SPEED CONTROL OF BRUSHLESS DC MOTOR USING PID CONTROLLER

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MASTER OF MECHANICAL ENGINEERING (AUTOMOTIVE)

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A thesis submitted
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DECLARATION

I declare that this thesis entitled "Speed Control of Brushless DC Motor with PID Controller" 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.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality as a partial fulfillment of Master of Mechanical Engineering (Automotive).

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DEDICATION

To my beloved mother, wife, children, and family who are always there for me.

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ABSTRACT

Brushless direct current (BLDC) motors are extensively utilized in a variety of industrial applications due to their high efficiency, high torque, and durability. However compared to conventional direct current motors, BLDC motor design requires a suitable controller for accurate speed and position control for its implementation. The goal of this study is to create a full model of the BLDC motor as well as a suitable controller for its speed tracking control within the predefined performance parameters. Although several controller schemes have been proposed, most are complex and require tedious computations. Due to its simplicity and ease of implementation, a Proportional Integral Derivative (PID) controller was used as the basis for the speed controller. The BLDC motor as well as the speed controller was simulated using MATLAB-Simulink software and the speed tracking simulation performance was then compared against experimental data using Hardware-in-Loop simulation. The experimental and simulation results indicate that the proposed controller achieves excellent speed tracking performance within the set performance objectives.

KAJIAN KAWALAN KELAJUAN MOTOR ARUS TERUS TANPA BERUS

ABSTRAK

Motor arus terus tanpa berus kini banyak digunakan di dalam pelbagai aplikasi industri atas mutu kecekapannya, daya kilas yang tinggi dan ketahanan yang sangat lasak. Namun jika dibandingkan dengan motor arus terus dengan berus, penggunaan motor arus terus tanpa berus memerlukan pengawal yang sesuai yang berfungi untuk menentukan kadar kelajuan dan kedudukan motor. Tujuan kajian ini dijalankan adalah untuk merekabentuk satu model motor arus terus tanpa berus beserta pengawal yang berkenaan untuk mengawal kelajuannya. Walaupun pelbagai kaedah kawalan telah diperkenalkan untuk motor arus tanpa berus, kebanyakan kaedah ini rumit dan memerlukan pengiraan yang kompleks. Disebabkan strukturnya yang ringkas di samping perlaksanaan yang tidak rumit, kawalan PID dipilih sebagai asas untuk sistem kawalan kelajuan motor untuk projek ini. Keberkesanan teknik kawalan ini diuji menggunakan simulasi melalui perisian MATLAB-Simulink dan hasil simulasi dibandingkan dengan data daripada ujian menggunakan perkakasan peranti kawalan kelajuan motor arus terus. . Hasil keputusan ujian menunjukkan teknik kawalan PID ini untuk mengawal kelajuan motor arus terus tanpa berus berfungsi dengan cemerlang dan menepati piawaian prestasi yang ditetapkan.

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LIST OF SYMBOLS

K_P	-	Proportional gain
K_i	-	Integral gain
K_d	-	Differential gain
e	-	Error
t	-	Instantaneous time
T_i	-	Integral time
T_d	-	Derivative time
b	-	Fraction of command signal
N	-	High frequency limiter of derivative action
U_{min}	-	Minimum saturation value
U_{max}	-	Maximum saturation value
h	-	Sampling time
K_{cr}	-	Critical value of proportional gain
P_{cr}	-	Corresponding period of sustained oscillation
t_s	-	Settling time
t_r	-	Rising time
M_p	-	Maximum overshoot
e_{ss}	-	Steady-state error
V	-	Voltage
E	-	Back electromagnetic force
R	-	Resistor
L	-	Inductance
I	-	Current flow
T_e	-	Motor torque
B	-	Damper constant
T_1	-	Reaction torque
θ	-	Angular rate of the rotor
J	-	Motor armature moment of inertia
K	-	Torque constant

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K_b - Electromagnetic force constant

θ - Desired position angle

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LIST OF ABBREVIATIONS

BLDC	-	Brushless Direct Current
DC	-	Direct Current
PID	-	Proportional-Integral-Derivative
MATLAB	-	Matrix laboratory
EMF	-	Electromagnetic force
RM	-	Ringgit Malaysia
HILS	-	Hardware in the Loop Simulation
SCM	-	Speed Control System
KVL	-	Kirchhoff Voltage Law

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CHAPTER 1

INTRODUCTION

1.1 Overview

The automotive industry is undergoing a massive technological shift towards electrification and intelligent vehicles as there are increasing demands for more sustainable and efficient forms of mobility. Central to the development of intelligent vehicles is drive by wire technology (Soumelidis and Egyetem, 2020). Drive by wire technology refers to the use of electrical or mechatronic systems to perform various vehicle functions that were previously accomplished with mechanical systems. In the automotive domain there are three major drive by wire technologies: throttle by wire, brake by wire and steer by wire. While the former two fields are increasingly common place in current production vehicles, the steer by wire technology is currently the focus of research in as much it is crucial for the development of intelligent and autonomous vehicles (Buechel *et al.*, 2015).

In steer by wire system, the mechanical connection between the steering wheel and front wheels are eliminated, i.e. the steering column is completely eliminated. The steer by wire system consists of two main systems: the steering component and the wheel component (Kader, 2006). The former consists of the steering wheel, the steering force feedback motor and the position sensor. The latter system is composed of the steering actuator acting on the rack and pinion assembly and the pinion angle sensor.

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In this study, the focus would be on studying the speed control mechanism of the steering actuator motor acting on the rack and pinion assembly. The requirements for selecting the appropriate type of motor is that it must be powerful enough to steer the wheels when it is loaded, as well as to minimize the effect of road disturbances (Bianchi *et al.*, 2009). Also to avoid mechanical vibrations and audible noise, the torque output characteristic should be smooth and ripple-free.

For this purpose, the type of electric motor chosen for this application is the brushless DC (BLDC) motor. In comparison to brushed DC and induction motors, BLDC motors have several advantages. They have improved speed-to-torque characteristics, high dynamic response, high efficiency, long operational life, noiseless operation, greater speed ranges, and durable construction, among other features. Furthermore, the torque provided to the motor size is higher, making it suitable in applications where space and weight are important considerations (Muhamad *et al.*, 2012).

Because of these favorable properties, BLDC is widely adopted in the automotive, appliance, aerospace, consumer, medical, instrumentation and automation industries (Yedamale, 2003). Particularly in the case of the steering rack actuator motor in steer by wire system which requires precise speed and position control. Therefore this study aims to develop a comprehensive simulation model utilizing PID control method to regulate the speed of a BLDC motor using MATLAB Simulink program.

1.2 Research Background

With increasing ubiquity of intelligent technology, smart automation is the prime driver to accelerate this trend. Automated tasks are accomplished via electric motors which translate electronic commands into mechanical force, thus performing as the essential cog to power any automated system. Lately brushless DC motor (BLDC) has been widely adopted particularly in fields which require high performance, due to its relatively compact structure, high power output, excellent durability and almost zero maintenance (Singh *et al.*, 2013).

Despite the inherent advantages of the BLDC motor, there remain several challenges which need to be addressed. Firstly is the modelling of the BLDC system. Due to the trapezoidal nature of the stator winding and the requirement to sense the position of the rotor magnets at every instant to operate specific switches in ON and OFF positions, the modelling of a BLDC motor is challenging for any user (Murali and Arulmozhiyal, 2021).

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Designing a BLDC drive system is a complex procedure which includes modelling, control scheme selection, simulation and parameter tuning, among others. Hence to obtain optimum performance of the BLDC drive, expert tuning of the controller parameters are essential. Various control methods have been proposed for BLDC motor, yet most of them are structurally complex and necessitate excessive calculation (Srikanth and Chandra, 2012). PID control, on the other hand, offers a simple yet effective approach to a variety of control problems (Ang, Chong and Li, 2005). The PID controller is tuned by the Ziegler-Nichols method, which is accepted as the standard method in control system practice (Prakash and Naik, 2014).

Another challenge when designing a BLDC system is to deal with the torque ripple. Ideally a BLDC motor has to be supplied with a rectangular current waveform in armature winding to produce a trapezoidal back EMF to produce constant torque. However practically the back EMF follows a sinusoidal pattern and not the ideal trapezoidal waveform due to mechanical tolerances since the motor windings are inductive in nature (Hanselman, 1994). Torque ripple usually cancels out at higher speeds due to system inertia, however it is problematic at lower speeds where torque ripple is prominent and is usually not tolerable in applications which require smooth torque output and low-noise. Generally the torque ripple is attributed to two main factors: motor structure and motor control (Pahlavani, Ayat and Vahedi, 2017). At present there are two main strategies to reduce torque ripple: first is the motor ontology design optimization, where the structure of the stator, rotor and winding are optimized to reduce air-gap magnetic field resulting in elimination of cogging torque thus approximating back EMF to ideal waveform. The second approach is to utilize advanced control methods by optimizing phase voltage and current to approximate the ideal back EMF waveform to produce a smooth torque output (Arafa and Mansour, 2015).

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Additionally, simulation of BLDC motor is necessary to prevent failure or malfunction in practical applications. This can occur due to component deterioration as a result of long-term operations, which is often missed (Xuan *et al.*, 2017). Unidentified and unaddressed safety concerns can result in system failures, emergency shutdowns, and catastrophic failures, resulting in irreversible economic losses and casualties. To avoid such catastrophes, it is vital to guarantee that BLDC motors and their application systems are operated safely and efficiently by appropriate modelling and simulation.

1.3 Problem Statements

From the above background studies, it can be seen that research on BLDC motor has significant impact on steer by wire system in that it can affect the accuracy and smoothness of the actuator motor on the steering rack that directly affects the handling quality and vehicle safety. It can also be observed however there are still limitations in the BLDC design that needs to be addressed:

i. There exist a variety of modelling for BLDC motor systems, however due to the challenging nature of designing these system the credibility of these modellings haven't been fully tested.

ii. BLDC motor design requires a suitable controller.

iii. Due to safety hazards, testing a BLDC motor in a real application is dangerous

1.4 Objectives of Study

The following goals are the focus of this research:

i. To determine the accuracy of the hypothesized BLDC motor mathematical model.

ii. To determine the proposed controller model's ability to regulate the intended BLDC motor speed control. .

iii. To utilize a HILS scenario to validate the performance of the proposed BLDC motor model.

1.5 Scopes of Study

The scopes of this research are:

i. The previous work of Meshram and Kanojiya (Meshram and Kanojiya, 2012)

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is used for the parametric modelling of the BLDC motor.

ii. A second order transfer function is used in the nonparametric modelling of the BLDC.

iii. Validation is performed by comparing the simulated data to the provided experimental data

iv. The proposed control structure's capabilities are evaluated using a BLDC motor test rig.

v. The ARDUINO UNO, which is available in the automotive lab, is employed as the experimental microcontroller in this work.

vi. The PID controller is fine-tuned using a statistical analysis method.

vii. All simulations and analyses are performed using simulation software, which is MATLAB-Simulink.

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CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter aims to highlight a brief literature review of brushless DC (BLDC) motor, the PID controller, PID tuning, PID auto-tuning and Ziegler-Nichols tuning method.

2.2 Brushless DC Motor

One of the most significant achievements in technology and engineering is the invention of electric motors, an electromechanical device that converts electrical energy into mechanical energy. The first working DC motor was invented by Frank Julian Sprague, which lead to the first elevator system in 1892 (Chi and Luk, 2015).

In terms of form and operating principle the initial DC machines are similar with the machines used today. Conventional DC motors (brushed DC motors) are consisted of a stator, which consists of permanent magnets and the rotor which consist of coil winding supplied by DC current. A magnetic field is formed within the stator when the motor is powered by DC current, attracting and repelling the magnets on the motor. The rotor begins to rotate as a result of this. A commutator is used in the motor to keep the rotor moving. The rotor would cease spinning when it aligned with the magnetic field, but the commutator would reverse the current through the stator, reversing the magnetic field therefore repeating the cycle over and over again, producing rotary movement (Emadi, 2014).

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