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Modeling Position Tracking System with Stepper Motor

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Abstract

The position tracking system is used in many applications like pointing an antenna towards a desired direction in order to minimize de-pointing losses or moving the telescope to track an star. The stepper motor is used in many positioning systems and constant speed devices where high speed is not required. Modeling and simulation of the electromechanical behavior of stepper motor and overall tracking system is important to analyze the behavior of overall tracking system in different conditions. MATLAB is used for modeling and simulation of position tracking system. Stepper motor is modeled using differential equations and its behavior is observed by solving these equations numerically. The complete tracking system is modeled which includes modeling of potentiometer, pulse and direction generator, sequence generator and gear reduction (if speed reduction or more resolution in position is required) along with stepper motor and simulation results are presented for different conditions.

Keywords**:** stepper motor, tracking system, MATLAB, modeling

1. Introduction

To track position of a body or target mechanical operation is required. This requires electromechanical devices like motor to position the body as commanded. Conventionally DC and AC motors are used but, with that it is difficult to determine exact position of the load or motor speed or how much motion has been produced, unless external encoders or sensors are used. Also stopping of motion requires clutches or brakes to be used, whereas stepper motor moves one step per one pulse. Starting and stopping operation is stepper motor's inbuilt characteristics. Speed of the tracking system depends on pulse rate which decides excitation change of stepper phases. [1][2]

Stepper motor is the device that translates an electrical command signal to change in position of a rotor shaft. This position change is linear and discrete in quantity. [1] Three basic types Variable reluctance stepper motor, Permanent magnet stepper motor and Hybrid stepper motor have been considered while modeling. Hybrid stepper motor comes with small step angles 1.8° and 0.9°. More resolution is achieved by using gear reduction or by micro stepping.

For this work, two phase stepper motor is modeled and method to extend it to 4 and 6 phase is also explained. Here, for modeling, stepper motor with step size 1° is considered with gear reduction to achieve resolution up to .00625°.

A position tracking system model is proposed and simulated for different step rates in MATLAB and its responses are presented in the later sections.

The details of stepper motor modeling are given in section 2. The stepper motor specifications and simulation results are presented in section 3. In section 0, tracking system model details are presented. The simulation results for tracking system are discussed in section 5.

2. Stepper Motor Model

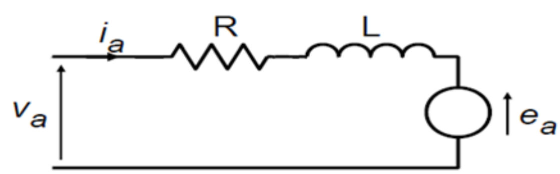

Figure 1: Stepper Motor Winding Model [1] [2]

A stepper motor with 2 phases (2 windings A and B) having winding resistance R, winding inductance L, N rotor teeth, Jr rotor inertia, Dr viscous damping coefficient, Kd detent torque constant can be modeled by,

$$\frac{d\Theta}{dt} = w$$

$$\frac{dw}{dt}=\{-T-K_d*\sin(2N\Theta)-D_r*\frac{d\Theta}{dt}-i_a K_c*\sin(N\Theta/2)+i_b K_c*\cos(N\Theta/2)\}/J_r$$

$$\frac{dIa}{dt}=\{V_a-RI_a+K_c*w*\sin(N\Theta/2)\}/L$$

$$\frac{dIb}{dt}=\{V_b-RI_b-K_c*w*\cos(N\Theta/2)\}/L$$

$Jr*\frac{d\frac{d\Theta}{dt}}{dt}$ gives total load acceleration torque T_A.

Va and Ia are the winding voltage and winding current of winding A. Similarly, Vb and Ib are the winding voltage and winding current of winding B.

These model equations can be solved by runge kutta method.

For variable reluctance and hybrid stepper motor

$$L = L0 + L1*\sin(N\Theta);$$

Where, L0 & L1 are minimum & maximum inductance respectively.

In modeling gear ratio 160:1 is considered. So when rotor moves 1° the load moves 1/160=.0063°

So, resolution of the system is .0063°.

Here to model 2 phase stepper motor we are taking two phases exactly out of phase (90°). So, we have taken sin (NΘ) and cos (NΘ). If we want to model 3 or 4 phase stepper motor, we should take them 60° and 45° out of phase. So for 3 phase stepper motor we will take sin (NΘ), sin (NΘ+60°) and sin (NΘ+120°).[3]

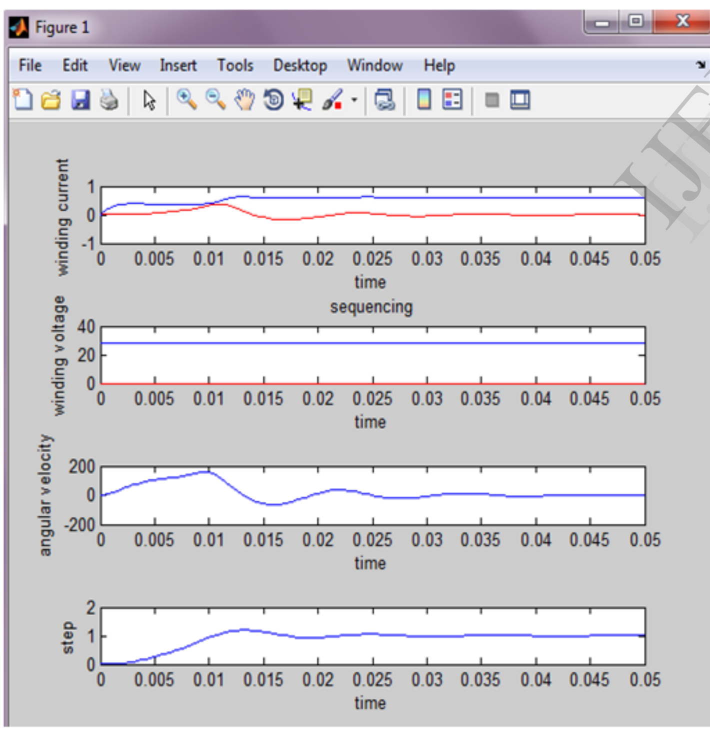

Figure 2 : Step response of stepper motor: Current, applied voltage, angular velocity and step

3. Stepper Motor Model parameters and Simulation results

Parameters	Value
Motor_Maximum_current I0	2
No of Rotor Teeth N	180
Winding Resistance R	46
Winding Inductance L	0.0828+0.0828*sin(NΘ)
Motor_Torque_Constant Km	0.15
Detent_Torque_constant Kd	0.10*Km*I0
Viscous_Friction_coefficient B	0.00
Motor and load Inertia J	1.6*10^-6
Load Torque Tl	0.0

The response of stepper motor modeled above for single step is shown in Figure 2. It can be seen that current in windings takes some time to build up and then remains constant over the one step time. Angular velocity also increases and at the end of step timing it becomes zero. This means after each step rotor comes to one detent position. The settling time for one step is .05 seconds as shown in **Error! Reference source not found.**. It also shows that its step angle is 0.00625°.

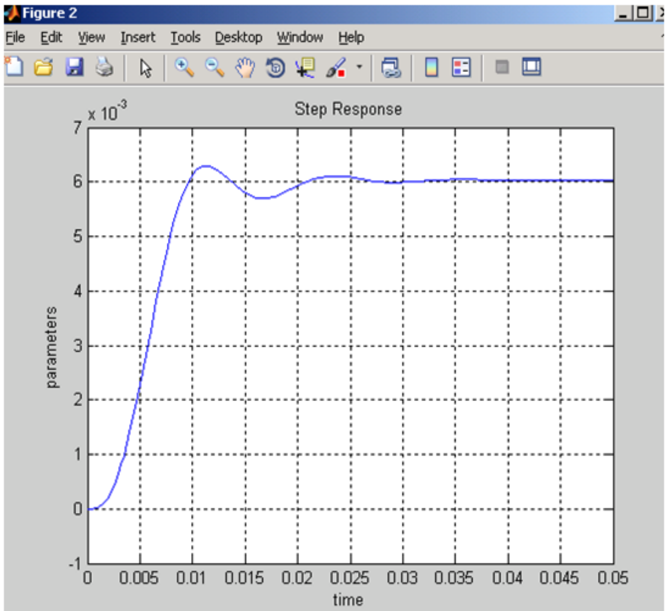

Figure 3 : step response of the modeled stepper motor

4. Tracking System Model

A tracking system consists of following elements as shown in Figure 4:

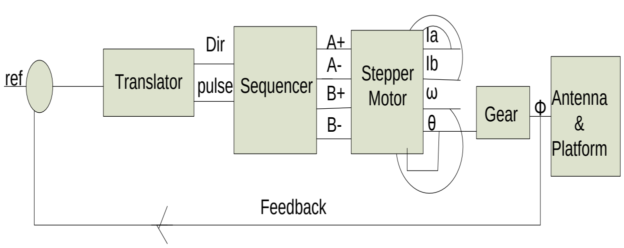

Figure 3 : stepper motor based position tracking system

Translator:

Translator takes error voltage as input and decides direction of rotation, clock wise or anti clock wise. Also it generates pulses to inform sequencer to take next sequence of excitation.

Sequencer:

It generates appropriate sequence for excitation change according to direction pulse on occurrence of the pulse.

Stepper motor:

It takes excitation change in account and moves the rotor one step in accordance with the sequence. It keeps RMS current constant with changing its direction as the excitation changes.

The above mentioned system is modeled as below:

If the error voltage received is positive then direction signal will be '1' and if negative then '-1'.

Then the sequence is generated by taking

$$V_a = -28 * \text{round}\ (\text{dir} * \sin\ (N * \text{Pre\_Motor\_posi}/(2)));$$

$$V_b = \ 28 * \text{round}\ (\text{dir} * \cos\ (N * \text{Pre\_Motor\_posi}/(2)));$$

Where, Pre_Motor_posi is present motor position. Hence, multiplication of voltage source of 28 volt with position dependent constant generates proper sequencing.

As stepper motor operation is step per pulse, maximum error possible is half the step size, because the error is non-cumulative for multistep operation. Speed of the tracking can be changed by changing pulse rate.

5. Simulation results and discussion

Case 1: The simulation result for 4 steps at 10 steps/sec is shown in Figure 5 and following are the observations:

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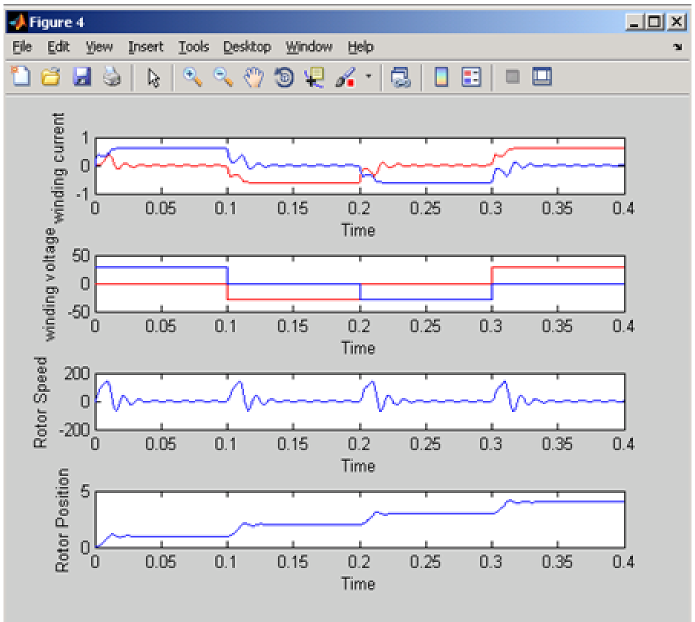

Figure 4 : 4 steps at 10steps/sec

In Figure 5	
Reference position	0.025
initial antenna position	0.0
present antenna position	0.024999674603542
error in tracking	3.253964580007818e-07

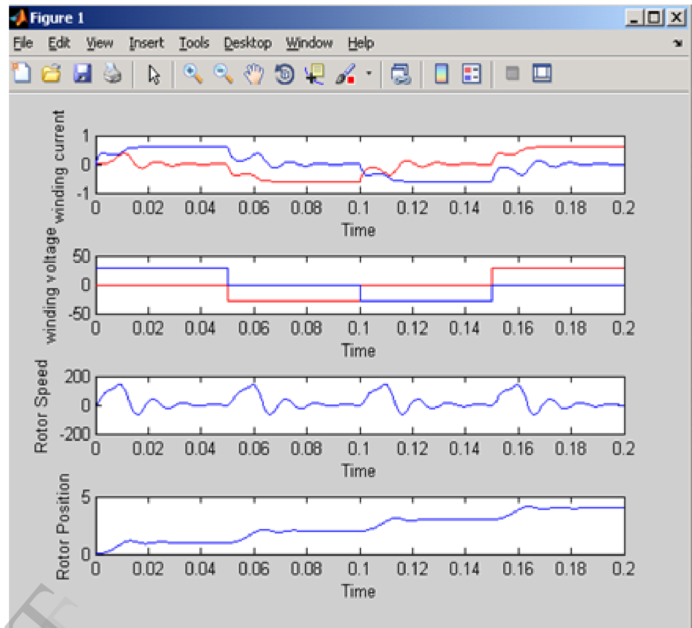

Figure 5 : 4 steps at 20steps/sec

Case 2: The simulation result for 4 steps at 20 steps/sec is shown in Figure 6 and Following are the observations:

In Figure 6	
Reference position	0.025
initial antenna position	0.0
present antenna position	0.025019105435733
error in tracking	1.910543573300019e-05

Case 3: The simulation result for 4 steps at 100 steps/sec is shown in Figure 7 and Following are the observations:

In Figure 7	
Reference position	0.025
initial antenna position	0.0
present antenna position	0.0242
error in tracking	-7.5097e-004

Figure 7 shows the response of modeled tracking system at different step rates. At the speed of 10steps/sec(Figure 5) and

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20steps/sec (Figure 6) after each step rotor comes to detent position, where it's speed is zero and in next step again it's speed is build up to move next step and at the end of one step movement, it reaches to zero. After reaching to one detent position current becomes constant until the excitation change occurs. In Figure 7 as the step rate is increased, it loses synchronization so at the end of commanded 4 steps motion also it keeps on moving as its speed is not becoming zero.

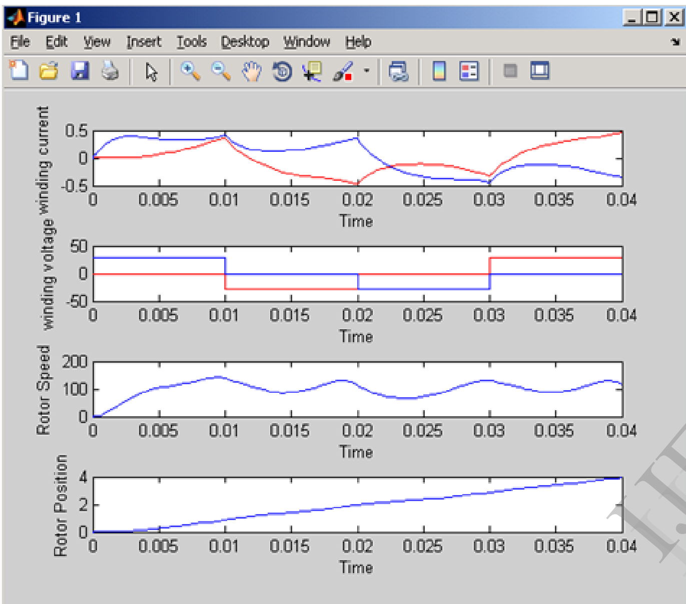

Figure 6 : 4 steps at 100 steps/sec

Case 4: Figure 8 shows that the model is working for both clockwise and anti clockwise rotation. In clockwise direction also we get error less than 2mDeg, and the rotor stops after reaching the reference position if operated at low step rate.

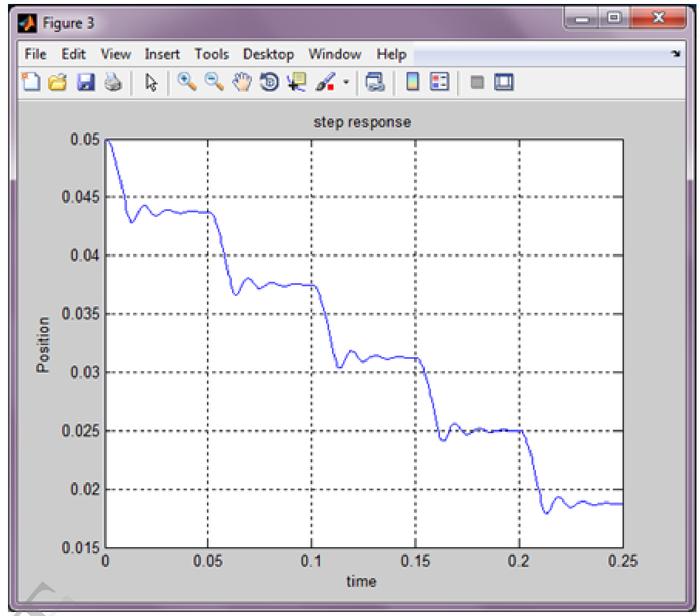

Figure 7 : clockwise rotation of antenna position at 20steps/sec

In *Figure 8*	
Reference position	0.018750000000000
initial antenna position	0.050000000000000
present antenna position	0.018730894675182
error in tracking	1.910532481800079e-05

6. Conclusion

Stepper motor is modeled using differential equations and then numerically solved by "Runge Kutta" method. Stepper motor performances for different step rates are tested. At higher step rates it loses synchronization and keeps on moving even after completing the required motion. The proposed tracking system operated within certain step rates operates well for both the direction. Tracking system using stepper motor is modeled and tracking error is calculated for clockwise and anticlockwise rotation, which is in the range of .0002▫ or less than that. Proposed Tracking system can be used for tracking moving object where higher accuracy is requirement.

7. Acknowledgment

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8. References

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