PMSM drive having hall position sensor for Electric Scooter

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Abstract —This thesis shows the control process of in-wheel PMSM for electricity scooter. This motor has a mechanical complex structure, so it is difficult to install resolver or encoder position sensor. It suggested the way of vector control for PMSM motor with hall sensor. After driving with BLDC control way in low speed, the control method of motor convert into the way of vector control with MRAS speed observer to obtain the accurate position information. By this position information, MTPA operation with field weakening control is carried out. This suggestion was verified through the practical experiment and simulation.

I. INTRODUCTION

Currently, the development of electric vehicles or electric scooters is being pursued with alternative plan for global warming which caused by the problem of soaring oil prices and environmental pollution. This thesis shows the control method of PMSM (Permanent Magnet Synchronous Motor) for electric scooter. The Motor for electric scooter will be used In-Wheel of Outer Rotor Type which dose not requires a mechanical driveline or decelerate for a limited space. Therefore, it is hard to install a resolver or encoder for this motor because the structure of spinning wheel and fixed its axis.

Fig. 1. Electric Scooter.

By this reason, it is difficult to apply this existing method to carry out vector control with rotor position information which has been found out through resolver or encoder. To overcome this problem, PMSM control method using low resolution hall sensor or position sensorless control method must be developed for electric scoter. There are many existing senseless algorithm but it does not have good starting characteristics. [1] There is some control method to sinusoidal drive PMSM with using low resolution hall sensor. The solution using only one hall sensor to overcome the problem of the weakness starting characteristics of sensorless algorithm [1], but the way of using linear hall IC can lead to mistake if it is not a pure Sine wave.[3] There is the way[4],[5] using 2 or 3 hall sensor or recovering rotor position through estimating speed but this is complicated comparatively.

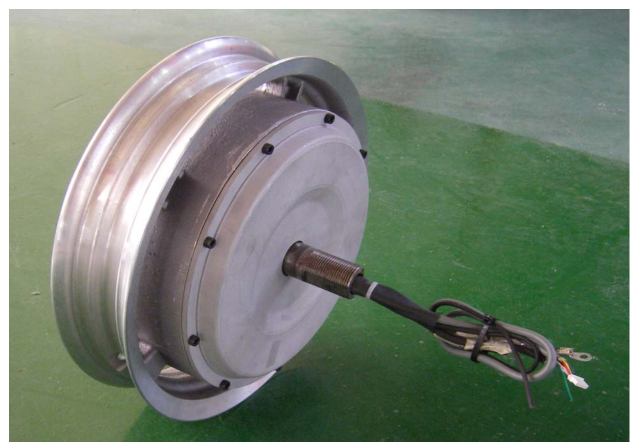

Fig. 1. In-Wheel Type PMSM for Scooter

This thesis suggests the way to carry out vector control which was able to find out with using low resolution hall sensor only. In this control method, the starting algorithm with Square-wave current control that is the motor control method of BLDC and using position information of hall sensor. When it comes to reach the steady speed after driving, the precise position information can get using MRAS speed observer with 6th of rotor position information (30,90,150,210,270,330) which can gain through the combination of hall sensor. MTPA and field weakening control can be made using a rotor position information in a moment through the vector control. It can constitute a control system with highly credibility more than senseless method and without resolver or encoder which is expensive though this way. This thesis used MRAS method which is simple for speed estimation comparatively. And It has been verified about this suggested method through the technique and experiment.

II. STARTING THE MOTOR

At first time of starting the motor, it drives Square-wave current motor with signal of hall sensor. This method is the way to control BLDC motor mostly. The reason that using this method in motor starting is that it is possible to take shape without position information of rotor and it is excellent more than senseless method. It change to vector control way after motor starting at steady speed, that is one of the electrical angle -30,90,150,210,270,330- and using information that can get a hall sensor combination at this time. If the speed lower than steady speed, it will control with BLDC method again.. Hysteresis control is necessary to avoid a chattering situation that changing the control method constantly

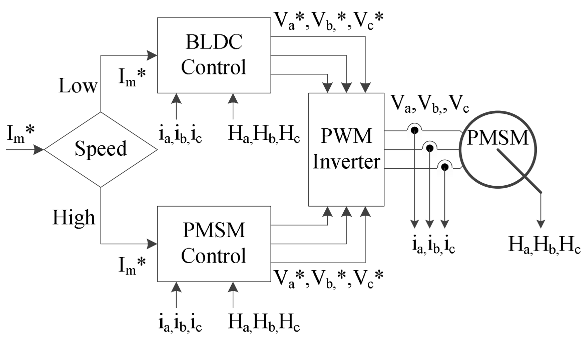

Fig. 3. Control Block Diagram

III. A ROTOR POSITION INFORMATION FOR VECTOR CONTROL

It is generally six pieces – 30,90,150,210,270,330 - for rotor position information get to know though the hall sensor but it doesn't know continuous rotor position. It is possible to get continuous rotor position information of vector control if you know this six of specific angle information and motor speed. There are two way to measure the speed of motor. One is that the T-Method which calculates the speed using signal cycle of hall sensor and other is MRAS method which calculates the speed of difference with an electric current and voltage [6]. It can get a mistake in a radical speed system because T-Method can update only when alteration of hall signal. Response of the MRAS method which estimating speed every PWM control period is more fast than T-Method. However because relying upon physical motor parameter, it is possible to get a mistake when changing motor parameter caused by the temperature alteration of motor and size of an electric current. (1)and (2) were used at speed estimate.

$$I_{qM}(k+1) = \frac{T}{L_s}\left(L_s\hat{\omega}_r(k)i_d(k) - r_s i_q(k) + v_q(k) - \hat{\omega}_r(k)\phi_f\right) + i_q(k) \quad (1)$$

$$\hat{\omega}_r(k+1) = \hat{\omega}_r(k) - K_\omega\left(i_q(k+1) - i_{qM}(k+1)\right) \quad (2)$$

T, I_{qM}, Ls, $\hat{\omega}_r$, i_d, r_s, v_q, ϕ_f, K_ω are time of sampling, q-axis model current, stator inductance, estimated electrical rotor speed, real d-axis current, stator resistance, q-axis voltage, magnet flux linkage and speed observer gain. K+1 is the result at present and K is prior to the result. As a result of both experiment, it shows excellent efficiency of the senseless method in both of a stationary state and a excessive state. So that is why I use the motor speed figured from senseless method in this thesis.

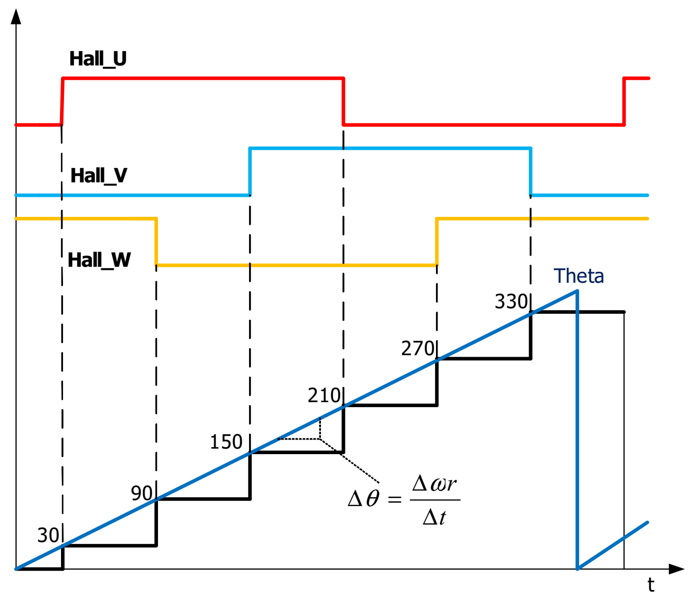

Fig. 4. Hall Signal and Electrical angle

IV. MTPA AND FIELD WEAKENING CONTROL

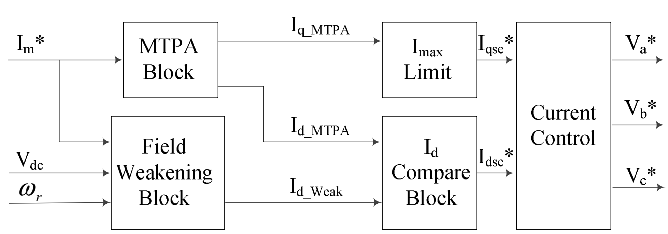

Fig. 5. PMSM control block diagram.

It could calculate on MTPA block for the D axis electric current and Q axis electric current which is to get a maximum torque per a flow of electricity from phase current reference of motor. In Field weakening block, it could calculate the D axis current for Field weakening control through put the motor speed , input voltage and the Q axis electric current. (3) and (4) are numerical formula for MTPA block. (5) and (6) are numerical formula for Field weakening block. In Id Compare block, it could calculate the modulus of D axis electric current for the MTPA and Field weakening control. It could use for bigger figure of D axis electric current. Imax Limit block is recalculated for Q axis electric current to do not overflow the maximum electric current which is the total of the D axis electric current and Q axis electric current. (7) is the numerical formula for Imax Limit block.

$$I_{d\_MTPA} = \frac{1}{4} \times \left(\frac{\phi_f^{\,2}}{Lq - Ld} - \sqrt{\left(\frac{\phi_f^{\,2}}{Lq - Ld} \right)^2 + I_m^{\,2}} \right) \quad (3)$$

$$I_{q\_MTPA} = \sqrt{I^2 - I_{d\_MTPA}^2} \quad (4)$$

$$a_1 = L_q^{\,2} - L_d^{\,2}, a_2 = -\phi_f L_d,$$

$$a_3 = \left(\frac{V_{\max}}{\omega_r} \right)^2 - (L_q I_m)^2 - \phi_f^{\,2} \quad (5)$$

$$I_{d\_weak} = \frac{-a_2 \pm \sqrt{a_2^{\,2} - a_1 a_3}}{a_1} \quad (6)$$

$$I_{q\_Limit} = \sqrt{I_{\max}^2 - I_{d\_weak}^2} \quad (7)$$

Each of them - I_{q_MTPA}, I_{d_MTPA}, Ld, Lq, Im, ϕ_f, Vmax, ω_r, I_{d_weak}, I_{q_Limit} - are Q axis electric current for MTPA, D axis electric current for MTPA, D axis inductance, Q axis inductance, phase current reference, magnet flux linkage, maximum output voltage of inverter, electrical rotor speed, D axis electric current and Q axis electric current for Field Weakening control.

V. Experiment

It was verified the proposed method through this test. The use of the specifications of motor for test is same with TABLE I. Inverter to control electric scooter is shown in Fig. 6. The use of the inverter for test has floating point DSP.

TABLE I
Motor Specification

No.	Item.	Value.	Unit.	Etc.
1	Pole / Slot	40 / 36		
2	Rated Torque	13.5	N.m	
3	Base Speed	230	rpm	20 [km/h]
4	Rated Current	13.5	Adc	
5	Magnet Flux Linkage	0.0077	Wb/turn	
6	Stator Inductance	0.0834	mH	Each Phase
7	Stator Registance	0.02483	mΩ	Each Phase
8	Rated Output Power	650	W	
9	Rated Speed	465	rpm	40 [km/h]
10	Rated Voltage	48	Vdc	
11	Max Output Power	3.5	kW	
12	Max Speed	700	Rpm	60 [km/h]
13	Torque at Max Speed	23	N.m	@ 700 [rpm]

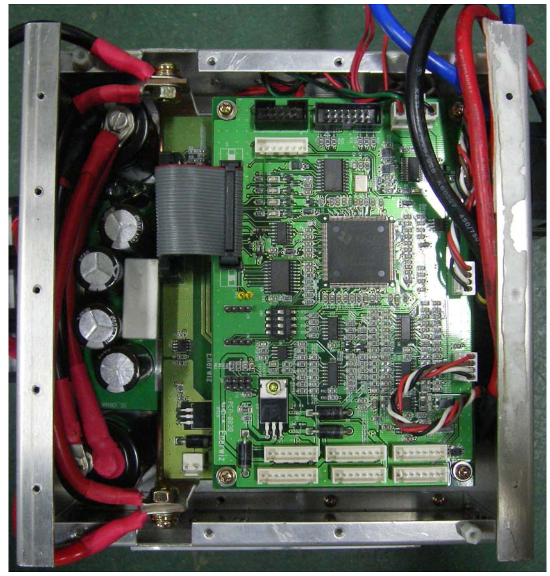

Fig. 6. Inverter for experiment

This Fig. 7 is the waveform when starting the motor. To drive in BLDC mode at the early driving, after estimating rotor position information, it is able to check the PMSM mode driving which is performing vector control. The Fig. 8 is the speed of acceleration, D axis electric current, Q axis electric current. It is able to check increasing speed with increasing Q axis electric current and being field weakening control with increasing D axis electric current.

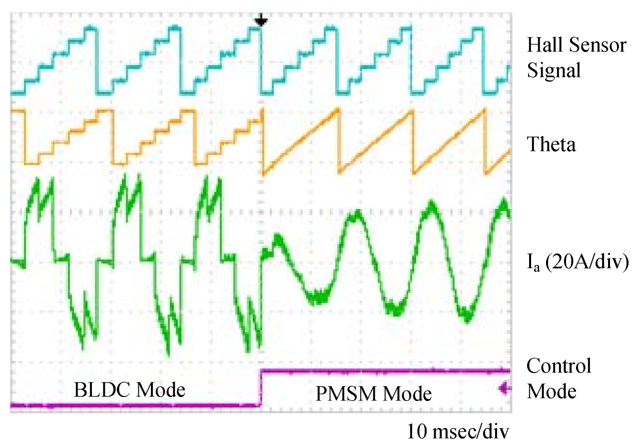

Fig. 7 Starting waveform

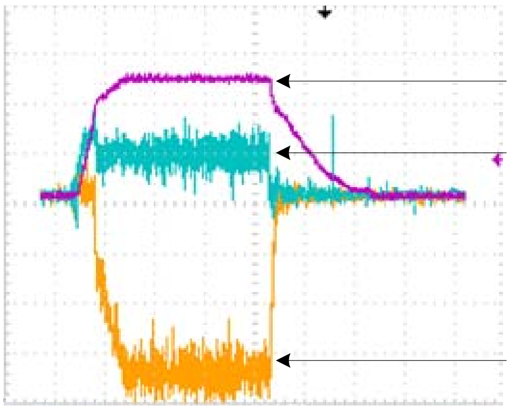

Fig. 8 Acceleration waveform

VI. CONCLUSION

This thesis suggests the control method of PMSM for scooter which has a complicated constitution to install a encoder or resolver. It used at lower price hall sensor to make up for credibility and the beginning driving efficiency which is fault and existing senseless control method.

To verify this suggestion, it take effect a real car experiment and check it superiority more than BLDC driving method even driving noise and highest speed. This suggestion forecasts the good results if applying with lower application which is hard to use encoder and resolver.

VII. REFERENCES

[1] Shen, J.X., Zhu, Z.Q., Howe, D., "PM brushless drives with low-cost and low-resolution position sensors", Power Electronics and Motion Control Conference, 2004. IPEMC 2004. The 4th International. vol. 2, pp. 1033-1038

[2] Morimoto, S., Sanada, M., Takeda, Y., "Sinusoidal current drive system of permanent magnet synchronous motor with low resolution position sensor", Industry Applications Conference, 1996. Thirty-First IAS Annual Meeting, IAS '96., Conference Record of the 1996 IEEE. vol. 1, pp. 9-14

[3] Caricchi, F., Capponi, F.G., Crescimbini, F., Solero, L., "Sinusoidal brushless drive with low-cost linear Hall effect position sensors", Power Electronics Specialists Conference, 2001. PESC. 2001 IEEE 32nd Annual. vol. 2, pp. 799-804

[4] Hyunbae Kim, Sungmo Yi, Namsu Kim, Lorenz, R.D., "Using low resolution position sensors in bumpless position/speed estimation methods for low cost PMSM drives", Industry Applications Conference, 2005. Fourtieth IAS Annual Meeting. Conference Record of the 2005, vol. 4, pp. 2518-2525

[5] Anno Yoo, Seung-Ki Sul, Dong-Cheol Lee, Cha-Seung Jun, "Novel Speed and Rotor Position Estimation Strategy Using a Dual Observer for Low-Resolution Position Sensors" Power Electronics, IEEE Transactions on, vol. 24, Issue. 12, pp. 2897-2906

[6] Nobuyuki Matsui, "Sensorless PM Brushless DC Motor Drives." IEEE Transactions on Industrial Electronics, VOL, 43, NO. 2, APRIL 1996