Online q-axis Inductance and Resistance Identification of IPM Synchronous Motor Based on Relationship between Its Parameter Mismatch and Current

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This paper proposes a new approach to achieve online identification of the q-axis inductance and the resistance of an interior permanent magnet synchronous motor (IPMSM) based on the relationship between the q-axis inductance mismatch and the d-axis feedback current. The value of the d-axis feedback current depends on the inductance mismatch, and the consecutive samplings of the d-axis feedback current make it possible to calculate the true value of the inductance. After the q-axis inductance is identified, the resistance also can be identified by using the same identification system. The proposed identification technique is examined through some computer simulations and experiment tests. The test results demonstrate the fast convergence of the identified value to the true one with a small error.

Keywords：interior permanent magnet synchronous motor, online, parameter, identification, P control, PI control

1. Introduction

In recent years, interior permanent magnet (IPM) motors are widely used in a variety of industry, home appliance and automotive applications, owing to their high-efficiency and high-power-density features. The IPM motor is usually controlled by means of a field-orientation technique (vector control), and requires a current controller on the synchronous rotating reference frame (dq-reference-frame) for the instantaneous torque and the magnetic flux control. The current control on the dq-reference-frame mainly consists of the coordinate transformation, the PI regulation, and the decoupling compensation, which is based on the mathematical model of the motor. Figure 1 shows the field-oriented control system of the IPM motor. As can be seen in the figure, it is indispensable for the controller not only to detect the magnetic-pole-position and the motor currents, but also to know the motor parameters accurately because the controller has an inverse model of the motor. Identification of the motor parameters is significantly important to control the motor properly in starting up of the control as well as the running operation, and the on-line parameter identification is particularly required during the running condition. This paper proposes a novel technique to achieve the on-line identification of the IPM motor parameters, which requires only the d-axis feedback current information of the motor. The proposed technique employs a P regulator instead of the PI regulator in the d-axis current control loop. Using this technique, the q-axis inductance L_q can be estimated by checking the d-axis feedback currents twice when the motor is working in the steady state. Some computer simulations and experimental tests have been conducted to check the

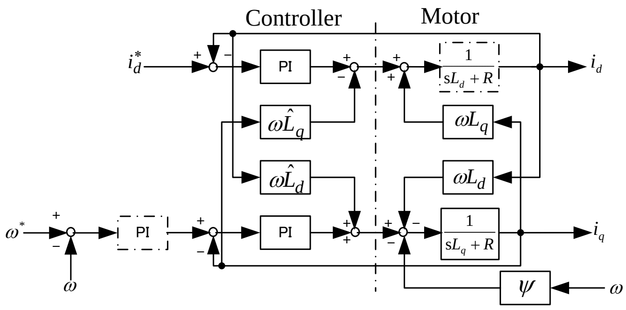
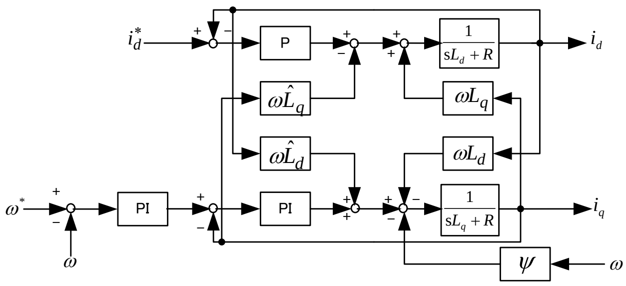
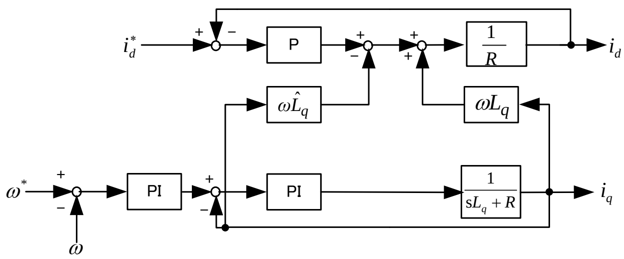


Fig. 1. Field-oriented control system of IPM motor.



(a) Proposed L_q identification system.



(b) Simplified L_q identification system.

Fig. 2. Online L_q identification system.

identification performance of the proposed technique in the paper.

2. Proposed Identification Technique

Figure 2(a) shows the proposed L_q identification system. In the system, the PI regulator used in the d-axis current control loop is replaced with a P regulator. Because the P regulator is unable to eliminate the steady-state error, the mismatch of L_q affects the d-axis feedback current. Figure 2(b) shows the simplified L_q identification system. From Fig. 2(b), the rotation speed is equal to its command, and the q-axis current is stable when the motor is operated in the steady state because both of the controllers consist of the PI regulators. By setting the d-axis current command at zero, the d-axis feedback current can be expressed as

$$I_d = \frac{\omega I_q}{K_d + R}(L_q - \hat{L}_q)\,. \tag{1}$$

From (1), it is found that the mismatch of L_q has a linear relationship with the d-axis feedback current I_d when the command of the d-axis current is set at zero. Based on this linear characteristic, it is possible to estimate the true value of L_q. As shown in Fig. 3, the basic mathematic knowledge tells that if two points on the straight line is given, the whole equation of the line is known.

By setting two different arbitrary values of L_q to the controller, which may have the parameter mismatch, two corresponding d-axis feedback current values are recorded in the memory. Assuming that the following consecutive sampling actions are performed:

$I_d = I_{d1}$ when $\hat{L}_q = L_{q1}$, and

$I_d = I_{d2}$ when $\hat{L}_q = L_{q2}$,

the true value of L_q can be calculated by the following equation:

$$L_q = \frac{I_{d1}L_{q2} - I_{d2}L_{q1}}{I_{d1} - I_{d2}}\,. \tag{2}$$

Equation (2) implies that the true value of L_q can be calculated regardless of any parameters and any variables used in (1). Therefore, the proposed identification technique requires only the d-axis feedback current information to estimate L_q.

3. Computer Simulation Results

Some computer simulations have been conducted to verify the identification performance of the proposed technique. Table 1 shows the test motor parameters which are used in the simulations.

Figure 4 shows at here helps to confirmed the linear characteristic which mentioned in Equation (2). After increase the $\hat{L}_q$ linear in the controller, the d-axis feedback current decreased linear. Based on this simulation result, the two-point speculate method is possible to adapt the online identification.

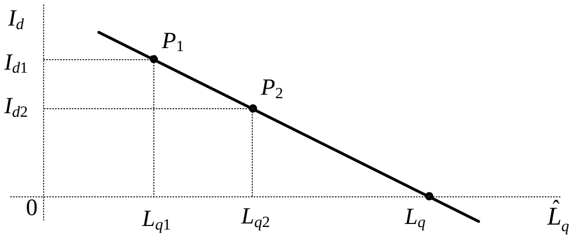


Fig. 3. Relationship between $\hat{L}_q$ and I_d.

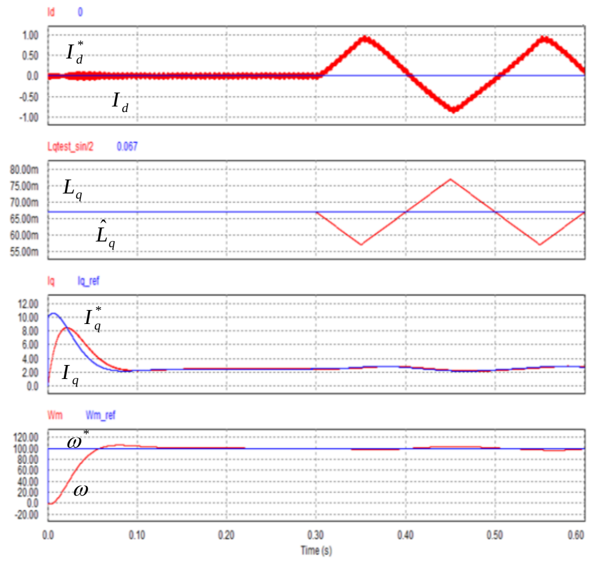


Fig. 4. Confirmation of relationship between $\hat{L}_q$ and currents.

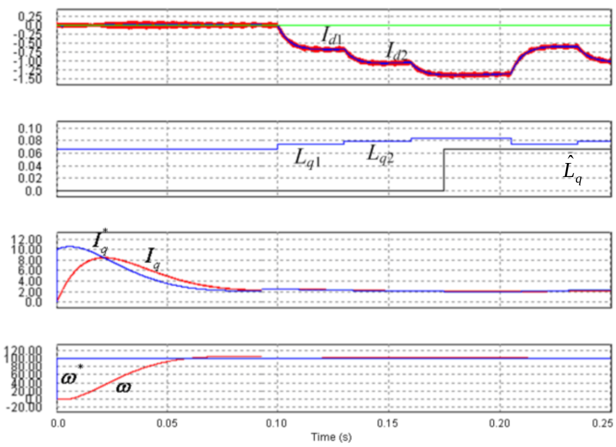
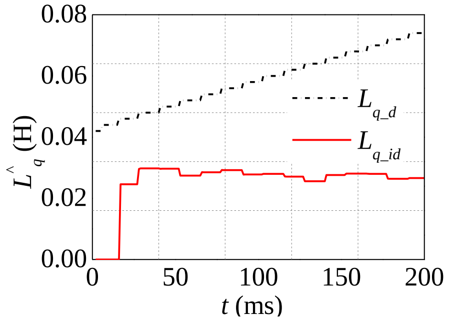


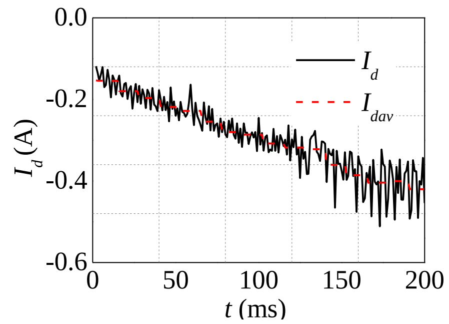
Fig. 5. Simulation result of L_q identification.

Table 1. Parameters of test IPMSM.

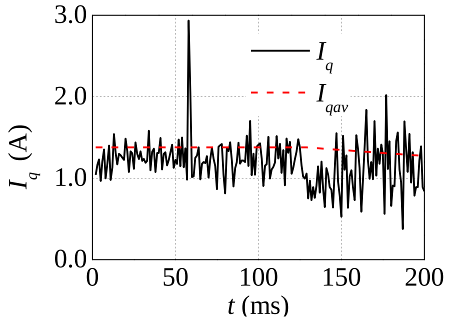
Number of poles	4
Winding resistance	4.3 Ω
Gain of d-axis P regulator	1 V/A
q-axis inductance	67 mH
d-axis inductance	27 mH
Setup d-axis inductance	1.0 mH
Field flux linkage	0.544 Wb
Setup field flux linkage	1.0 Wb
Rotation speed	6000 r/min



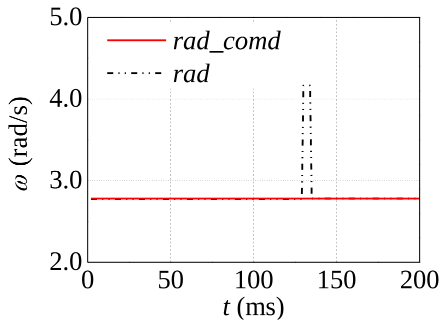
(a) $\hat{L}_q$ and its identified value.



(b) *d*-axis current.



(c) *q*-axis current.



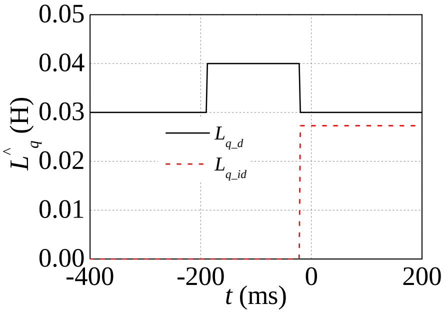
(d) rotation speed.

Fig. 6. Experimental result to confirm relationship between $\hat{L}_q$ and currents.

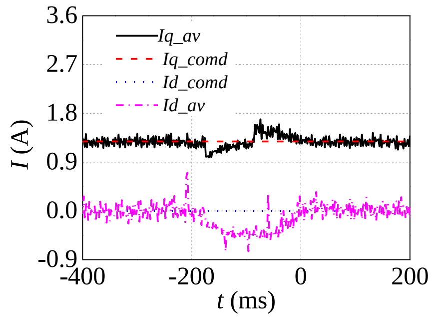
Then another simulation result is shown in Fig. 5 which uses the proposed identification theory. The rotation speed and the *q*-axis current are controlled to be equal to their commands. As $\hat{L}_q$ of the controller changes from L_{q1} to L_{q2} and so on, the d-axis feedback current also changes accordingly. The final identified

Table 2. Physical constants of test setup.

Symbol	Description	Value
R	Winding resistance	0.48 Ω
L_d	d-axis inductance	13.0 mH
L_q	*q*-axis inductance	24.5 mH
ψ	Magnetic flux linkage	0.0674 Wb
K_d	*d*-axis P regulator gain	5.0 V/A
p	Number of poles	6
ζ	Damping coefficient	0.0002 Ns/r
P_o	Rated output power	1.5 kW



(a) *q*-axis inductance.



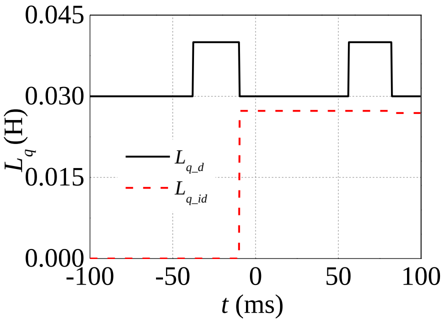
(b) Current waveforms.

Fig. 7. Experimental result of L_q identification.

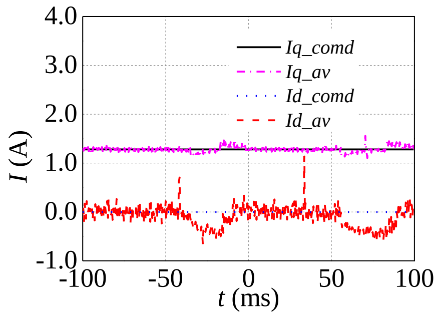
value is 66.48 mH, where the true value is 67 mH. The identification error is 0.78 %, and the convergence time for the identification is only 0.08 s.

4. Experiment Result of L_q Identification

Experimental tests have been conducted to confirm the current and the L_q identification characteristics. The experimental setup parameters are listed in Table 2. Figure 6 shows the experimental results when $\hat{L}_q$ is intentionally changed as indicated by the dotted line in Fig. 6(a). While $\hat{L}_q$ is changed, the *d*-axis current and the *q*-axis current vary as shown in Fig. 6(b) and Fig. 6(c). From the results, the *d*-axis current decreases linearly with $\hat{L}_q$, while the *q*-axis current is kept stable as described in the theoretical consideration. The identified value is around the true value and the error is within 15 %. As the *d*-axis current decreases, the identification result exhibits



(a) q-axis inductance.



(b) Current waveforms.

Fig. 8. Experimental result of L_q identification with extra R.

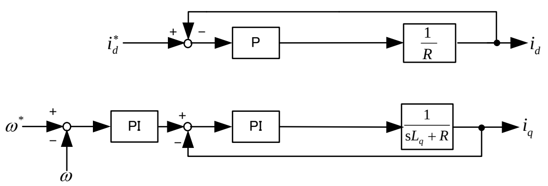


Fig. 9. Simplified R identification system.

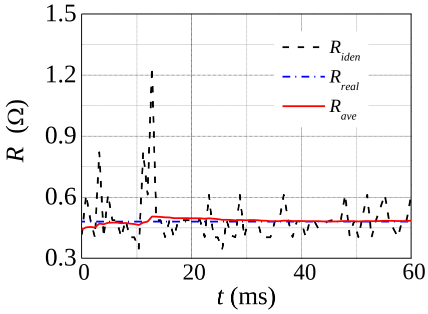


Fig. 10. Experimental result of R identification.

tendency of the decrease due to the magnetic saturation. Based on Fig. 6(d) in the identification, the speed is kept stable even it go over the command signal the PI regulator can recovery it. But based on Fig. 6(b) when the $\hat{L}_q$ far beyond true value the current fluctuation be came larger.

Fig. 7 gives an experiment result by employing the two-point speculate method. For checking the current, K_d is changed to a low value such as 1.0. Because of that the identification also caused more time. The result is 27.3 mH, where the identification error is 11.3 %. This result shows two-point speculate method can be effectively used to identify L_q. If K_d is changed to another value, it is possible to adjust the identification time.

One of the most important advantages of the proposed identification method is no sensitivity to the winding resistance. Figure 8 shows the identification result with the extra resistance added to the motor windings. After consecutive sampling of the currents, the final result is obtained as 26.9 mH and the error is 9.8 %. By setting K_d = 5, the identification time can be shortened to 80 ms.

5. Winding Resistance Identification

The same system can be used for the winding resistance identification. After L_q is identified as described in the previous section, the system is changed to the configuration shown in Fig. 9. By giving a certain value of the d-axis current command, e.g., $i_d^* = 1$, the winding resistance R can be calculated by the following equation:

$$R = \frac{K_d(i_d^* - i_d)}{i_d} . \qquad (3)$$

Figure 10 shows the experimental result. The identification result is 0.493 Ω and the true value is 0.48 Ω, where the identification error is within 2.7 %.

6. Conclusion

An online parameter identification technique of the IPM motor has been proposed in this paper. The most unique features of the technique are capability to identify L_q and R by using only the motor d-axis feedback current information, and robustness to the winding resistance variation as well as the control variables. According to the simulation and the experiment results, the proposed technique can estimate L_q and R within the identification error of 9.8 % and 2.7 %, respectively. The identification takes 100 ms. In the future, the identification of the other motor parameters will be presented on the basis of the same algorithm.

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