A comparative study of sensorless speed control

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Abstract. In this paper, a sensorless control scheme using back-EMF observer for permanent magnet synchronous motor drive (PMSM) is presented. Based on a general relationship between back-EMF and rotor position, observed rotor position is calculated and corrected with position estimation error. To obtain the velocity information from the observed rotor position, the velocity observer method and state of the art direct difference method are implemented and compared with each other.

Keywords: back-EMF, permanent magnet synchronous motor, sensorless speed control

1. Introduction

Accurate speed information is crucial for a sensorless speed control of permanent magnet synchronous motor drives (PMSM). Many approaches have already been successfully studied that have advantages and disadvantages in their uses [1][2][3][4][5][6]. In this paper, two approaches are compared and analyzed that obtain the speed information from the observed rotor position.

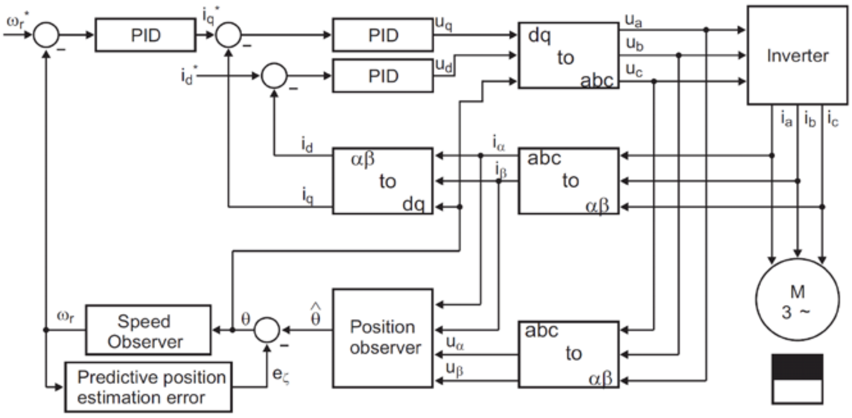

Fig. 1. Sensorless control scheme of PMSM.

Fig. 1 shows a sensorless speed control scheme for a PMSM using two observers. An implemented compensation algorithm of position estimation improves the speed control performance. An effective low complexity approach is requested to allow for a robust sensorless speed control.

2. Position estimation using back-EMF observer

The observer model of a PM synchronous motor in state space form using a fixed α-β coordinate system can be represented by

$$\dot{\underline{x}} = \begin{bmatrix} -\frac{R_s}{L_s} & 0 & -\frac{1}{L_s} & 0 \\ 0 & -\frac{R_s}{L_s} & 0 & -\frac{1}{L_s} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \cdot \underline{x} + \begin{bmatrix} \frac{1}{L_s} & 0 \\ 0 & \frac{1}{L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \cdot \underline{u},\ \underline{y} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix} \cdot \underline{x}, \tag{1}$$

where $\underline{x} = \left[i_\alpha, i_\beta, u_{p\alpha}, u_{p\beta}\right]^T, \underline{u} = \left[u_\alpha, u_\beta\right]^T$, $\underline{y} = \left[i_\alpha, i_\beta\right]^T$ and $i_\alpha, i_\beta, u_{p\alpha}, u_{p\beta}$ are transformed current, back-EMF and u_α, u_β are transformed voltages. The parameters R_s and L_s are stator resistance and inductance. The state vector $\underline{x}$ can be determined with help of Luenberger Observer [1], that has a observer gain $\underline{L}$. The rotor position can be defined with respect to $u_{p\alpha}$ und $u_{p\beta}$ [3] as

$$\hat{\theta} = \arctan\left(-u_{p\alpha} / u_{p\beta}\right) \tag{2}$$

or

$$\hat{\theta} = \arccos\left(\frac{u_{p\beta}}{\sqrt{u_{p\alpha}{}^2 + u_{p\beta}{}^2}} \right) . \tag{3}$$

To minimize the effect of intrinsic rotor position estimation error in back-EMF based rotor position observers for PMSMs, a self compensation approach was implemented [1]. The predictive estimation position error is given by

$$e_\varsigma = \arctan\left(-\omega_r L_s / r\right). \tag{4}$$

It depends on the angular speed ω_r of the rotor. Stator inductance L_s and parameter $r = l_2 / l_1$ can be calculated from elements of observer gain matrix

$$\underline{L} = \begin{bmatrix} l_1 & 0 & l_2 & 0 \\ 0 & l_1 & 0 & l_2 \end{bmatrix}^T \tag{5}$$

of the Luenberger observer. The calculated position is obtained by

$$\theta = \hat{\theta} - e_{\varsigma} . \tag{6}$$

3. Speed estimation

Using speed observer approach [2], first the electromagnetic torque T is calculated using the stator currents

$$T = p \cdot \left[\psi_F i_q - \left(L_d - L_q \right) i_d \right] . \tag{7}$$

The rotor acceleration is $\dot{\omega}_t = T / J$ (Fig. 2). This acceleration is integrated twice to produce the theoretical angular speed ω_t and the theoretical rotor position θ_t. The error $e_\theta = \theta - \theta_t$ is transferred to a PID controller to complete the observer loop. In order to correct the theoretical angular speed ω_t, the output of the PID controller is added to acceleration $\dot{\omega}_t$ to keep the rotor inertia J out of the observer loop, preventing the change of J from causing any changes of all other parameters in the loop.

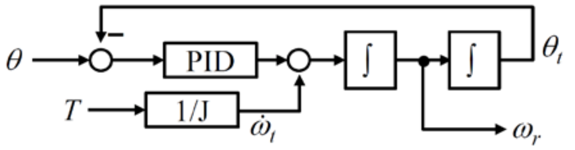

Fig. 2. Speed observer with compensation.

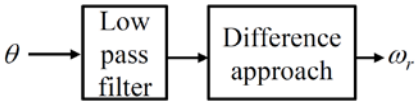

Fig. 3. Difference method.

The difference approach is illustrated in Fig. 3. The angular speed can be expressed by

$$\omega_r = d\theta / dt . \tag{8}$$

Since measurements are contaminated by stochastic noise, a low pass filter is employed.

4. Results

4.1. Estimated results

The Specifications of the permanent magnet synchronous machine are summarized in Table 1. Some of the specifications of the machine are measured, e.g. standstill torque T_0, stator resistance R_s, Stator inductance (quadrature axis) L_q and stator inductance (direct axis) L_d. The simulation results of the position observer with and without compensation are plotted in Fig. 4.

Table 1

Specifications of the permanent magnet synchronous machine

Parameters and constraints	Value
Rated speed n_N	6000 [rpm]
Standstill torque T_0	7.1 [Nm]
Maximum permitted motor current I_{max}	55.8 [A]

Stator resistance Rs	0.62 [Ω]
Stator inductance (quadrature axis) L_q	0.005 [H]
Stator inductance (direct axis) L_d	0.005 [H]
Number of pole pairs p	3

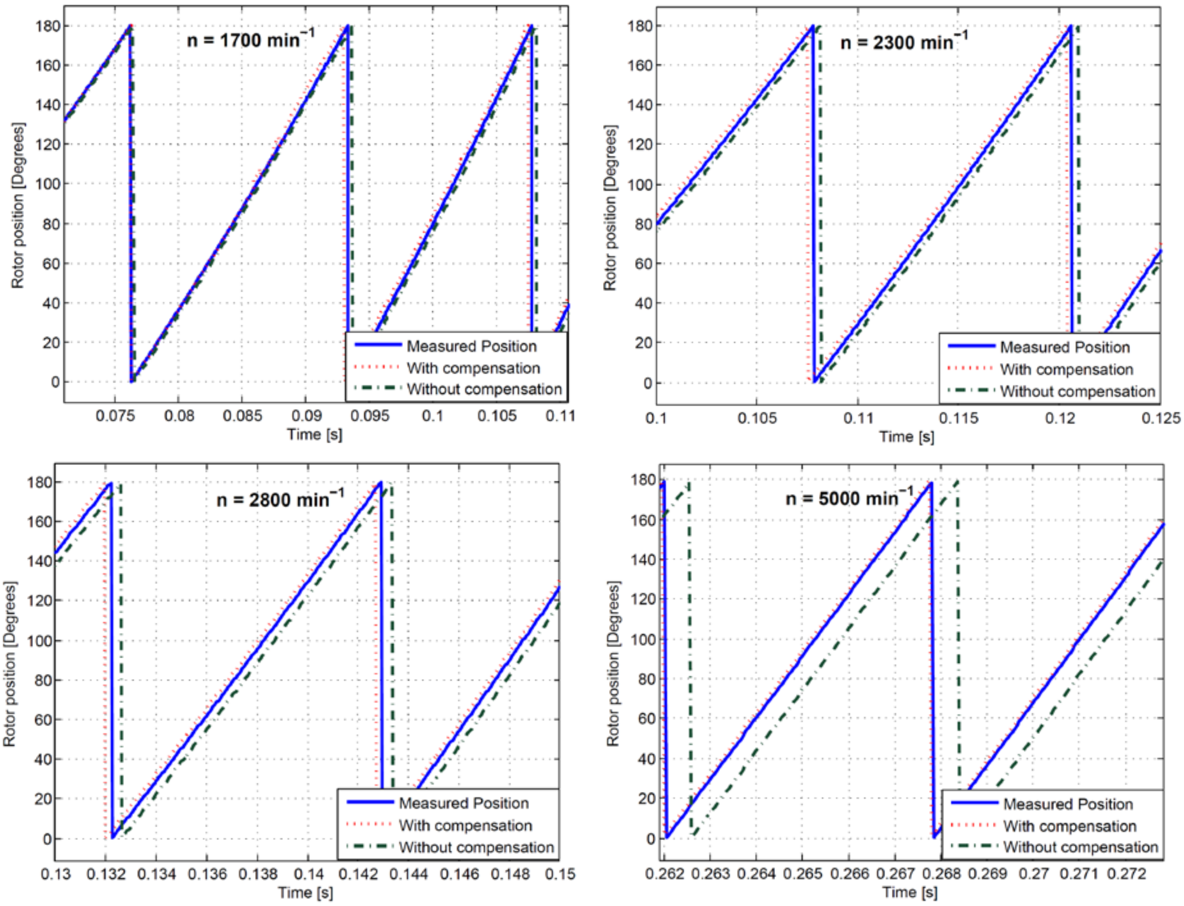

Fig. 4. Position observer.

In the beginning, the observed position with and without compensation are similar to the measured rotor position. The observer error of the standard position observer augments as rotor speed ascends. The diagrams evidently demonstrate that due to the compensation the observed position maintains almost identical to the measured rotor position. Thereby, this scheme can guarantee the accuracy of position estimation, and furthermore provides an adequate speed estimation in succeeding research.

4.2. Control results

The speed control results on the test bench from two approaches of online speed estimation are shown in Fig. 5. Overshoot occurs in the observed speed with the compensation. By comparison, although having a tiny time delay around 8 ms to the measured speed, the control result of the difference method with less intricacy is much more stable when compared to the former.

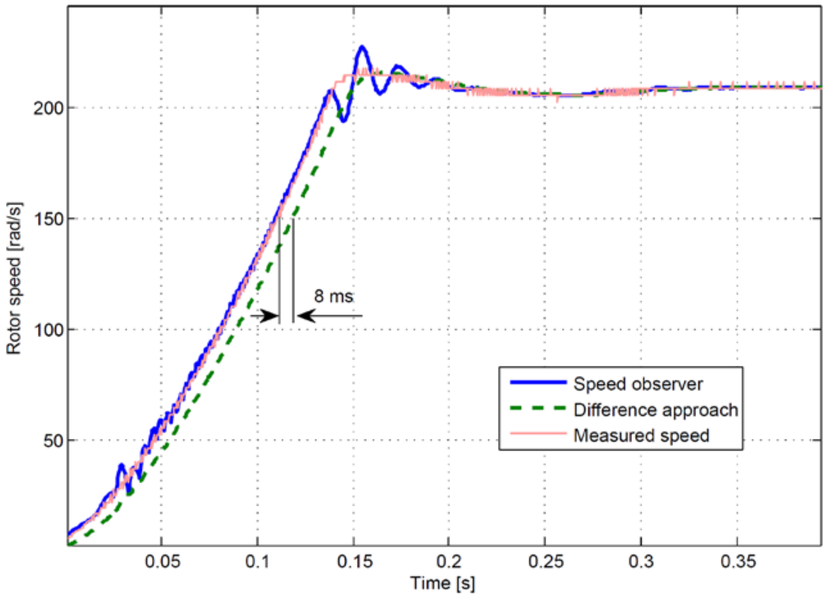

Fig. 5. Speed control results.

5. Conclusions

This paper presents a sensorless control approach based on a state observer to control the speed of permanent magnet synchronous motor. The work performance of the EMF observer with compensation is superior to standard position observer on the test bench. It is shown that, the difference approach in comparison to speed observer is more suitable for a robust sensorless speed control.

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