UNIVERSITI PUTRA MALAYSIA

REDUCTION OF TOTAL HARMONIC REDUCTION IN TORQUE CHARACTERISTICS IN TWO-PHASE SIDE BY SIDE BRUSHLESS DC MOTOR

NG SENG SHIN

FK 2013 60
REDUCTION OF TOTAL HARMONIC REDUCTION IN TORQUE CHARACTERISTICS IN TWO-PHASE SIDE BY SIDE BRUSHLESS DC MOTOR

By

NG SENG SHIN

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfillment of the Requirements for the Degree of Master of Science

January 2013
Dedication

TO
MY BELOVED PARENTS, MY BROTHER, MY FAMILY AND MY FRIENDS.
This research deals with the reduction of total harmonic distortion (THD) in torque characteristics for the improvement of torque ripple in two-phase side by side brushless DC motor. The sinusoidal waveform in torque characteristic create uniform flux distribution that produces smooth speed rotation.

By creating an uniform flux distribution, the torque ripple produced by the motor is reduced. To reduce the torque ripple, the flux density distribution in the gap must be adjusted. It gives a more balanced flux density distribution in the motor. The ideal situation is that the developed torque being higher with low torque ripple value. By variation of various parameters, the flux flows inside the motor changes. The final aim is to get sinusoidal waveform and reduce the torque ripple as much as possible. Simulation studies to evaluate the aspects of the flux distribution inside the machine and the torque characteristic are presented.
There are studies to reduce the cogging torque produced by the brushless DC motor. By reducing the cogging torque, the THD of the torque characteristic can be reduced. In those previous researches, the combination of each pole of different structure is not being discussed before. Thus, the combination method introduced in this research is a new technique that can further reduce the THD of the torque waveform produced by the motor.

In this study, the structure of individual single phase brushless DC motor is adjusted to get near sinusoidal waveform in the torque characteristic which has low THD value. Combination of different pole structure motor is presented to get the lowest THD in torque characteristic possible. Then, two phase side by side brushless DC motor is presented to reduce the torque ripple produced by the motor. The simulation result in the original model is verified by experimental result.

Simulation analysis using finite element method (FEM) is performed to analyze the magnetic circuit on various shapes of rotor and stator. The analysis parameters include the magnetic field flux, the cogging force and the developed torque. The optimum model is derived. In the end, the torque ripple generated by the original motor is reduced by 70.5% compared with the torque ripple produced by the optimized motor. So, the proper choice of parameters is important in getting sinusoidal waveform and reduce the torque ripple produced by the motor.
Abstrak thesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENGURANGAN HEROTAN HARMONIK DALAM CIRI DAYA KILAS DALAM MOTOR DC DUA FASA TANPA BERUS SEBELAH-SEBELAH

Oleh

NG SENG SHIN

Januari 2013

Pengerusi : Prof. Madya Norhisam Misron, PhD
Fakulti : Kejuruteraan

Kajian ini bagi mengurangkan herotan harmonik (THD) dalam ciri daya kilas ke atasdaya riak dalam motor DC dua fasa tanpa berus sebelah-sebelahan. Bentuk gelombang sinus dalam ciri daya mewujudkan taburan fluks seragam yang menghasilkan kelajuan putaran yang lancar.

Dengan pengagihan ketumpatan fluks yang lebih seimbang, dayariah yang dihasilkan oleh motor dapat dikurangkan. Untuk mengurangkan dayariah, taburan ketumpatan fluks dalam jurang mestilah diimbangkan. Ia memberikan ketumpatan fluks pengagihan yang lebih seimbang dalam motor. Situasi yang ideal adalah menghasilkan daya kilas yang lebih tinggi dan daya riak yang dihasilkan oleh motor adalah lebih rendah. Jadi, dengan perubahan pelbagai parameter di motor, aliran fluks yang dihasilkan dalam motor turut berubah. Matlamat akhir adalah untuk mendapatkan bentuk gelombang sinusoidal dan mengurangkan daya riak seberapa
banyak yang mungkin. Kajian simulasi untuk menilai aspek taburan fluks di dalam mesin dan ciri-ciri daya cogging akan dibentangkan.

Terdapat kajian untuk mengurangkan daya riak yang dihasilkan oleh motor DC tanpa berus. Dengan mengurangkan daya riak, THD daripada ciri daya kilas boleh dikurangkan. Dalam kajian sebelum ini, gabungan setiap tiang struktur yang berbeza tidak dibincangkan sebelum ini. Oleh itu, kaedah gabungan yang diperkenalkan dalam kajian ini adalah teknik baru yang boleh terus mengurangkan THD daripada hasil gelombang daya kilas oleh motor.


Analisis simulasi menggunakan kaedah unsur terhingga (FEM) dilakukan untuk menganalisis litar magnet pada pelbagai bentuk pemutar dan pemegun. Parameter analisis termasuk fluks medan magnet, daya cogging dan daya kilas yang dihasilkan. Model optimum dibangunkan. Pada akhirnya, riak tork yang dijanakan oleh motor asal dikurangkan sebanyak 70.5% berbanding dengan riak tork yang dihasilkan oleh motor dioptimumkan. Jadi, pilihan parameter yang betul akan berkesan dalam mendapatkan gelombang sinusoidal dan mengurangkan daya riak yang dihasilkan oleh motor.
I would like to express my deepest appreciation and gratitude to my supervisor, Prof Madya Dr. Norhisam for his guidance, effort in guiding support, valuable advice and patience throughout this project. His support and guidance helped me gone through various difficulties during the whole process to produce good quality works.

Besides that, I would like to take this opportunity to express my appreciation to the panel examiners, Dr. Noor Izzri b Abd.Wahab for their comment and suggestion that lead me to make greater improvement in my project. Apart from that, I would like to express my heartfelt thanks to Mr. Raja Nor Firdaus Kashfi and Mr.Suhairi Rizuan for their guidance and helps in my software and hardware part of this project.

Finally, special thanks to my family and friends for their care and support which contributes to the successfully completion of this project.
I certify that a Thesis Examination Committee has met on 30 January 2013 to conduct the final examination of Ng Seng Shin on his thesis entitled "Reduction of Total Harmonic Reduction in Torque Characteristic in Two-Phase Side By Side Brushless DC Motor" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the degree of Master of Science.

Members of the Thesis Examination Committee were as follows:

**Ishak b Aris, PhD**  
Professor  
Faculty of Engineering  
University Putra Malaysia  
(Chairman)

**Hashim b Hizam, PhD**  
Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Internal Examiner)

**Chandima Gomes, PhD**  
Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Internal Examiner)

**Abdul Halim b Mohamed Yatim, PhD**  
Professor  
Faculty of Engineering  
University Teknologi Malaysia  
Malaysia  
(External Examiner)

---

**SEOW HENG FONG, PhD**  
Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:
This thesis submitted to the Senate of University Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee are as follows:

**Norhisam Misron, PhD**  
Associate Professor  
Faculty of Engineering  
University Putra Malaysia  
(Chairman)

**Noor Izzri b Abd. Wahab, PhD**  
Senior Lecturer  
Faculty of Engineering  
University Putra Malaysia  
(Member)

___________________________________  
BUJANG BIN KIM HUAT, PhD  
Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia  

Date:
DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Putra Malaysia or other institutions.

NG SENG SHIN
Date: 30 January 2013
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEDICATION</td>
<td>ii</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>iii</td>
</tr>
<tr>
<td>ABSTRAK</td>
<td>v</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENTS</td>
<td>vi</td>
</tr>
<tr>
<td>APPROVAL</td>
<td>viii</td>
</tr>
<tr>
<td>DECLARATION</td>
<td>x</td>
</tr>
<tr>
<td>LIST OF TABLES</td>
<td>xiii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>xv</td>
</tr>
<tr>
<td>LIST OF ABBREVIATIONS</td>
<td>xviii</td>
</tr>
</tbody>
</table>

## CHAPTER

### I INTRODUCTION

1.1 Problem Statement 3
1.2 Aim and Objectives 4
1.3 Scope of Work 5
1.4 Thesis Outline 6

### II LITERATURE REVIEW

2.1 Introduction to DC Brushless Motor 7
2.2 Overview of Other Related Research 11
2.3 Concept of Finite Element Method 16
2.4 FEM in DC Brushless Motor Structure Modelling 19
2.5 Summary 22

### III METHODOLOGY

3.1 General Design Concept 23
3.2 FEM Design Concept 26
   3.2.1 Modelling Structure for Simulation 27
   3.2.2 Magnetic Analysis 29
3.3 Basic Structure 34
3.4 Parameter of Structure 34
   3.4.1 Stator Modification 34
   3.4.2 Rotor Modification 35
3.5 Combination Design Method 42
3.6 Matrix Combination Method
3.7 Total Harmonic Calculation
3.8 Torque Measurement Method in Brushless DC Motor
3.9 Two-Phase Side by Side Motor
3.10 Summary

IV RESULTS AND DISCUSSION
4.1 Models and Simulation Results
   4.1.1 Analysis on Normal Stator Pitch teeth
   4.1.2 Analysis on Y Shape Slit
   4.1.3 Analysis on Half Y Shape Slit
   4.1.4 Analysis on V Shape Slit
   4.1.5 Analysis on V Shape Big Gap
   4.1.6 Analysis on V Shape Small Gap
   4.1.7 Analysis on Sharp Stator Pitch teeth
   4.1.8 Analysis on Right Hand Shape Slit
   4.1.9 Analysis on Left Hand Shape Slit
   4.1.10 Analysis on 4 slits
   4.1.11 Analysis on 6 slits
4.2 Comparison on the Best Model for each Parameter Varied
4.3 Combination Final Model
   4.3.1 Two Pole Structure
   4.3.2 Three Pole Structure
4.4 Data Validation and Comparison
   4.4.1 Data Comparison
   4.4.2 Data Validation
4.5 Combination of Two Phase Side by Side Motors
   4.5.1 Two-Phase Side by Side Motor with Single Pole Structure
   4.5.2 Two-Phase Side by Side Motor with 2 Pole Structure
   4.5.3 Two-Phase Side by Side Motor with 3 Pole Structure
4.6 Summary

V CONCLUSION AND RECOMMENDATION FOR FUTURE WORK
5.1 Conclusion
5.2 Future Recommendations

REFERENCES
APPENDICES
PUBLICATION
BIODATA OF STUDENT