Faculty of Electrical Engineering

Modeling and Analysis of Constants For Various Double Stator Permanent Magnet Brushless DC Motor

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MODELING AND ANALYSIS OF CONSTANTS FOR VARIOUS DOUBLE STATOR PERMANENT MAGNET BRUSHLESS DC MOTOR

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DECLARATION

I declare that this thesis entitled "Modeling and Analysis of Constants for Various Double Stator Permanent Magnet Brushless DC Motor" 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 candidates 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 term of scope and quality for the award of Master of Science in Electrical Engineering.

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Supervisor Name : Dr. Raja Nor Firdaus Kashfi Bin Raja Othman

Date :……………………………………………………….

DEDICATION

TO MY BELOVED PARENTS

En. Md Zuki bin Yaacob and Pn. Rihana binti Abu Johar

TO MY BROTHERS AND SISTERS

Zarina, Muhammad Ridhuwan, Muhd Firdaus, Zuraini, Mohd Zolhelmi, Nor Syafiqah and Muhammad Khairul Fahmi

And lastly to all individuals who always supports all my works without any doubts.

ABSTRACT

Double stator topology is recently used for various applications where power segmentation and reliability are the main key factors. Double Stator Permanent Magnet Brushless DC Motor (DSPM BLDC) has high torque density because it has two air gaps due to two permeances. Thus, the torque produced will be almost doubled as a single stator. Therefore, many researchers interested to increase the torque density using double stator topology. However, most double stators used surface mount rotor structure. The problem with this structure is that it requires large air gap that could reduce percentage of achieving higher torque with low volume ratio at optimum level. In addition, application such as hybrid or electric vehicle requires fast response motor that capable to react as soon as possible. Thus, the motor must have higher time response with lower electrical time constant, T_e and mechanical time constant, T_m. However, there are few literature reported about time response for double stator topology. Basically, most of the literature studies the time response for linear motor and servo motor due to their application for high precision positioning. The time response is relates to various constant parameters of the motor. The advantage of high torque density offered by the double stator is very likely to be implemented for another application in the future. Therefore, to overcome this problem, a new type of double stator permanent magnet motor with Slotted Rotor (DSPM-SR) is introduced and this thesis is the study of the constants for various types of DSPM BLDC motor through model analysis. The usage of the proposed DSPM-SR is to minimize the flux leakage, thus increasing the flux linkage. The proposed DSPM-SR also has the highest torque density among other double stator topology. The objective of this research is to model various types DSPM BLDC and investigate the values of torque, electromotive force (emf), inductance, resistance, flux density, electrical time constant, T_e and also mechanical time constant, T_m. For the modeling, the Permeance Analysis Method (PAM) will be used to derive the analytical equations that indicate the presence of two time constants, which are T_e and T_m. Finite Element Method (FEM), is used to simulate the real characteristics of various types of DSPM BLDC motor that consider the presence of values T_e and T_m. The smaller the response, the better the performance for fast response application. The result shows that the proposed DSPM-SR has good performance such as highest back emf, highest torque and good time response. A prototype of DSPM-SR has been fabricated and measured. The percentage difference of Analytical-FEM for T_e and T_m is 4.2 % and 9.1 %, respectively. As a conclusion, this thesis provides an overview of modeling and analysis of various constants that could affect the performance of the double stator topology.

ABSTRAK

Motor DC Tanpa Berus Magnet Kekal Dua Pemegun (DSPM BLDC) mempunyai daya kilas yang tinggi kerana ia mempunyai dua jurang udara disebabkan oleh dua telapan. Oleh itu, daya kilas yang dihasilkan hampir dua kali ganda bebanding motor satu pemegun. Oleh itu, ramai penyelidik berminat untuk meningkatkan ketumpatan daya kilas menggunakan topologi motor dua pemegun. Walau bagaimanapun, kebanyakan motor dua pemegun mempunyai struktur pemutar jenis timbunan permukaan. Masalah struktur ini adalah ia mempunyai jurang ruang udara yang besar yang dapat mengurangkan penghasilan daya kilas yang lebih tinggi dengan nisbah isipadu yang rendah pada tahap yang optimum. Tambahan pula, aplikasi seperti hibrid atau kenderaan elektrik memerlukan motor tindak balas motor segera yang mampu bertindak secepat mungkin.Oleh itu, motor mestilah mempunyai masa tindak balas yang lebih tinggi dengan pemalar masa elektrik, T_e *dan pemalar masa mekanikal,* T_m *yang lebih rendah. Walau bagaimanapun, terdapat beberapa literatur melaporkan tentang tindak balas masa untuk topologi dua pemegun. Pada dasarnya, kebanyakan literatur mengenai tentang tindak balas masa adalah untuk motor lelurus dan motor servo kerana aplikasi mereka untuk kedudukan ketepatan yang tinggi. Tindak balas masa adalah berkaitan dengan pelbagai parameter motor yang pemalar. Kelebihan ketumpatan daya kilas yang tinggi yang ditawarkan oleh motor dua pemegun boleh dilaksanakan untuk aplikasi yang sama pada masa akan datang. Oleh itu, untuk mengatasi masalah ini, sejenis motor magnet kekal dua pemegun dengan pemutar berlubang alur (DSPM-SR) telah diperkenalkan dan tesis ini adalah mengenai pemalar untuk beberapa jenis motor DSPM BLBD melalui permodelan and menganalisa. Kegunaan DSPM-SR yang dicadangkan adalah untuk meminimumkan kebocoran fluks dan secara tidak langsung dapat meningkatkan pautan fluks. DSPM-SR yang dicadangkan mempunyai ketumpatan daya kilas yang tertinggi berbanding topology dua pemegun yang lain. Objektif penyelidikan ini adalah untuk memodel beberapa motor DSPM BLDC dan menyiasa nilai daya kilas, daya gerak elektrik balik (emf), kearuhan, rintangan, ketumpatan fluks, pemalar masa elektrik,* T_e *dan juga pemalar masa mekanikal,* T_m*. Untuk pemodelan, Kaedah Analisis Telapan (PAM) akan digunakan untuk memperolehi persamaan beranalisis yang menunjukkan kehadiran dua pemalar masa iaitu* T_e *dan* T_m*. Kaedah Unsur Terhingga (FEM) digunakan untuk mensimulasikan ciri sebenar pelbagai jenis bentuk motor DSPM BLDC dengan kehadiran* T_e *dan* T_m*. Sekiranya tindak balas yang lebih kecil. prestasi untuk aplikasi yang cepat akan lebih baik. Keputusannya menunjukkan bahawa DSPM-SR mempunyai prestasi yang baik seperti daya gerak elektrik balik yang lebih tinggi, daya kilas yang tinggi dan tindak balas terhadap masa yang baik. Prototaip DSPM-SR telah difabrikasi dan diukur. Peratusan perbezaan bagi Beranalis-FEM untuk* T_e *dan* T_m *adalah masing-masing menunjukkan 4.2 % dan 9.1 %. Kesimpulannya, tesis ini memberikan gambaran keseluruhan pemodelan dan analisis pelbagai pemalar yang boleh mempengaruhi prestasi topologi motor dua pemegun.*

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a	-	Area of coil
a_g	-	Air gap area
a_{gi}	-	Inner air gap
a_{go}	-	Outer air gap
A_{mg}	-	Area of permanent magnet
AC	-	Alternative Current
B	-	Flux density of stator
BLDC	-	Brushless DC
B_r	-	Remanent of flux density
B_k	-	Magnetic flux density of permanent magnet at operating point
d_c	-	size of coil diameter
DC	-	Direct Current
DSPM	-	Double Stator Permanent Magnet
DSPM-SR	-	Double Stator Slotted Rotor Permanent Magnet
DSPM-DP	-	Double Stator Double Pole Permanent Magnet
DSPM-IP	-	Double Stator Interior Permanent Magnet
DSPM-ST	-	Double Stator Spoke Type Permanent Magnet
e	-	electrical degree
emf	-	Electromotive force
f	-	frequency
FEM	-	Finite Element Method

g	-	Air gap
g_1	-	Air gap between stator teeth and rotor
g_2	-	Air gap between inside the rotor
G	-	Motor constant square density
h_c	-	height of coil
h_i	-	Height of inner coil
h_m	-	Height of permenant magnet
h_o	-	Height of outer coil
H	-	Henry
H_c	-	Coercive force
H_k	-	Magnetic field intensity of permanent magnet at operating point
I	-	Current
I_D	-	Diameter inner stator
IGBT	-	Insulated-gate bipolar transistor
IPMSM	-	Interior permanent magnet synchronous motor
J	-	Inertia
k_e	-	Back emf constant
k_t	-	Torque constant
K_m	-	Motor constant
l	-	Stack length
l_c	-	Length of coil
L	-	Inductance
LOA	-	Linear oscillatory actuator
m	-	Equivalent of rotating parts

n_r	-	speed regulation constant
N	-	Nouth
N	-	Total number of turns
N_{slot}	-	the number of slot in one phase
O_D	-	Diameter outer stator
p	-	number of pole in DSPM-SR
PAM	-	Permeance Analysis Method
P_{copper}	-	Copper losses
$P_{coreloss}$	-	Core losses
P_{hys}	-	Hysteresis losses
P_{eddy}	-	Eddy current losses
$P_{friction}$	-	Friction losses
P_{in}	-	Input Power
P_{out}	-	Output Power
r	-	Radius at ring with semi-circular section
r_i	-	Radius of inner rotor
r_o	-	Radius of outer rotor
r_r	-	Rotor radius
rpm	-	Revolution per minute
R	-	Resistance
R_{inner}	-	resistance at inner stator
R_{outer}	-	resistance at outer stator
R_T	-	Total resistance
S	-	South

T	-	Tesla
T_d	-	Torque density
T_e	-	Electrical time constant
T_m	-	Mechanical time constant
T_{stall}	-	stall torque
V	-	voltage applied to the motor
V_{ol}	-	Active volume
V_{PM}	-	Permanent magnet volume
w_c	-	width of coil
w_i	-	Width of inner coil
w_m	-	Width of permanent magnet
w_o	-	Width of outer coil
W	-	co-energy of DSPM-SR
ε_h	-	Hysteresis coefficient
ε_e	-	Eddy current coefficient
ρ	-	Resistivity of copper
Þ	-	permeance
μ_o	-	Permeability factor
μ_r	-	Relative permeability
μ	-	Permeability material
θ	-	Angle of stator teeth
θ_m	-	Maximum angle of voltage
θ_{stat}	-	Angle of stator teeth
θ_{slot}	-	Slot opening

ϕ_{coil}	-	flux at the coil
ϕ_M	-	Maximum flux
ϕ_{mg}	-	flux of the permanent magnet
ψ	-	Flux Linkage

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