

# Optimizing speed and angle control of stepping motor by using field oriented control

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## Abstract

In the present study, field oriented control of step motor implementation has been analyzed so that it can make a Sensorless control. Efficiency and Facilities of step motor is more than other types of electromotor. Therefore, the numbers of mechanisms and different types of turning can be made into them. Also controlling these motors is easier than other available motors. Stepping motor has been designed with oriented control in MATLAB software by using a Simulink tool box. In two methods above, current, torque and engine speed have been investigated by and without using Kalman filter. The results showed that using field oriented control can eradicate resonance abnormalities. By using field oriented control, the maximum theoretical engine performance can be achieved.

**Key words:** step motor, Kalman filter, field oriented control

## 1. Introduction

By growing development of science and technology, new requirements have been created to newer instrument and machines to harmonize all industrial parts. For this purpose, cognition and design of new approaches and instrument are unavoidable, consisting the development of making a type of new and more improving electromotor called stepping motor which will slowly takes a place on complex mechanical

mechanisms by increasing types of costs in industries [1].

Stepper motor is an electromotor having discretization angle turning and works by connections with beats on specific frequency [2]. Any beat has been sent to rotor determines the movement of the motor shaft to a certain angle that is called stepping angle [3]. In the step motor, the rotor is made up of permanent magnets and has six teeth located on N and S poles around rotor with equal intervals and alternatively it has

four poles. Winding on different electromagnets is connected to each other, so that the five wires A, B, C, D and V+ are pulled out of engine. The winding is activated by sending current to wire V+ and entering out it from other activated wires. In next step, the order of a given induction causes to rotate the rotor in clockwise or if this induction sequence is reversed, direction of movement will also be reversed [4].

Based on studies mentioned, the designing and producing of step motors are carried out with novel facilities and abilities that decrease costs in all using approaches of these systems [5,7]. One of several advantages of this electromotor type is to converse more complex mechanical mechanisms. In spite of recent improvements in implementation control and modeling algorithms of stepper motors, open loop control has been less attended in achieving maximum motor implementation [8].

The step motor that is also used in industrial applications can produce stepping resonance and stepping escapade [9]. Field oriented control can eradicate resonance abnormalities and stepping escapade and maximum theoretical implementation can be found by field oriented control. In field oriented control, the entrance current of

engine is aligned for regulating specific angel between the stator magnetic field and the rotor magnetic field. Four main factors in a step motor are: Voltage, current, torque and stepping angle. Consequently, two phase-stepping motors have been designed, including PWM generator power driver, circuit sense and DSP programmed in MATLAB software, and the frequency, entrance voltage and constant in motor power is optimized by using a Kalman filter.

## **2. Definitions**

### **2.1. Field oriented control**

In field oriented control, the motor input currents are adjusted to set a specific angle between the fluxes produced in the rotor and stator windings [10]. The key to field oriented control is the knowledge of the rotor flux position angle with respect to the stator. The angle between the stator and rotor flux is computed regarding shaft position. For any position of the rotor, there is an optimal direction of the net stator field, which maximizes torque; there is also a direction which will produce no torque. If the permanent magnet rotor is in the same direction as the field produces the net stator field, no torque is produced. The fields interact to produce a force, but because the force is in line with the axis of rotation of the rotor, it only serves to compress the

motor bearings, not to cause rotation [5, 8]. On the other hand, if the stator field is orthogonal to the field produced by the rotor, the magnetic forces work to turn the rotor and torque to be maximized. A stator field with arbitrary direction and magnitude can be decomposed into parallel and orthogonal to the rotor field components. In this case, only the orthogonal (quadrat) component produces torque, while the parallel component produces useless compression forces. For the purpose of control system modeling and analysis, it is convenient to work in terms of winding currents rather than stator magnetic field [11]. This is because motor currents are easily measured externally while fields (flux) are not.

## 2.2. Stepper motor

Stepper motor is an electromotor having discretization angle turning and works by connections with having beats on specific frequency [8]. Any beats sent to rotor cause the movement of the motor shaft to a certain angle that is called stepping angle [6]. In step motor, the rotor is made up of permanent magnet and has six teeth located on N and S poles around rotor with equal intervals and alternatively it has four poles. Windings on different electromagnets are connected to each other, so that the five

wires A, B, C, D and V+ are entered out of engine. The winding is activated by sending currents to wire V+ and sending it out from other activated wires.

- If B-wire is active, pole 1 and pole 2 are north and south, respectively. And if A-wire is active, pole 1 and pole 2 are south and north, respectively.
- If C-wire is active, pole 3 and pole 4 are north and south, respectively. And if D-wire is active, pole 3 and pole 4 are south and north, respectively.

The step motor implementation is based on this law that the opposite poles are absorbed when similar poles are exerted. This happens if winding wires locate in the correct sequence activation [4].

## 3. Kalman Filter

The Kalman filter was developed by R.E. Kalman in 1960 [5]. Due to advances in the development of digital computing, the Kalman filter is a subject of extensive research and application. Kalman filtering has been applied in aerospace, navigation, manufacturing, and many others.

The Kalman filter provides a means for inferring missing information from indirect (and noisy) measurements. It provides the optimal (minimum variance) state estimate

when the dynamic system is linear and the statistical characteristics of the various noise elements are known [18]. The system can be described with following equation.

$$\begin{aligned} \dot{x} &= Ax + Bu + Bw & \text{(system)} \\ y &= Cy + Dv & \text{(value)} \end{aligned} \quad (1)$$

Where,  $x$  is the state,  $y$  is the measurement,  $u$  is the control input, and  $w$  and  $v$  are the system and measurement noise. The measurement vector could be a function of the control as well as the state. The assumptions regarding stationary noises, white, uncorrelated, and their expectation is zero. The definition of the covariance matrices of these noises is:

$$Cov(w) = E \{ww^T\} = Q \quad (2)$$

$$Cov(v) = E \{vv^T\} = R \quad (3)$$

Where,  $E\{0\}$  denotes expected value

The overall structure of the Kalman filter leads to the system equation:

$$\dot{x} = (A - KC)x + Bu + Ky \quad (4)$$

Where,  $K$  denotes the Kalman gain matrix. The setting of the matrix  $K$  depends on the covariance of the noises.

The quality of measurement of the goodness of the observation is given by;

$$H = \min E \left\{ \int (x - \hat{x})^T (x - \hat{x}) dt \right\} \quad (5)$$

$H$  can be minimized by choosing  $K$  as;

$$K = PC^T R^{-1} \quad (6)$$

Where,  $P$  can be calculated from the solution of the following equation:

$$PC^T R^{-1} CP - AP - PA^T - Q = 0 \quad (7)$$

$Q$  and  $R$  have to be set up based on the stochastic properties of the corresponding noises.

Since these are not usually known, they are used as weight matrices in most cases.

#### 4. Motor Equivalent Circuit

When the motor rotates, the rotor rotates in the stator magnetic field. The induced emf appears across the rotor terminal as an internally generated voltage  $E_b$ . Therefore, the equivalent electrical circuit of the motor is the impedance at stall, connected in series to a voltage source,  $E_b$ . The motor resistance is represented as  $R$  and motor inductance as  $L$  [7].

##### 4.1. Motor Transfer Function

When the motor is used as a component in a system, it is desired to describe it by the appropriate transfer function between the motor voltage and its velocity. For this purpose assume  $T_L=0$  and  $T_f=0$ , since neither affects the transfer function. If we now apply Laplace transformation to the motor equations, we get:

$$\begin{aligned} V(s) &= (sL + R) I(s) + K_E \omega(s) \\ T(s) &= K_T I(s) \\ T(s) &= (j_m + j_L) s(s) + D(s) \end{aligned} \quad (8)$$

The total moment of inertia J is given by

$$J = j_m + j_L \quad (9)$$

By using equation (8) and (9) we obtain an expression for the current:

$$I(s) = \frac{V(s)}{(sJ + R)(sJ + D) + K_E K_T} \quad (10)$$

Combine Equation (10) and Equation (8) to form:

$$V(s) = (sJ + R)(sJ + D)I(s) + K_E \omega(s) \quad (11)$$

The corresponding transfer function is

$$G_m(s) = \frac{\omega(s)}{V(s)} = \frac{K_T}{(sL + sJ)(sJ + D) + K_E K_T} \quad (12)$$

The motor impedance is given by;

$$Z(s) = \frac{V(s)}{I(s)} = \frac{(sL + R)(sJ + D) + K_E K_T}{(sJ + D)} \quad (13)$$

The torque constant is always related to the voltage constant in the following way:

$$K_T = K_E \left[ \frac{Nm}{A} \right] \quad (14)$$

By using proper units for the torque constant, the motor impedance is given by

$$Z(s) = \frac{V(s)}{I(s)} = \frac{(sL + R)(sJ + D)\omega(s) + K_T \omega(s)}{(sJ + D)} \quad (15)$$

## 4.2. Torque Constant

The torque constant is measured by operating the motor as a generator at a constant velocity [8]. The torque constant is given by the following relationship

$$\begin{aligned} K_T &= \left( \frac{\text{Induction voltage}}{\text{Mechanical speed}} \right) \text{ (volt / rad / sec)} \\ &= \frac{\text{Induction voltage}}{2 \times 3.14 \times \text{Mechanical frequency}} \\ &= \text{mechanical frequency} \left( \frac{2}{p} \right) \text{ (electrical frequency)} \end{aligned}$$

Where, p is number of poles in motor.

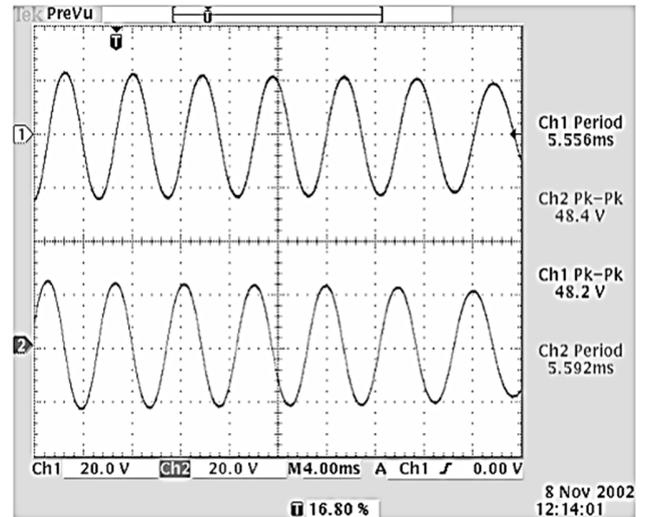


Fig. 1. Winding Back-emf Voltage

The induced voltages (back-emfs) for both windings A and B while running the SMC3 motor as a generator are shown in Fig. 1. From the waveform shown in Fig. 1,

$$\begin{aligned} \text{Mechanical frequency} &= \\ &= \left( \frac{2}{100} \right) * \left( \frac{1}{0.00574} \right) = 3.484 \end{aligned}$$

So torque constant for SMC3 motor is obtained as

$$K_T = \left( \frac{24.1}{2 \times 3.14 \times 3.484} \right)$$

$$K_T = 1.01 \left[ \frac{Nm}{A} \right] \quad (16)$$

### 5. Result and discussion

Efficiency and Facilities of a stepper motor is more than other electro motors. Therefore,

many of mechanisms and different modes of turning can be taken from them and also the control of this motor is simpler than the others, so that it mainly does not need any instruments of additional control vehicles such as electrical and mechanical brakes. In order to implement FOC Simulink, the useable parameters have been presented in table 1. This parameter has been extracted from references.

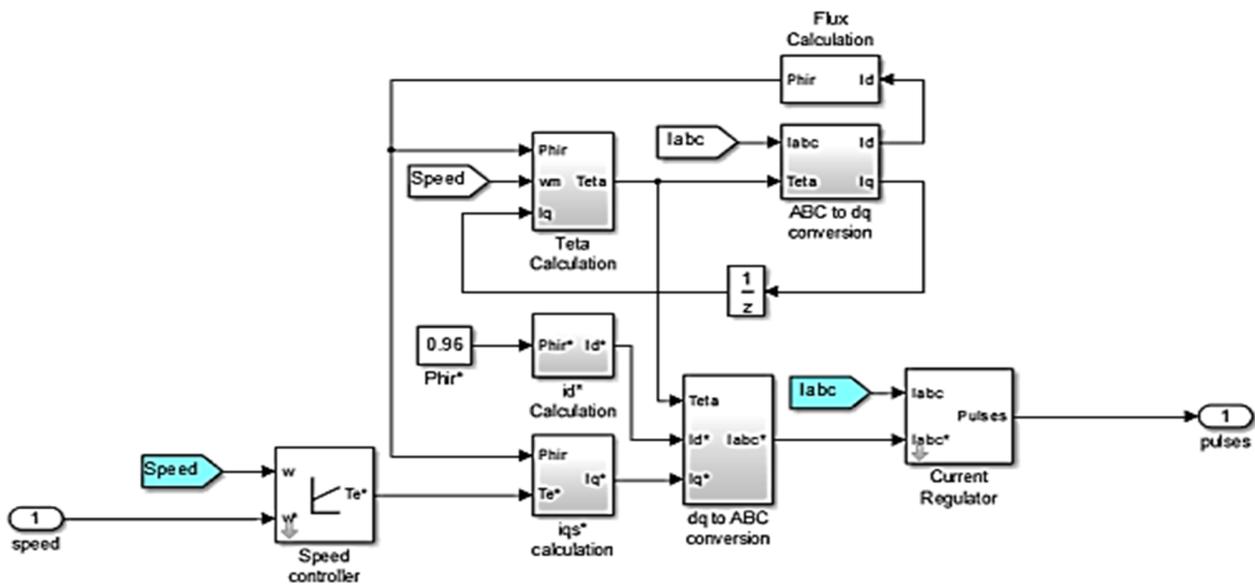


Fig. 2. FOC diagram simulink

Table 1. The parameters used in FOC designing[12]

Value	Parameter
0,96	Phir
34,7mH	Lm
0,1557s	Tr
0,228ohms	Rr
35,5mH	Lr

### 5.1. Step motor simulink

There is diagram block of step motor in MATLAB Simulink library. Therefore, there is no necessity to design it. This diagram block has been presented in fig 3. As it can be observed available motors have had different abilities from 2-phases to 4-phases. The present study has used 2-phases mode. In suggested control, the angle references of rotor and rotor angle have been investigated and the results have been presented in figs.3-8.

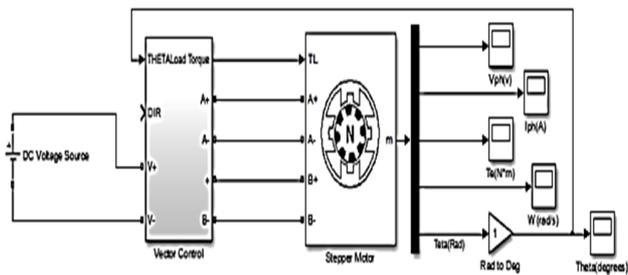


Fig 3. The diagram block of 2-phases step motor associated with FOC

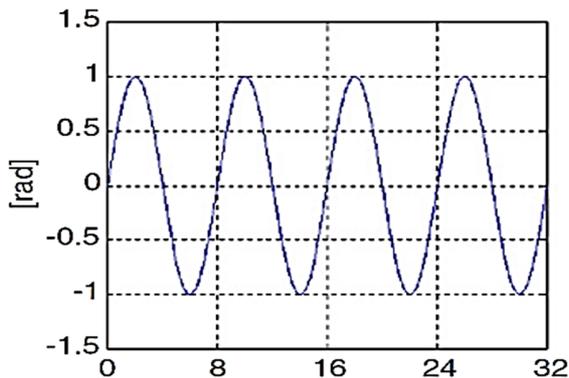


Fig. 4. Reference angle of rotor according to radian

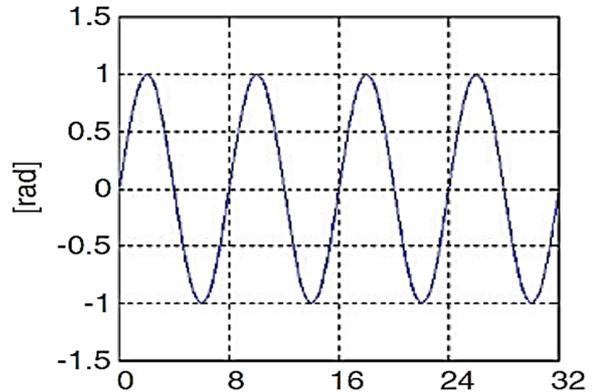


Fig .5. Motor angle

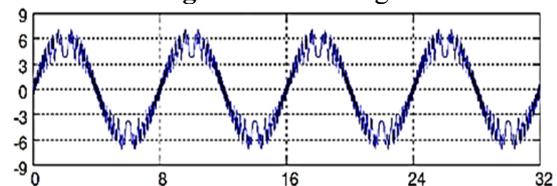


Fig.6. Motor phase

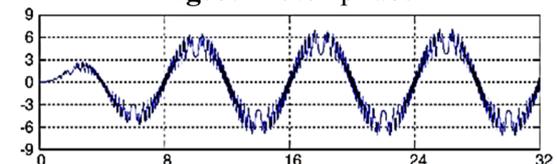


Fig. 7. Motor current

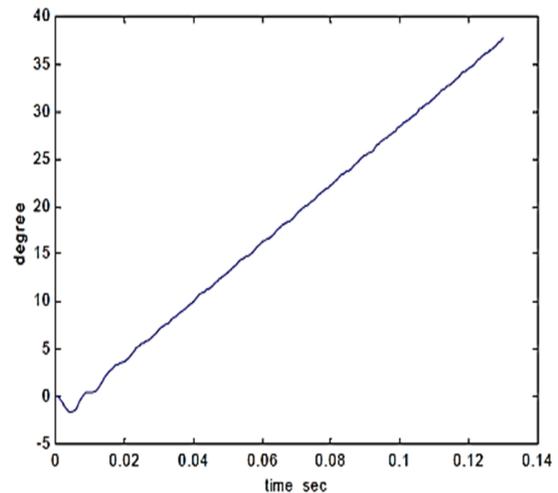
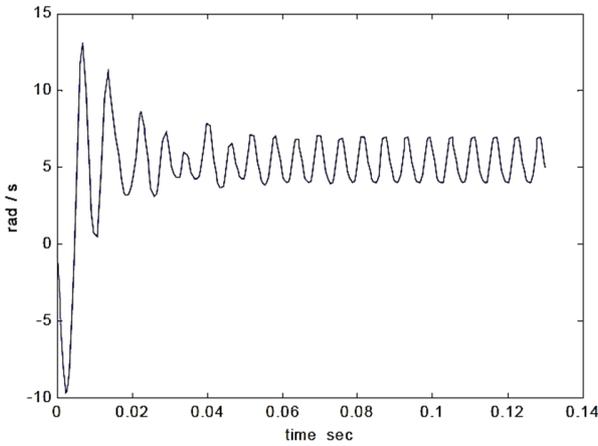
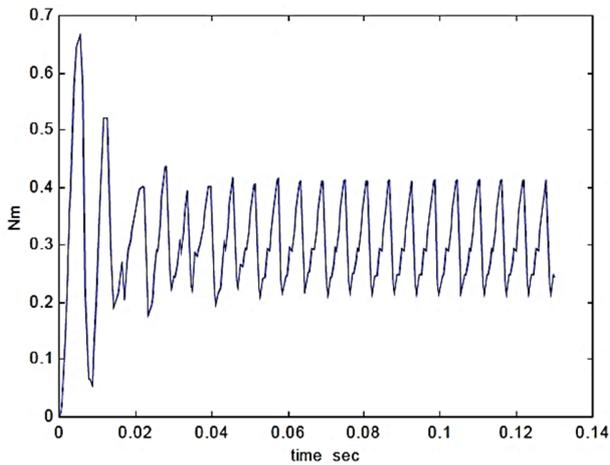


Fig. 8. The situation of step motor associated with FOC

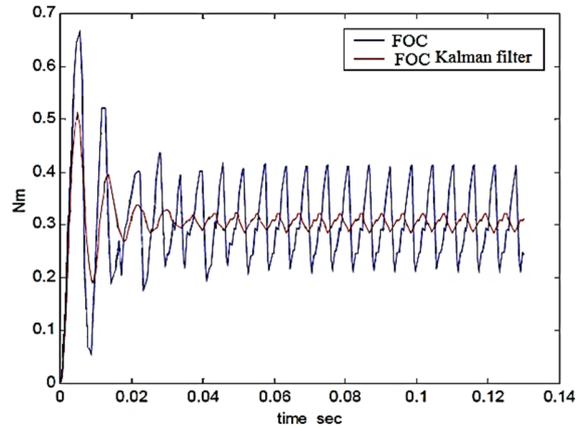


**Fig. 9.** Speed on step motor associated with FOC

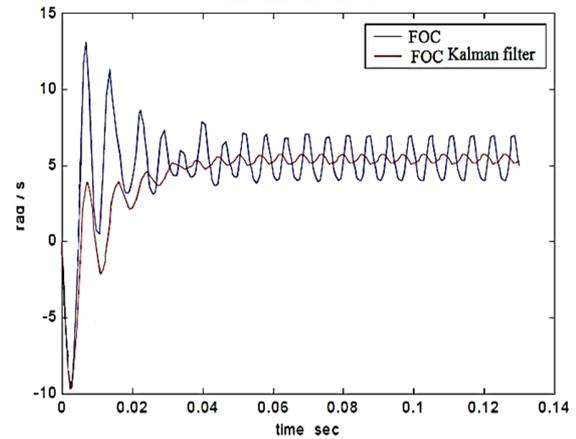


**Fig. 10.** Torque on step motor associated with FOC

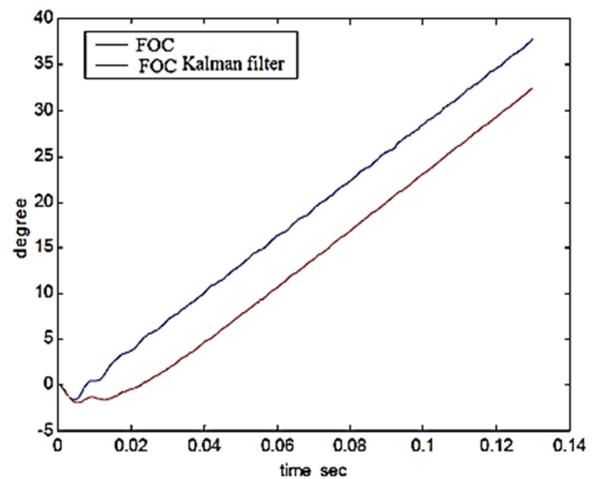
As it is respectively observed on fig 9 and 10, motor speed and motor torque consisted of swings was the reason for the phase because current swings are terminated into PWM inverter effect. Next, in order to compare dynamic properties of step motor under non-filter FOC and FOC and filter figs 9 and 10 have been presented. As it is shown in figs, the swings in torque of step motor and their speed will be decreased after filtering, and also in stable modes, high speed is obtained resulting in the best effect of torque controlling.



**Fig. 11.** Comparing step motor torques in two modes associated with FOC and FOC by Kalman filter



**Fig. 12.** Step motor speed in two modes associated with FOC and FOC by Kalman filter



**Fig. 13.** Position of step motor in two modes associated with FOC and FOC by Kalman filter

## 6. Conclusion

In this research, first we described step motor, field oriented control and Kalman filter. After that, field oriented control in step motor has been simulated by MATLAB software and use of Simulink tool box in previous studies was presented. The open loop implementation of step motor is limited because it is not able to control step motor torque and it tunes field oriented control and torque of step motor. The results showed that anomalies of resonance can be destroyed by field oriented control (figs. 11 to 13) and also maximum theory implementation is being possible by field oriented control (fig. 7). In present study, we used field oriented control technique in order to control step motor associated with Kalman filter. Therefore, in future studies, we can also apply field oriented control in hybrid step motors and synchronous motors.

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