Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
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DAAAM Symposium

SENSORLESS CONTROL OF PMSM WITH LOW CHANGE OF INDUCTANCE

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***Abstract**: This paper describes a possibility for estimation of the rotor position in low speed of interior permanent synchronous motor (IPMSM) with low change of stator inductance. Sensorless algorithm uses the information about rotor position is contained in the changes of stator inductance. This allows the algorithm to work in the whole range of synchronous motor speeds.*
***Key words:** sensorless control, IPMSM, saturation, estimation*

1. INTRODUCTION

Permanent magnet synchronous motors have been used in many industrial applications because they have several inherent advantages e.g. rugged construction, easy maintenance, high power factor and suitability for wide speed ranges of constant power operation. However, rotor position information is necessary even to be able to control drive speed. Conventional speed and position sensing was obtained using encoder, resolver. These sensors add cost, weight.

Many authors publish paper about algorithms for rotor position and speed estimation. Most of these algorithms are based on state estimation. Conventional algorithms base on state estimation are developed with simple model of PMSM ($L_d = L_q = L_s$), thereby provide bad performance in the low speed range. State estimator with model of IPMSM (L_d Í L_q Í L_s) makes it possible operate in the low speed, because information about rotor position is contained in changes of stator inductance. If the changes of stator inductance are too small, these algorithms fail too. In this case we use the solution described in this paper, use the saturation effect. However, it requires a DC current in the measuring signal (measured L_d and L_q inductance) to determine the initial rotor position. This may be a problem, because the DC current produces electric torque, which can move with the rotor.

2. MODEL OF PMSM

The model of PMSM is derived from schematic representation of stator and rotor windings. The three-phase windings are representation by phase a, b, c.

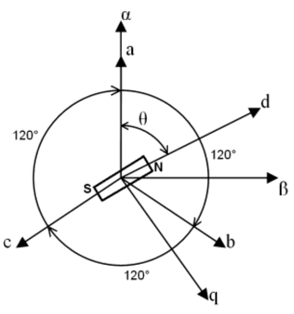

Fig. 1. Model of PMSM

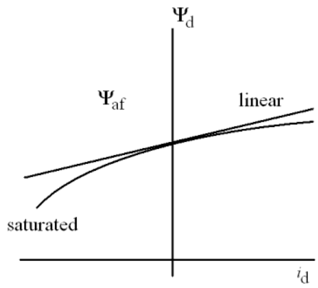

Fig. 2. Flux linkage as a function of applied current in the rotor reference frame

Figure 1 shows the model of the PMSM. The d-q frame shows the synchronously rotating reference frame where the d axis coincides with the north pole of the rotor. The orthogonal two-phase Ŭ-ɓ frame is fixed to the stator windings and ɗ represents the actual angle of the rotor position.

The polarity-dependent magnetic saturation is dominant for saturation in the d-axis. The magnetization curve of PMSM is shown in Fig. 2. The variables are d-axis components in the rotor reference frame and Ψ_{af} denote the flux linkage of the rotor magnet without stator current. A positive d-axis current increased the stator iron saturation, resulting in a decreased d-axis inductance, and vice versa.

The d-axis flux linkage is approximated by a Taylor series with two terms.

The following assumptions are made in the derivation:

- The induced EMF is sinusoidal
- Eddy currents and hysteresis losses are negligible
- There is no cage on the rotor

The two axis form of the equations (1) and (2) can be obtained with these assumptions above,

$$u_d = Ri_d + \frac{d\Psi_d}{dt} - \omega_s \Psi_q \tag{1}$$

$$u_q = Ri_q + \frac{d\Psi_q}{dt} + \omega_s \Psi_d \tag{2}$$

where

$$\Psi_q = L_q i_q \tag{3}$$

$$\Psi_d = \Psi_{af} + L_d i_d + \frac{1}{2}\frac{d^2\Psi_d}{d\, i_d^2}(0)\, i_d^2 \tag{4}$$

and

$$L_q = \frac{d\Psi_q}{d\, i_q}(0) \tag{5}$$

$$L_d = \frac{d\Psi_d}{dt}(0) \text{ and } \quad L_d = \frac{d^2\Psi_d}{d\, i_d^2}(0) < 0 \tag{6}$$

u_d, u_q are the *d,q* axis voltages, i_d, i_q are the *d,q* axis stator currents, L_d, L_q are the *d,q* axis inductances , Ψ_d, Ψ_q are the *d,q* axis stator flux linkages, *R* is stator resistance and ω_s is synchronous frequency. These equations directly follow form the equations of the smooth-air-gap synchronous machine expressed in the rotor reference frame, but instead of the flux linkage produced by field winding, now the magnetic flux Ψ_{af} is present.

The model is non-linear as it contains product terms such as speed with i_d and i_q. Note that ω_r, i_d and i_q are state variables.

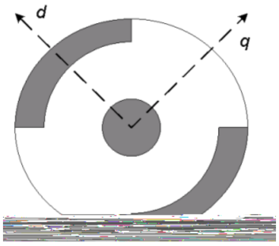

Fig. 3. a)IPMSM (L_d Í L_q) b) SPMSM ($L_d = L_q$)

Fig. 3.a) shows interior permanent magnet motor with salient rotor type. Fig. 3.b) shows surface permanent magnet motor with non-salient rotor type.

4. RESULTS

Fig. 4 shows the course of stator inductance, which was measured on a real interior permanent synchronous motor. Fig. 5 shows stator inductance with saturation effect. This effect is used for increase the difference between L_d and L_q inductance.

Some algorithms initial rotor position estimation try to find a minimum or a maximum of stator inductance and then determine the angel of rotor position. However noise and small variations in the stator inductance form an insoluble problem.

We can use the saturation effect. However it requires a DC current in the measuring. This may be a problem, because the DC current produces electric torque, which can move with the rotor.

We developed an algorithm compares the sample size of the stator inductance (measured) with an ideal waveform. We do not seek the minimum or maximum that can be influenced by the noise.

Fig. 4. Stator inductance

Fig. 5. Stator inductance with saturation effect

The parameters of PMSM:
R - stator resistance = 44q
L_d - *d* axis inductances = 0.038 H (200Hz)
L_q - *q* axis inductances = 0.042H (200Hz)
Ψ_{af} - flux linkage of the rotor magnet = 0,195 Wb
J - the moment of inertia = 0.0125kgm^2
p_p - number of pole pairs = 3

3. CONCLUSION

This paper has described the model of interior permanent magnet synchronous motor and introduced possibility of estimation of rotor position using saturation effect at low change of stator inductance. Model will be used for testing the reliability of algorithm for estimating the initial rotor position, if we change the level of noise. We would like to use this model for the extended Kalman filter.

4. ACKNOWLEDGEMENTS

The research has been supported by Czech Science Foundation under the project GA P103/10/0647 "Intelligent Electrical Drives Predictive and Robust Control Algorithms", the Ministry of Education of the Czech Republic under the project 1M0567 "Center for Applied Cybernetics" and by Freescale Semiconductor Czech Republic (former division of Motorola)

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