Motor Control of a Hub Motor for Electric Skateboard Propulsion

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Abstract

An electric powered skateboard was designed and built for testing and development of an innovative hub motor propulsion system and motor controller. The electric skateboard prototype is able to reach speeds of over 50km/h and achieve a range of over 35km on a single battery charge. The prototype weighs 8.6kg and can easily be carried by the user. This mode of transport has potential uses in recreational use, motor sports (racing), short commutes, and most notably, in ‘the last mile’ of public transport – getting to and from a train station, bus stop, etc. to the user’s final destination.

Typical electric powered skateboards use external motors(s) requiring a power transmission assembly to drive the wheels. The hub motor design places the motor(s) inside the skateboard wheels and drives the wheels directly. This removes the need for power transmission assemblies therefore reductions in size, weight, cost, audible noise, and maintenance are realised. The hub motor built for this prototype has proven to be a highly feasible option over typical drive systems and further improvements to the design are discussed in this report.

Advances in the processor capability of low cost microcontrollers has allowed for advanced motor control techniques to be implemented on low cost consumer level motor controllers which, until recent times, have been using the basic ‘Six-Step Control’ technique to drive Permanent Magnet Synchronous Motors. The custom built motor controllers allow for firmware to be flashed to the microcontroller. Firmware was written for the basic motor control technique, Six-Step Control and for the advanced motor control technique, ‘Field Oriented Control’ (FOC). This allowed for the two control techniques to be tested and compared using identical hardware for each.

Six-Step Control drives a three phase motor by controlling the inverter output to six discrete states. The states are stepped through sequentially. This results in a square wave AC waveform. Theory shows that this is not optimal as the magnetic flux produced in the stator is not always perpendicular to the magnet poles but rather aligned to the nearest 60°. FOC addresses this by controlling the magnetic flux to always be perpendicular to the magnet poles in order to maximise torque. The inverter is essentially controlled to produce a continuously variable voltage vector output in terms of both magnitude and direction (vector control).

Bench testing of the control techniques was performed using two motors coupled together with one motor driving and the other motor running as a generator. The generator motor was shown to provide a highly consistent and repeatable load on the driving motor under test and therefore comparisons could be made between the performance of the motor while controlled under Six-Step Control and FOC. This test indicated that FOC was able to drive the motor more efficiently than Six-Step Control, however the FOC implementation requires further development to achieve greater efficiency under high load demands. Furthermore, on-road testing was performed using the motor controllers in the electric skateboard prototype to compare the performance of the two control techniques in a real world application. The results from this test were inconclusive due to large variation in the results between repeated tests.

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Table of Contents

List of Figures

List of Tables

Glossary

Term	Definition
Back EMF	The voltage that is generated across a motor’s windings as the rotor turns.
Commutation	Switching the electrical current path through a motor’s windings in order to achieve continuous rotation.
Copper Loss	Power loss in an electric motor associated with the motor’s windings.
Delta (Δ)	Refers to three phase loads where the three phases are terminated in a triangle formation.
Eddy current	Circulating currents within a conductor due to an induced electromotive force.
Electrical angle	The angle of the rotor magnet poles relative to the stator.
H-bridge	A transistor arrangement that allows an output to be connected to the positive DC bus or the negative DC bus.
Integrated Development Environment	Refers to a computer programme suite that provides all the necessary tools and resources for programming and developing software.
Iron Loss	Power loss in an electric motor associated with the iron core of the electromagnets.
Mains supply	A power source from the power supply network. In New Zealand this is 230V, 50Hz single phase AC or 415V, 50Hz three phase AC.
PID Controller	An algorithm which aims to regulate an output based on the difference between a set-point and the measured value of the output (error), the sum of previous errors, and the predicted future error.
Rotor	The rotating component of an electric motor.
Rotor angle	The angle of the rotor relative to the stator.
Remanence	The remaining magnetisation of a ferromagnetic material after an external magnet field has been removed.
Stator	The stationary component of an electric motor.
Windage loss	A term used to represent the energy loss due to the movement of air by a rotating machine.
Wye (Y)	Refers to three phase loads where the three phases are terminated in a wye formation. Also commonly referred to as ‘star’ terminated loads.

Acronyms

Term	Definition
AC	Alternating Current
ADC	Analogue to Digital Converter
BLDC	Brushless Direct Current
BMS	Battery Management System
CAD	Computer Aided Design
CNC	Computer Numerical Control
DAC	Digital to Analogue Converter
DC	Direct Current
EMF	Electromotive Force
I/O	Input / Output
I2C	Inter-Integrated Circuit
IC	Integrated Circuit
IDE	Integrated Development Environment
LEV	Light Electric Vehicle
LCD	Liquid Crystal Display
MMF	Magnetomotive force
PCB	Printed Circuit Board
PID	Proportional, Integral, Derivative
PM	Permanent Magnet
PMSM	Permanent Magnet Synchronous Motor
PWM	Pulse Width Modulation
RC	Radio Controlled
RPM	Revolutions per minute
SI	Scientific International
SVM	Space Vector Modulation
SWD	Serial Wire Debug
USART	Universal Synchronous Asynchronous Receiver Transmitter

Nomenclature

Symbol	Definition	Units short	Units long
A	Area	m^2	Meters squared
B	Magnetic field	T	Tesla
b	Friction constant	Nm.s/rad	Newton meter seconds per radian
C	Capacity	Ah	Amp hours
C_d	Coefficient of drag	-	-
C_r	Coefficient of rolling resistance	-	-
D	Wheel diameter	m	meters
E	Electric field	N/C	Newtons per coulomb
F	Force	N	Newtons
f	Frequency	Hz	Hertz
H	Magnetic field Strength	A/m	
h	Time	H	Hours
I	Current	A	Amperes
J	Moment of inertia	$kg.m^2$	Kilogram meters squared
k_m	Per phase motor constant	Nm/A	Newton meters per ampere
K_m	Total motor constant	Nm/A	Newton meters per ampere
K_v	Motor speed constant	$V/(rad.s^{-1})$	Volts per radians per second
K_E	Motor eddy current coefficient	-	-
K_H	Motor core hysteresis coefficient	-	-
l	Length	m	Meters
M	Multiplier for number of active poles	-	-
m	Mass	kg	Kilograms
N	Number of active turns of wire	-	-
P	Power	W	Watts
P_e	Electrical power	W	Watts

P_m	Mechanical power	W	Watts
Q_H	Hysteresis energy loss	J/m^3	Joules per cubic meter
q	Charge	C	Coulombs
R	Resistance	Ω	Ohms
R_m	Reluctance	H^{-1}	Inverse henry
r	Radius	m	Meters
t	Time	s	Seconds
V	Voltage	V	Volts
v	Velocity	m/s	Meters per second
v_w	Wheel Speed	km/h	Kilometres per hour
ε	Electromotive force	V	Volts
η	Efficiency	-	-
η_d	Drive efficiency	-	-
η_m	Motor efficiency	-	-
θ	Angle of incline	rad	Radians
θ_m	Magnet angle	rad	radians
ρ	Density	kg/m^3	Kilograms per meter cubed
ρ_r	Resistivity	Ωm	Ohm meters
τ	Torque	Nm	Newton meters
ω	Angular velocity	rad/s	Radians per second
Φ_B	Magnetic flux	Wb	Weber