Temperature Compensation Algorithm for Current of IPMSM for Electric Scooter

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Abstract — The interior permanent magnet synchronous motor (IPMSM) with its robust rotor construction, using reluctance torque and flux weakening capability is suitable for Electrical scooter application where wide speed and torque range is required. Characteristic of permanent magnet is dependent on temperature, so flux of motor is varied and torque is also changed according to temperature. This paper presents temperature compensation algorithm for current of IPMSM for electric scooter. To reduce effect of temperature in IPMSM, command current is selected using current map which is obtained by recursive least square method and Lagrange interpolation. Point is selected at 20, 80, 100 and 150 degrees. We make simulation and experiment to confirm current controllability.

I. INTRODUCTION

With the development of the global economy, more and more serious problems occur in air pollution and environment depravation. Electric Scooter is one way to solve these problems. Nowadays, PM motors have a number of advantages. 1) Higher power density 2) higher efficiency 3) heat is efficiently dissipated to the surrounding. Therefore PM motors are in the limelight one for electric vehicle applications [1], [2].

Characteristics of permanent magnet are dependent on a lot of factors. Temperature is one of important factors. IPMSM generates torque using flux from permanent magnet in rotor. Because it is expected that surrounding temperature is over 80 degrees in industry when car is driving, we usually control IPMSM that map reference temperature is fixed 80 degrees. But permanent magnet is dependent on temperature, so flux is varied and torque is change also. In accordance with temperature increasing, maximum energy product is decreased.

This paper presents a current compensation algorithm according to temperature of IPMSM for electric scooter. To improve controllability of current, command current is obtained by linear interpolation at 20, 80, 100 and 150 degrees.

II. MATHEMATICAL MODEL OF IPMSM

Permanent magnet generates magnetic torque by owns field flux. Barriers set up both side of permanent magnet to decrease leakage flux. In *d-q* reference, voltage equations are expressed by followings.

$$v_d = R_s i_d + (d\Phi_d / dt) - \omega_r L_q i_q . \tag{1}$$

$$v_q = R_s i_d + L_q (di_q / dt) + \omega_r L_d i_d + \omega_r \Phi_a . \tag{2}$$

where, $\Phi_d=L_d i_d$, $\Phi_q=L_q i_q$. R_S is stator resistance. v_d and v_q are voltage, i_d and i_q are current, Φ_d and Φ_q are magnetic flux, and L_d and L_q are inductance in the *d* and *q*-axis, Φ_a is flux which is generated by permanent magnet, ω_r is angular speed of rotor in motor.

The torque is given in

$$T_e = (3/2)(p/2)\{[L_d(i_d,i_q) - L_q(i_d,i_q)]i_d i_q + \Phi_a i_q\} . \tag{3}$$

where, p is number of pole of motor.

III. COMPENSATION ALGORITHM OF IPMSM

A. Interpolation

Interpolation is a numerical method of obtaining new data points within the range of a discrete set of known data points. We use Lagrange interpolation.

$$f(x) = \sum_{k=0}^{N} f(x_k) L_k(x) . \tag{4}$$

Where, $L_k(x) \equiv \dfrac{(x-x_0)(x-x_1)\cdots(x-x_{N-1})(x-x_N)}{(x_k-x_0)(x_k-x_1)\cdots(x_k-x_{N-1})(x_k-x_N)}$

B. Recursive Least Square Method

Recursive Least Square method is gain unknown parameters of mathematical model to minimize the error between observation and estimation.

This method can be only applied to the models given by

$$y(i) = \varphi^T(i)\theta . \tag{5}$$

Where y is the observed variable, φ is vector of unknown functions that may depend on other known variable, and θ is vector of parameters of the model. The number of observed value is determined by i squared size of matrices. So, the Recursive least square method is rearranged from the above method which enables recursive sequential computations in real-time system.

C. Operation according to speed

Limit-constraint of voltage is dependent on speed. That is, as more and more speed is increased, limit-constraint of voltage ellipse is diminished.

In low speed region, voltage limit-constraint doesn't efforts operation. However IPMSM doesn’t control torque well, because flux of permanent magnet is varied in case of difference of map temperature and motor temperature. Torque is insufficient than command torque at command current in temperature of motor is higher than one of map, and it is exaggerated than command torque at command current in temperature of motor is higher than one of map.

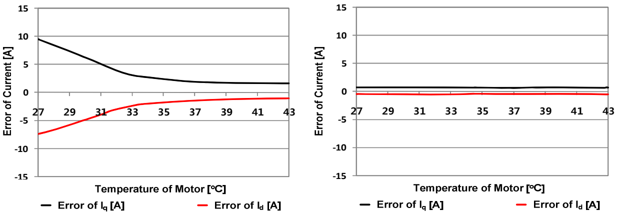
In high speed region, voltage limit-constraint is changed by speed. Especially, because of voltage limit-constraint, actual current is reduced than command current in temperature of motor is higher than one of map. Therefore, operating point needs to change according to motor temperature.

IV. EXPERIMENTAL TEST RESULTS

Command current is decided from current map which is obtained by recursive least square method and Lagrange interpolation using 20, 80, 100 and 150 degrees in experimental test. We make simulation and experiment to confirm current controllability. Specifications of test motor are shown in TABEL I. Modified currents of 3-phase are decided by current compensation algorithm for actual 3-phase currents and temperature of motor. Currents of *d*- and *q*-axis are obtained using Forward Clark and Forward Park transformation. PI controller is used for current control and vector control is applied for torque control.

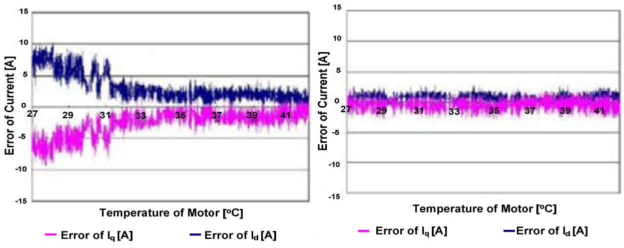
Fig. 1 shows simulated error of currents at 1500[RPM] and 9.55[N·m]. (a) is before application current compensation algorithm and (b) is after application current compensation algorithm.

Fig 2 is experimental error of current at 1500[RPM] and 9.55[N·m]. (a) is before application current compensation algorithm and (b) is after application current compensation algorithm.



(a) (b)

Fig. 1. Simulated error of currents at 1500[RPM] and 9.55[N·m]. (a) Before application current compensation algorithm. (b) After ones.

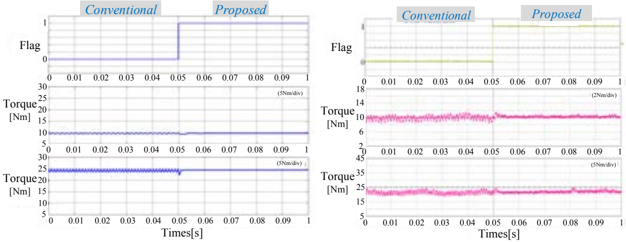


(a) (b)

Fig. 2. Measured error of currents at 1500[RPM] and 9.55[N·m]. (a) Before application current compensation algorithm. (b) After ones.

TABLE I
SPECFICATIONS OF TEST MOTOR

Item	Unit	Values
Rated Power	kW	1.5
Instantaneous Power	kW	3.8
Rated Torque	Nm	9.55
Instantaneous Torque	Nm	24.2
Rated Speed	RPM	1500
Maximum Speed	RPM	6000
Rated Current	A	46.5
Maximum Current	A	119
Battery Voltage	V	48



(a) (b)

Fig. 3. Torques at instantaneous and rated operating points. (a) is simulation. (b) Experimental result.

Fig 3 is torques at instantaneous and rated points. (a) is simulation result and (b) is experimental result.

V. CONCLUSION

In this paper, current compensation algorithm of IPMSM to control for traction of a electric scooter operated in 48V battery system is presented. To reduce effect torque control on temperature in IPMSM, command current is decided using current map which is obtained by recursive least square method and Lagrange interpolation.

VI. REFERENCES

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