ISSN(Online): 2319-8753
ISSN (Print): 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Issue 11, November 2015

Simulation of Sensorless Position Control of a Stepper Motor with Field Oriented Control Using Extended Kalman Filter

Nilu Mary Tomy [1], Jebin Francis [2]

P.G. Student, Department of Electrical and Electronics Engineering, RSET, Kochi, India[1]

Assistant Professor, Department of Electrical and Electronics Engineering, RSET, Kochi, India [2]

ABSTRACT: Stepper motors are used for position control applications. The sensorless position control for a hybrid stepper motor without using mechanical sensors is presented in this paper. Extended Kalman filter is used to estimate the instantaneous speed and position required for the field oriented control of the stepper motor. Extended Kalman filter algorithm estimates the state of the system from the currents and voltages of the two phases of the hybrid stepper motor. The estimated position is compared with the desired position and motor is stopped at the desired position. Due to the absence of mechanical sensors, the system is less complex and less expensive. Simulation is done in MATLAB/Simulink.

KEYWORDS: Extended Kalman filter, Field oriented control, MATLAB, Position control, Sensorless control, Stepper motor.

I. INTRODUCTION

Open loop operation of stepper motors is not suitable for applications requiring precise positioning. Closed loop mode has much more accuracy compared to the open loop operation. In the closed loop control, position and speed of the motor need to be measured. The use of encoders for measurement increases the cost, complexity and volume of the system. Also the reliability of the system is reduced as the accuracy of measurements depends upon the working conditions.

An observer can be used to estimate the non measurable states of the system. The Kalman filter is an observer which estimates the measurable and non measurable states of a system using a recursive algorithm. Sensorless control is done using extended Kalman filter algorithm. The currents and voltages of the motor are used to estimate the speed and position by the extended Kalman filter algorithm. . Flux and torque of the stepper motor can be controlled separately by field oriented control. FOC improves the dynamic performance of stepper motor. The instantaneous rotor position required for field oriented control is estimated by the EKF algorithm.

II. RELATED WORK

Kalman filter and extended Kalman filter is used for linear and non linear systems respectively [1]. Even though unscented Kalman filter has less computations and less estimation error than extended Kalman filter, for real time implementation extended Kalman filter is preferred [2]. The extended Kalman filter can be implemented in continuous time [1] and discrete time. For real time implementation discrete time Kalman filter is used. In [4] the experimental result of a position control of stepper motor considering the effects of variation in load torque is presented.

DOI:10.15680/IJIRSET.2015.0410052

III. HYBRID STEPPER MOTOR

The step angle of hybrid stepper motor is smaller than permanent magnet and variable reluctance stepper motor. In addition to the advantage of small size, it has high holding torque. The following electrical and mechanical equations are used in the modelling of the hybrid stepper [5].

$$\frac{di_a}{dt} = \frac{v_a + K_m\omega \sin(N_r\theta) - Ri_a}{L} \tag{1}$$

$$\frac{di_b}{dt} = \frac{v_b + K_m\omega \cos(N_r\theta) - Ri_b}{L} \tag{2}$$

$$\frac{d\omega}{dt} = \frac{K_m i_b \cos(N_r\theta) - T_L - K_m i_a \sin(N_r\theta) - B\omega}{J} \tag{3}$$

$$\frac{d\theta}{dt} = \omega \tag{4}$$

where v_a and v_b are voltages in the two phases of stepper motor, i_a and i_b are currents in phase A and B respectively, T_L is the load torque, ω is the angular velocity, Θ is the rotor position, torque constant K_m=0.458Nm/A, number of rotor teeth per phase N_r=50, phase resistance R=1.13Ω, inertia of motor J=0.000048Kg/m^2, phase inductance L=3.6mH, frictional coefficient B=0.0014N-m/rad/sec. For field oriented control, the model in d-q frame is used. The voltages and currents are transformed by Park transformation using the following equations.

$$v_d = v_a cosN_r\theta + v_b sinN_r\theta \tag{5}$$

$$v_q = -v_a sinN_r\theta + v_b cosN_r\theta \tag{6}$$

$$i_d = i_a cosN_r\theta + i_b sinN_r\theta \tag{7}$$

$$i_q = -i_a sinN_r\theta + i_b cosN_r\theta \tag{8}$$

The hybrid stepper motor model in d-q frame is given below.

$$\frac{di_d}{dt} = \frac{v_d - Ri_d}{L} + N_r\omega i_q \tag{9}$$

$$\frac{di_q}{dt} = \frac{v_q - Ri_q - K_m\omega}{L} - N_r\omega i_d \tag{10}$$

$$\frac{d\omega}{dt} = \frac{K_m i_q - T_L - B\omega}{J} \tag{11}$$

$$\frac{d\theta}{dt} = \omega \tag{12}$$

DOI:10.15680/IJIRSET.2015.0410052

IV. EXTENDED KALMAN FILTER

R.E Kalman developed the Kalman filter algorithm [6]. EKF uses the state space model for estimation of states. Measurable and non measurable states of the system can be estimated by extended Kalman filter. The series of noisy sensor outputs is used for state estimation. The difference between the output vector and the estimated state vector is multiplied by the Kalman filter gain to correct the estimated state variables. Only the current data is used to predict state at next time step. The discrete system model in state space form is given below.

$$x_{k+1} = x_k + Tf(x_k, u_k) + w_k \tag{13}$$

$$y_k = h(x_k) + v_k \tag{14}$$

The state vector, $x_k = [i_{dk}\ i_{qk}\ \omega_k\ \Theta_k\ T_{Lk}]^T$, input vector, $u_k = [v_{dk}\ v_{qk}]^T$ and output vector, $y_k = [i_{dk}\ i_{qk}]^T$. Sampling period T, is chosen as 0.00002 seconds. Load torque does not change as the sampling period is very small. w_k is the process noise with covariance matrix Q and v_k is the measurement noise with covariance matrix R. The EKF algorithm is given by the following equations.

$$\hat{x}_{k+1/k} = \hat{x}_{k/k} + Tf\left(\hat{x}_{k/k}, u_k\right) \tag{15}$$

$$P_{k+1/k} = F_k P_{k/k} F_k^T + Q_k \tag{16}$$

$$K_{k+1} = P_{k+1/k} H_k^T (H_k P_{k+1/k} H_k^T + R_k)^{-1} \tag{17}$$

$$\hat{x}_{k+1/k+1} = \hat{x}_{k+1/k} + K_{k+1}(y_{k+1} - H_k \hat{x}_{k+1/k}) \tag{18}$$

$$P_{k+1/k+1} = P_{k+1/k} - K_{k+1} H_k P_{k+1/k} \tag{19}$$

P is the estimation error covariance matrix, K is the Kalman gain matrix, F and H are the Jacobian matrices of the system and output respectively. Trial and error method is used to tune the covariance matrices.

V. SIMULATION OF POSITION CONTROL

The simulation diagram of position control of hybrid stepper motor in MATLAB is shown in fig. (1). Voltages v_a, v_b and currents i_a, i_b are measured and converted to d-q frame by Park transformation. The currents i_d, i_q and voltages v_d, v_q are used to estimate the position and speed by extended Kalman filter algorithm. The position estimated by the extended Kalman filter is compared with the desired position and the error is given to the PI controller. The output of PI controller is compared with current i_q and this error is given to a PI current controller. Current i_d is compared with reference current i^{ref}_d=0 and the error is given to a PI current controller. The d and q axis voltages v_d and v_q have linear and decoupling components. The outputs of the 2 current controllers are the linear components of voltages v_d and v_q i.e v^l_d and v^l_q. The linear components of voltages v_d and v_q are given below.

$$v_d^l = Ri_d + L\frac{di_d}{dt} \tag{20}$$

$$v_q^l = Ri_q + L\frac{di_q}{dt} \tag{21}$$

The decoupling components of voltages are added to the output of the current controllers to get the d and q axis voltages. The decoupling components of voltages v_d and v_q are given below.

$$v_d^d = -LN_r\omega i_q \tag{22}$$

$$v_q^d = LN_r\omega i_d + K_m\omega \tag{23}$$

Then the resulting voltages v_d and v_q are transformed to v_a and v_b using inverse park transformation using the equations given below.

$$v_a = v_d cosN_r\theta - v_q sinN_r\theta \tag{24}$$

$$v_b = v_d sinN_r\theta + v_q cosN_r\theta \tag{25}$$

Voltages v_a and v_b are given to a PWM generator to generate pulses to operate the H-bridge. Each phase of the motor is driven by a H-bridge.

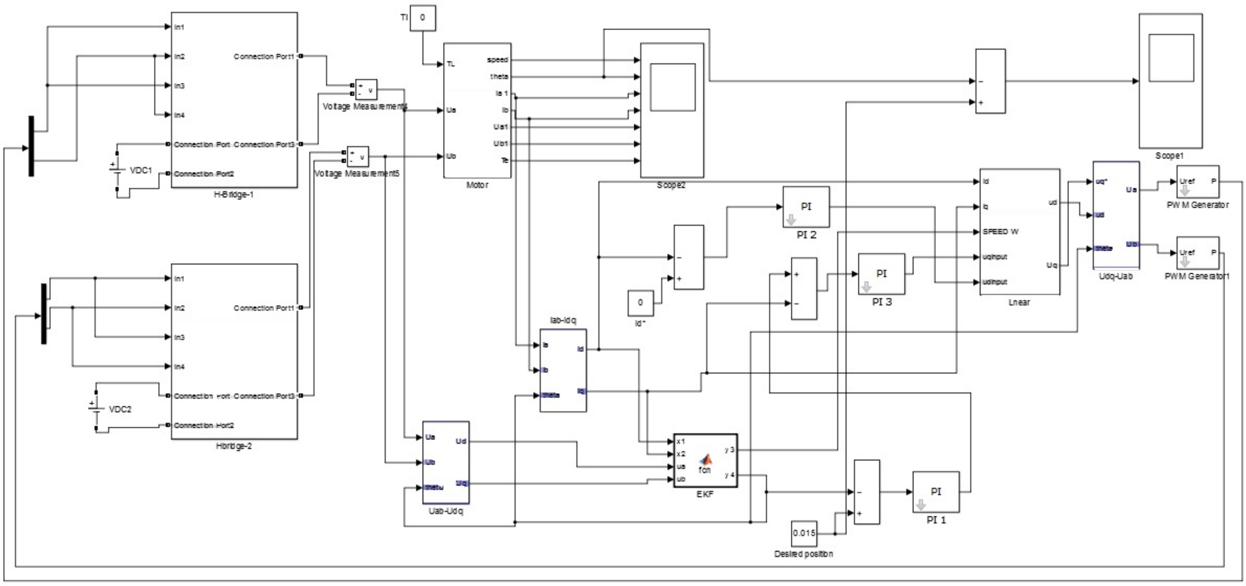

Fig. 1 Simulation diagram of position control of stepper motor

The currents in the 2 phases remain constant when position is constant. Fig. (2) shows the currents in the 2 phases.

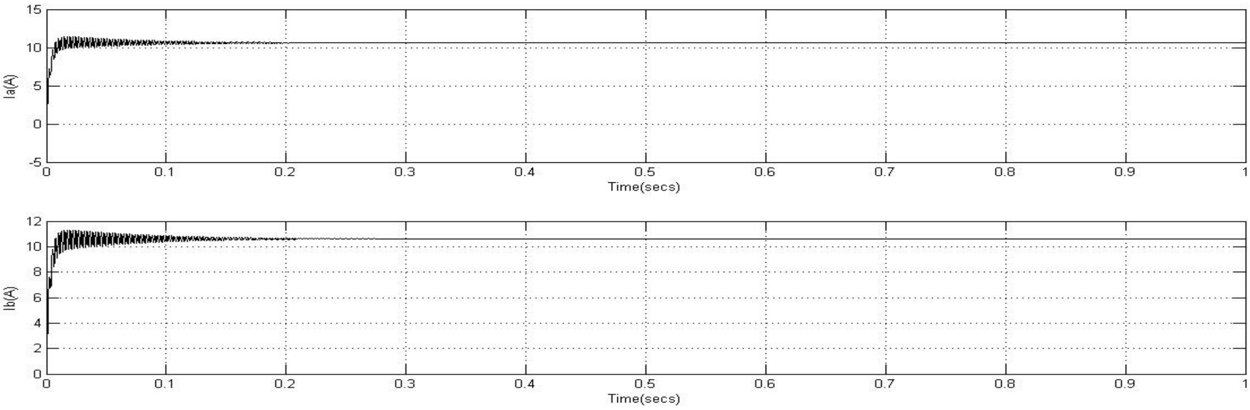

Fig. 2 Current in phase A and B

The voltages in the two phases of stepper motor are also constant. Fig. (3) shows the voltages in the two phases.

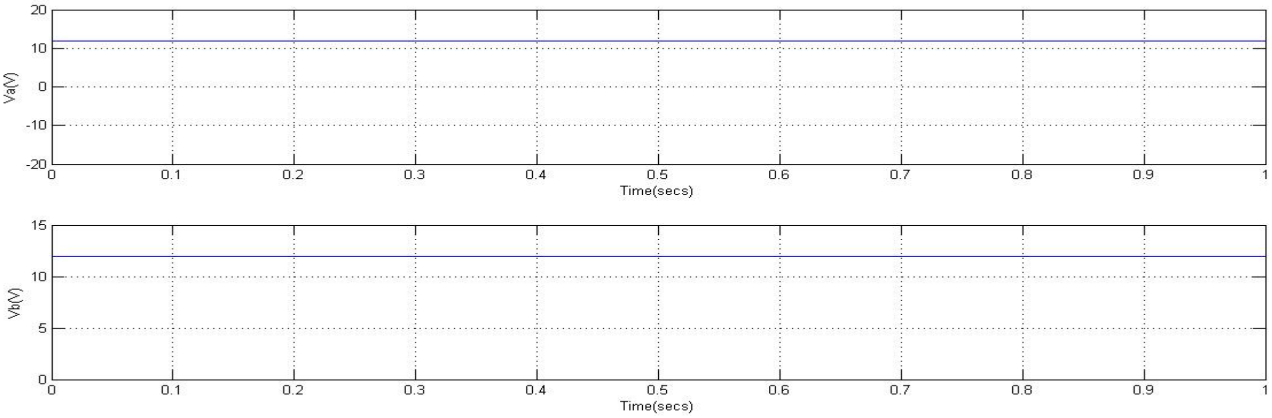

Fig. 3 Voltage in phase A and B

The desired position is 0.015rad. Fig. (4) shows the position waveform.

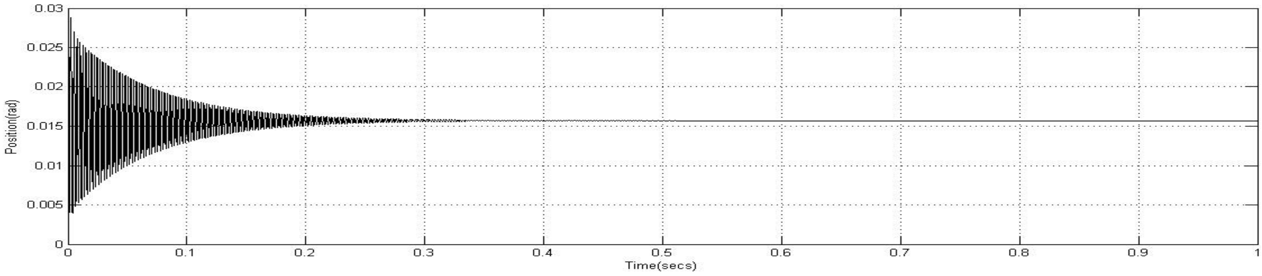

Fig. 4 Position

Fig. (5) shows the speed waveform. Speed settles to zero as position is constant.

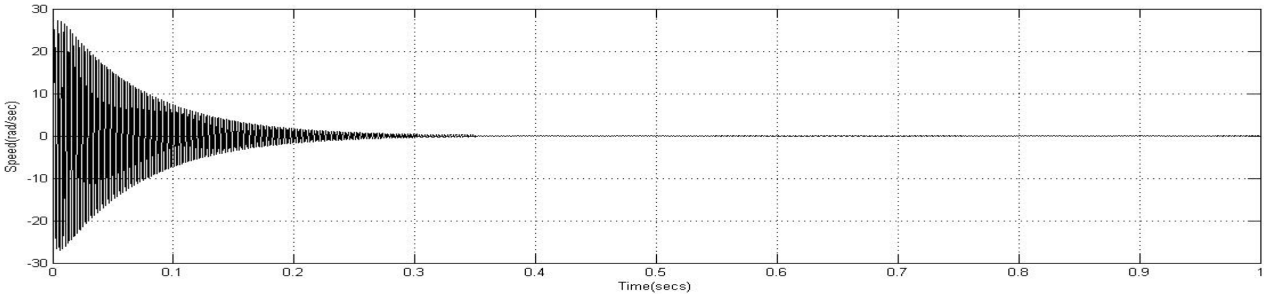

Fig. 5 Speed waveform

Fig. (6) shows the difference between the desired position and actual position. Error is very small.

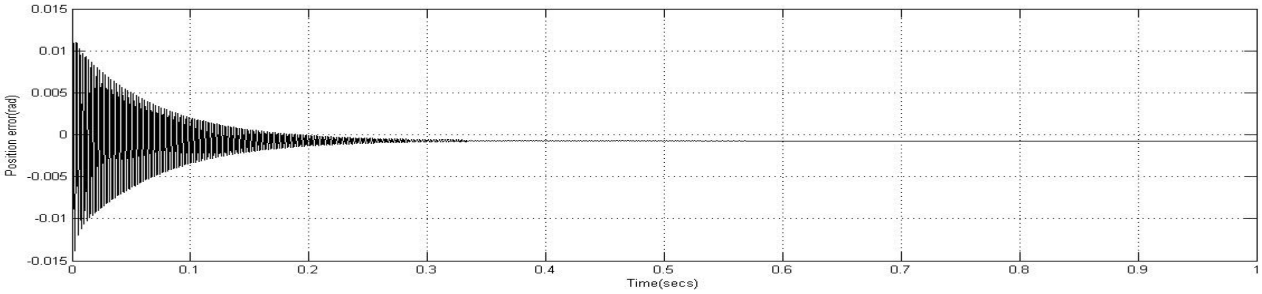

Fig. 6 Difference between desired and actual position

VI. CONCLUSION

We have implemented the sensorless position control of a hybrid stepper motor using PI control algorithm. From the simulation results it can be concluded that the difference between the desired position and actual position is very small. The size, maintenance requirements and cost of the system is reduced because of the absence of mechanical sensors. The drawback of Kalman filter is the complexity of the algorithm. Online computation of Kalman gain matrix is not possible in low speed microcontrollers in real time implementation. A high speed DSP can be used for the real time implementation of sensorless position control of stepper motor with field oriented control using extended Kalman filter.

REFERENCES

[1] Akhilesh Singh, Nagendra Kumar et.al, "State Estimation Of Permanent Magnet Stepper Motor Using Kalman Filter", International Journal on Recent Trends in Engineering & Technology, Vol. 05, no. 02, March 2011.
[2] B. Akin, U. Orguner, A. Ersak, "A Comparative Study on Kalman Filtering Techniques Designed for State Estimation of Industrial AC Drive Systems ", in Proc. Int. Conf. Mechatronics, pp. 439-445, Jun. 2004.
[3] Rafik Salloum, Mohammad Reza Arvan, Bijan Moaveni, "Modeling and Variables Estimation of a Two phase Stepper Motor by using Extended Kalman Filter", International Journal of Scientific & Engineering Research, ISSN 2229-5518, Vol. 4, Issue. 9, September-2013.
[4] M. Bendjedia, Y. Ait-Amirat, B. Walther, A. Berthon, "Position control of a sensorless stepper motor", IEEE Transactions on Power Electronics, Vol. 27, no. 2, pp. 578 -587, February 2012.
[5] Nilu Mary Tomy, Jebin Francis, "Modeling and Simulation of a Hybrid Stepper Motor in Microstepping Mode", International Journal of Advanced Technology in Engineering and Science, ISSN 2348-7550, Vol. 3, Issue. 9, pp.31-35, September-2015.
[6] Reenu George, S. Kanthalakshmi, Manoj G, "Sensorless position Control of Stepper Motor Using Extended Kalman Filter", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, ISSN 2278-8875, Vol. 3, issue. 2, February 2014.