopascal
d	-	Brake piston initial position
e	-	Brake piston position at initial clamping force
f	-	Brake piston position at saturated clamping force
F_C	-	Real time clamping force of EWB actuator
F_{CS}	-	Maximum clamping force of EWB actuator
x	-	Brake piston displacement
T_b	-	Brake torque
$F_{friction}$	-	Friction force generated at the contact interface
r_{eff}	-	Effective brake pad radius
F_{normal}	-	Normal force
μ	-	Coefficient of friction

LIST OF ABBREVIATIONS

ABS	-	Antilock Brake System
ACC	-	Adaptive Cruise Control
AD	-	Analog to Digital
BBW	-	Brake by Wire
CAD	-	Computer Aided Drawing
DA	-	Digital to Analog
DC	-	Direct Current
DOT	-	Department of Transportation
EBD	-	Electronic Brake-Force Distribution
ECU	-	Electronic Control Unit
EHB	-	Electro-Hydraulic Brake
EMB	-	Electro-Mechanical Brake
EPB	-	Electro-Pneumatic Brake
ESC	-	Electronic Stability Control
ESP	-	Electronic Stability Program
EWB	-	Electronic Wedge Brake
HIL	-	Hardware-in-the-Loop
HILS	-	Hardware-in-the-Loop Simulation
IMC	-	Integrated Measurement and Control
LVDT	-	Linear Variable Displacement Transducer

MCU	-	Microcontroller Unit
MILS	-	Model-in-the-Loop Simulation
Minsys	-	Microcontroller minimum system
NI	-	National Instrument
PID	-	Proportional Integral Derivative
PWM	-	Pulse Width Modulation
SIL	-	Software-in-the-Loop
SILS	-	Software-in-the-Loop Simulation

LIST OF PUBLICATIONS

Journal

Abd. Rahman, M.L.H., Hudha, K., Ahmad, F. and Jamaluddin, H. (2013) „Design and clamping force modelling of electronic wedge brake system for automotive application", *Int. J. Vehicle Systems Modelling and Testing*, Vol. 8, No. 2, pp.145–156.

Patent Document

An Electronic Wedge Brake - Patent Pending (PI 2013003599)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Overview

Automotive brake system is one of the most important systems in automotive technology to slow and stop vehicle movement and also to hold a vehicle stationary. Given a package of its reliability and cheap cost in mass production, the hydraulic braking system is common in automobile industry. Although there are several shortcomings in the hydraulic braking system such as leakage in the hydraulic line and vaporization of hydraulic fluid at high temperature, researchers continue striving for alternative solutions to improve the existing system.

In vehicles, the hydraulic braking is typically performed by pressing friction pads on disks or drums through hydraulic pistons, which are directly activated by the driver through a pressurized circuit by pushing the brake pedal. Meanwhile, an assisted braking is indirectly provided from the engine mechanically to reduce the physical effort required by the driver. In the last few decades, active safety systems have been gradually introduced to improve the braking effectiveness, such as Antilock Brake System (ABS) and Electronic Brake-Force Distribution (EBD), for emergency braking, especially on slippery road. Basically, these systems compose of a central electronic management unit, speed sensors

and fast electrically-operated hydraulic valves or pistons that are able to modify the actual braking torque (Jitesh, 2014).

Recently, many new brake-by-wire technologies are being developed due to the difficulties in improving the hydraulic braking system (Isermann et al., 2002). The basic architectural issue for brake-by-wire systems is to keep a suitable mechanical structure permitting the driver to perform a direct braking action when necessary, as a safety backup intended to avoid tragic accidents in case of sudden complete failure of the brake-by-wire system. Since braking is actually the most important action to be undertaken in such emergency event, and may even suffice to avoid damage when the failure takes place during travel on a straight road, which constitutes the most common operating condition. Moreover, it must be considered that some kind of purely mechanical subsystem is kept for permanent stationary braking because it would make no sense to use active devices that consume energy to perform this non-dissipative action.

1.2 Problem Statement

This research is initiated to overcome the weakness of the existing brake system and would also complement the green technology initiatives. Various failures of the brake components, change in properties of the brake fluid and careless human interactions over the system can contribute to failure in controlling the vehicle, leading to possible fatality. To overcome those failures, a non-fluid-based brake system has been developed utilizing EWB concept. The EWB system offers a great advantage over conventional hydraulic brake system. With its power-electronics interface, electronic wedge brake system reduces the number of component and complexity of hydraulic power in the overall system, thus reducing the total weight of the vehicle and improving the braking response.

1.3 Background of the Study

An EWB system is a system in which the existing component, of hydraulic or pneumatic brake system is replaced by an electronic interface controlling electromagnetic input with a wedge mechanism for brake output that has low dissipated energy from applying force to brake pedal until clamping force on brake pad. This means, with electronics to electric interface as compared to electro-pneumatic or electro-hydraulic, fast response can increase the controllability over the entire vehicle brake system under various conditions. Commonly, the EWB system uses wedge mechanism to clamp brake pad on brake rotor or drum driven by the DC motor with 12V input.

Currently, hydraulic and pneumatic based electronic brake systems are available in the market. Although electro-hydraulic and electro-pneumatic brake systems have been researched and developed extensively, electro-mechanical brake system is an alternative to be explored. Independently from fluid behavior and drawbacks, a simple and fast response controller can increase the reliability of modern brake system. Also, by replacing the powerline transmitter with wiring harness for electronic circuit, the overall vehicle weight is reduced and the ride and handling performance is improved. In this research, wedge mechanism driven by an electric motor is used as a wheel brake actuator. The effectiveness of using a wedge mechanism in electronic brake depends on the accuracy of model behavior and the ability to develop a suitable controller for the actuator. Furthermore, simulation and experimental evaluation of the electronic wedge brake system are performed to study the performance of the EWB prototype on control implementation.

1.4 Objectives and Scopes of the Study

The first objective of this study is to develop a prototype of wedge mechanism driven by motor to actuate the brake wheel caliper. The second objective is to develop a mathematical model of the EWB caliper behavior. Finally, the third objective is to implement the EWB control strategy using the Hardware in The Loop Simulation (HILS) and Software in The Loop Simulation (SILS).

The scopes of this study are defined as follows:

1. Design and fabrication of an EWB caliper prototype.
2. Investigation and characterization of EWB caliper behavior.
3. Performance evaluation of the proposed mathematical model of EWB caliper.
4. Performance evaluation of the EWB control structure using position and torque tracking control.

1.5 Significance of the Study

The significant contribution of this study is to introduce a novel design of the EWB caliper which is also known as „dry" brake system or non-lubricant brake system. Also, its improvement increases the safety of the vehicle in terms of ride and handling capabilities. Thus, it is hoped that this research can contribute in reducing the number of braking system failure related accidents in this country as well as improving the ride of a vehicle.

1.6 Methodology

A literature review and patent document search were conducted at the earliest stage of the study to have a better overview and understanding of the problem statement. The area of interest was related to wedge mechanism of the EWB actuator for necessity system requirement for this project. Then, prototype development involved CAD software and fabrication of first prototype through machining process. The finished parts and components were assembled with some minor modification to best suit the experimental work. It includes an attachment of sensors and development of test rig for brake system at the Autotronic Laboratory at Universiti Teknikal Malaysia Melaka (UTeM). After completion of the system assembly, the brake force and torque characterization could be performed.

Next, the identification system of EWB actuator mechanism through the experimental setup (piston gaping and brake force relation) using non-parametric modeling method and then validates through experimental evaluation. Then, Model-in-the-Loop Simulation (MILS) is developed by using two methods. Software-in-the-Loop Simulation (SILS) is conducted in a way of the EWB mathematical model is an actuator in the loop system while Hardware-in-The-Loop Simulation (HILS) is being done with the prototype of EWB as an actuator in the loop system. Torque tracking control evaluation is being done through both SILS and HILS setup in MATLAB-SIMULINK environment.