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An Application of Observer For Position Sensorless Stepper Motor Drives

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Abstract

A control method for stepper motor drives system can be made in open-loop circumstance which mean the system control did not require any feedback input signal in order to run the system. By applying the right sequences of pulses, the stepper motor capable to operate as other motion control. However, the performance of such system cannot be achieved to high level condition and demanded a feedback signal input to compensate the error produced while running the drive system. Therefore, a physical sensor or an encoder is placed in the motor system to obtain the feedback and form a close-loop system for error compensation. Nevertheless, the prices of these instruments are expensive, bulky and also may degrade the system performance. As a result this project presents a sensorless system in stepper motor drive system as an alternative to develop a close-loop system where the input signals are taken from voltage and current of the magnetic flux of the stepper motor. Therefore, this paper is described to investigate the performance of position control of stepper motor using PIC controller and to study the application of sensorless in position control system of stepper motor.

Introduction

In recent years, a real robust of motion control in mechatronics technique is required in a very precise positioning and broad speed range applications. It means that drive systems are robust-controllable for precise positioning and broad speed range including from an ultra small to large positioning and ultra low to ultra high speed range. Both speed and positioning controller is very important for the performance improvement of drive systems. One of the important motion controls is to design a self reconfigurable controller such as electric motor controller for a hybrid electric vehicle application. This system detects the current sensors failure and will estimate the current successfully such that the motor continues working safely. The motor model is used for estimating the currents and the phase are estimated using Luenberger observer. The hall sensors with 60 degrees resolution have been used for positioning sensor. [1]. For advanced controls of a power-assisted wheelchair, the control for speed of power assisting motors is needed. One of the features of a wheelchair is operating at very slow speed and even stops frequently. Thus, an instantaneous speed observer is necessary for the control of a power-assisted wheelchair since the instantaneous speed observer has fast convergence speed, and applies it to gravity compensation controller of a power-assisted wheelchair especially when it goes on a hill [2]. Observer also called a sensorless system is a popular application in motion control where the physical sensor such as encoder will not be used to obtain the system feedback. Besides be able to remove space allocation for rotation-sensor hardware, it also is able to eliminate mechanical adjustment and maintenance. The observer detects the rotor magnet flux components in the two-phase stationary reference frame using the motor electrical equations [3]. The observer also used in solving the speed estimation problem in high-power railway traction applications, including the very low speed range. In motion control, accurate speed and positioning information is necessary to realize high performance and precision control. Many techniques were developed to achieve speed and positioning including mechanical sensors such as shaft encoder or a resolver. Nevertheless, the prices of these instruments are expensive, bulky and degrade the system. Therefore, a sensorless motion control is developed to replace the hardware part [4].

The System

i. *Model Reference Adaptive System (MRAS)*

MRAS observer is one of the method to estimate speed the of a drive machines that is directed towards the high performance speed control without a mechanical sensor for speed feedback. The method MRAS observers based on rotor flux as the error vector. The MRAS observer used to estimate the rotor speed and rotor flux angle is shown in below. The rotor flux angle will be used to detect the position of the motor shaft. The observer is based on a current-model is derived from rotor flux equation and the voltage-model is derived from stator flux equation. Figure 1 shown the block diagram of MRAS estimator for speed and angle estimator [5].

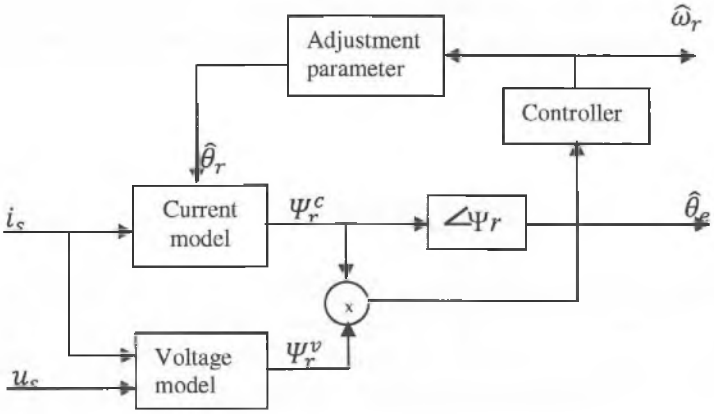

Figure 1 Block Diagram of MRAS Estimator

The induced voltage occur because of the permanent magnet flux linkage at each windings are varies sinusoidally with the rotor position. The flux linkage for four phase hybrid stepper motor with p rotor teeth can be described as;

$$\psi_i = \psi_M \sin(p\theta - x)$$
$$p = 90/step\ lenght$$

Where x is angle for each phase (i=1,2,3,4) of stepper motor, φ_M, is the maximum flux linkage each winding, p is number of rotor teeth. $p\theta$ is integration of the average rotor velocity over one supply cycle with respect to time. This will give the variation of rotor position with time as expressed below;

$$p\theta = \omega t - \delta$$

The voltages in the phase windings are equal to the rate of change of flux linkages.
Thus,

$$e_i = \frac{d\psi_I}{dt} = p\psi_M \cos(p\theta - x)\frac{d\theta}{dt}$$

Then, the instantaneous voltages and currents in each phase can be expressed as;

$$v_i = Ri_I + L\frac{di_i}{dt} + e_i$$
$$i_i = Icos(\omega t - \delta - a - x)$$

Where a is a phase angle, $\delta$is the load angle. By taking phase A, the flux linked with phase is the product of current and inductance;

$$\psi_A = L_A i_A$$

Where L_A is the phase inductance with rotor teeth which is given by [8];

$$L_A = L_0 + L_1 \sin p\theta$$

And the rate of changes in flux linkage with time can divided into two portions, the first part is the voltage induced in the phase windings by the rotor motion and the second is the changing current in the phase inductance [6]. Thus can be described as;

$$\frac{d\psi_A}{dt} = \omega L_1 i_A \cos(\omega t - \delta) + L_A\frac{di_A}{dt}$$

ii. *Close loop and transformation from 4ϕ into 2ϕ*

The close loop system required the transformation of four phase system to two phase system using $d\theta - q\theta$ rotational condition. Based on the space-phasor theory, the space phasor for voltage and current are given by;

$$\vec{v} = \frac{2}{k}\sum v = \frac{2}{k}(v_A + v_B + v_C + v_D) = v_d + jv_q$$

Where v_d, jv_q, i_d and ji_q are the components in the complex plane and k is the number of phase. The homopolar components $v_{0+}$and v_{0-} are needed for the transformation of four phase system into two phase system as;

$$v_{0+} = \frac{1}{k}(v_A + v_B + v_C + v_D)$$
$$v_{0-} = \frac{1}{k}(v_A - v_B + n_C - v_D)$$

These homopolar components are linked to each other together with space phasor in matrix form where $k = 4$ as follow;

$$[\vec{v}] = [\vec{a}_4][v]_4 = [\vec{J}_4][v]_2$$

Where,

$$[\vec{v}] = \begin{bmatrix} \vec{v} \\ \vec{v}^* \\ v_{0+} \\ v_{0-} \end{bmatrix}, [v]_4 = \begin{bmatrix} v_A \\ v_B \\ v_C \\ v_D \end{bmatrix}, [v]_2 = \begin{bmatrix} v_d \\ v_q \\ v_{0+} \\ v_{0-} \end{bmatrix}$$

$$[\vec{a}_4] = \frac{1}{2}\begin{bmatrix} 1 & i & -1 & -i \\ 1 & -i & -1 & i \\ 0.5 & 0.5 & 0.5 & 0.5 \\ 0.5 & -0.5 & 0.5 & -0.5 \end{bmatrix}; \quad [\vec{J}_4] = \begin{bmatrix} 1 & i & 0 & 0 \\ 1 & -i & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Therefore, the formulae of transformation from four phase system into two phase system or vice verse are;

$$[v]_2 = [A_4][v]_4 \quad \text{and} \quad [v]_4 = [A_4]^{-1}[v]_2$$

Where;

$$[A_4] = [J_4]^{-1}[a_4] \quad \text{and} \quad [A_4]^{-1} = [a_4]^{-1}[J_4]$$

The above equations are in fixed stator $d - q$ system. In order to construct the system in rotational $d\theta - q\theta$ system, the rotational operator of $[D_4(\theta)]$ is used where the two phases can be constructed from;

$$[v_2]_{2\theta} = [D_4(\theta)][v]_2$$

Where

$$[D_4] = \begin{bmatrix} cos\theta & sin\theta & 0 & 0 \\ -sin\theta & cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}; \quad [v_2]_{2\theta} = \begin{bmatrix} v_{d\theta} \\ v_{q\theta} \\ v_{0+\theta} \\ v_{0-\theta} \end{bmatrix}$$

As a result, the rotational stators $d\theta - q\theta$ for the voltages and current are presents as[7];

$$\begin{aligned} v_{d\theta} &= v_d cos\theta - v_q sin\theta \\ v_{q\theta} &= v_q cos\theta - v_d sin\theta \\ i_{d\theta} &= i_d cos\theta - i_q sin\theta \\ i_{q\theta} &= i_q cos\theta - i_d sin\theta \end{aligned}$$

And adjustable models can be expressed as;

$$\frac{d\psi_D}{dt} = \omega L_1 i_D \cos(\omega t - \delta) + (L_0 + L_1 \sin p\theta)\frac{di_D}{dt}$$

For reference model in $d\theta - q\theta$ system are;

$$\begin{aligned} v_{d\theta} &= 0.5(v_A - v_C)cos\theta + 0.5(v_B - v_D)sin\theta \\ v_{q\theta} &= 0.5(v_B - v_D)cos\theta - 0.5(v_A - v_C)sin\theta \end{aligned}$$

Meanwhile for adaptation model in $d\theta - q\theta$ system are;

$$i_{d\theta} = 0.5(i_A - i_C)cos\theta + 0.5(i_B - i_D)sin\theta$$
$$i_{q\theta} = 0.5(i_B - i_D)cos\theta - 0.5(i_A - i_C)sin\theta$$

When substituting, the flux linkage for adaptation models can be formed as;

$$\frac{d\psi_{d\theta}}{dt} = \omega L_1 i_{d\theta}\cos(\omega t - \delta) + (L_0 + L_1 \sin p\theta)\frac{di_{d\theta}}{dt}$$
$$\frac{d\psi_{q\theta}}{dt} = \omega L_1 i_{q\theta}\cos(\omega t - \delta) + (L_0 + L_1 \sin p\theta)\frac{di_{q\theta}}{dt}$$

Result and Discussion

These close loop simulations were carried out with MRAS with feedback in many time in order to obtain and verify the performance of the speed and position as accurate as possible. The simulation was done in MATLAB Simulink. Figure 2 shows the comparison between open loop system and open loop MRAS system without feedback for speed and position. Many time simulations were throughout in order to obtain the PI value to produce the best performance. The value of Proportional is 1120000 and Derivative is 1. Generally the figure illustrates the MRAS system without feedback is able to achieve the target position with slowly raising the speed. On the other hand, the position is slowly increases when forward condition and stay at position 0.8 rad for almost 0.06s but very fast decrease when backward condition and stop at low position i.e. 0.5 rad.

The comparison between open loop system HSM and close loop MRAS system (with feedback) for speed and position was shown in Figure 3. It shows the MRAS system is able to increase position at speed around 140 rad/s. The motion stays at position 0.8 rad at time 0.106s before it reverse the direction from 0.158s to 0.206s and stop at position 0.45rad, which is higher from MRAS without feedback. The Proportional value for this simulation is 26000 and Derivative value is 1 which is lower than open loop MRAS without feedback.

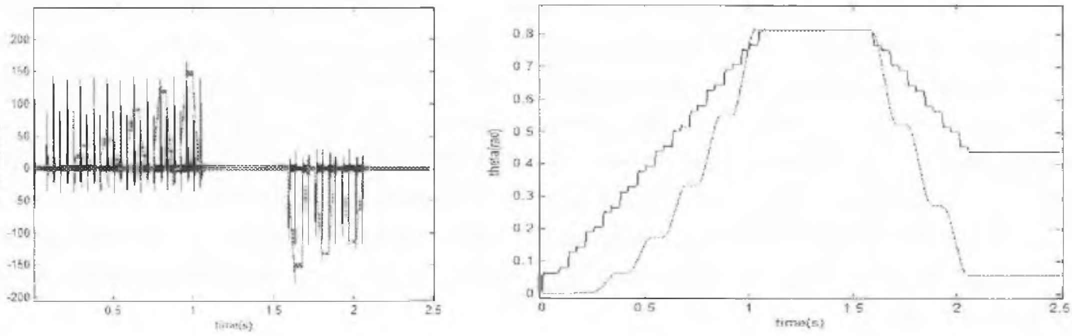

Figure 2 The Comparison Between Open Loop System And Open Loop MRAS System

Without Feedback For Speed (left) And Position (right)

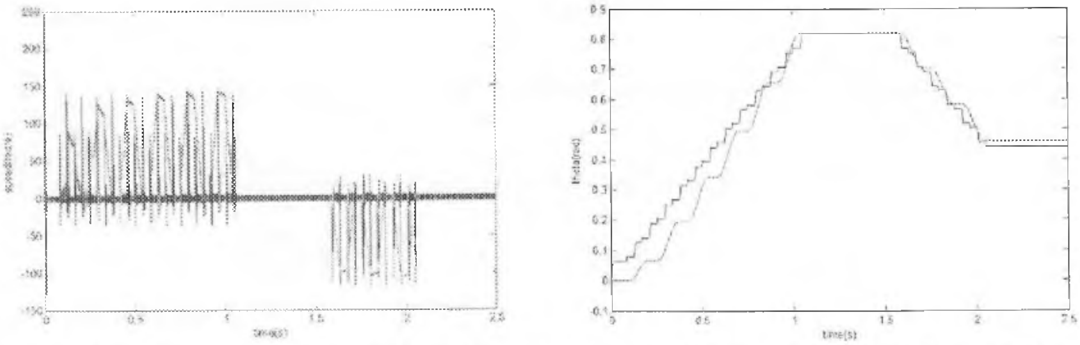

Figure 3The Comparison Between Open Loop System And Close Loop MRAS System For Speed (left) And Position (right)

The uneven speed and position cannot be acquired as expected since the parameter of the HSM cannot be obtain fully. However, when applying 0.00023Nm load torque, the starting point of the HSM can be improved as shown in Figure 4.

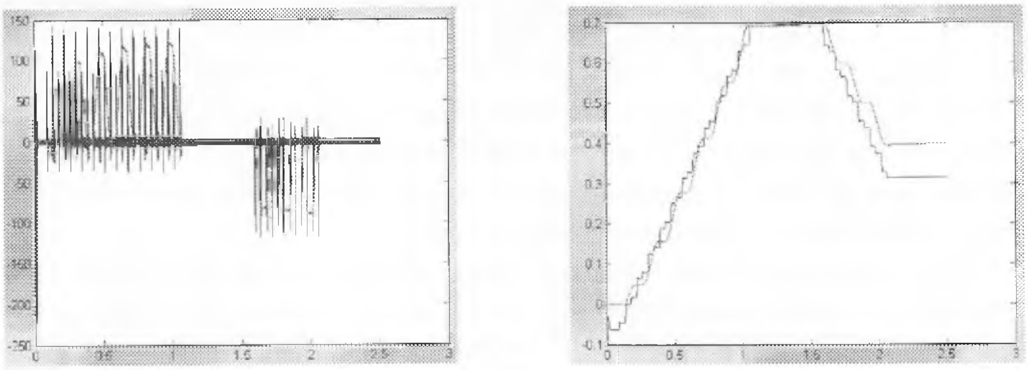

Figure 4 Close Loop MRAS System with Load Torque

Generally, both open loop and close loop or sensorless systems of the hybrid stepper motor were investigated. Both simulation and hardware for open loop system were shown that the speed and position can be getting easily. However, by applying the sensorless system can improve the performance of the motion control. In this project the MRAS was implemented to form a sensorless system for a hybrid stepper motor. The MRAS can be acting as a non physical sensor in motion control. Via MRAS, the speed and position ware estimated before applying both parameters to the HSM system. However, by considering the load torque the result can be improved. One option is by using Extended Kalman filter together with MRAS.

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