Application of Matlab/Simulink in hybrid stepper motor modeling

Vasilija Sarac,
Univeristy Goce Delcev, Macedonia
Slobodan Pesic
Agency for electronic communications, Macedonia

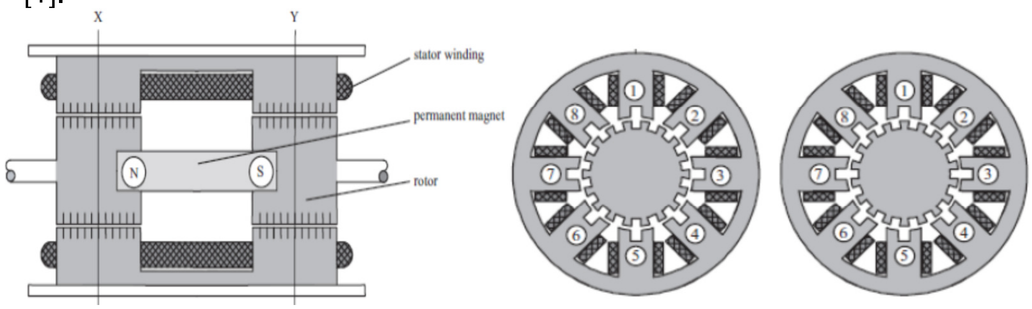
Abstract: *Development of digital electronics and microprocessor systems has led to development of electrical motors capable to be digitally controlled. These motors are widely known as stepper motors and the enable transformation of pulsed electrical excitation into mechanical energy. Matlab/Simulink is used as a simulation tool for hybrid stepper motor enabling motor transient characteristics of current, voltage, torque and speed to be obtained. Different operating motor regimes are simulated as no-load and rated load operation. Adequate conclusions regarding motor performance characteristics are derived.*
Keywords: *hybrid stepper motor, Simulink, motor's operating regimes*

1. Introduction

Stepper motors are very important in robotics, process control and instrumentation. They enable precise control of motor angular position, speed and direction of motor rotation. They are capable of discrete precise movements i.e. movements in precise steps so they are named as 'stepper motors'. Stepper motors are transforming electrical energy (excitation) into mechanical movement. They are constructed as rotating or translating motors. Although stepper motor are known for a long time, they have achieved their wide popularity in the last thirty years due to development of electronics which enables construction of cheap and reliable control circuits capable to satisfy complex requirements regarding motor torque, speed and angular displacement. In order their transient performance characteristic to be analyzed Matlab/Simulink is chosen as simulation tool and motor characteristics are analyzed under different operating regimes: no-load, rated load and over load. Advantages of stepper motors are: low costs, small dimensions, possibility to transform the pulses from digital inputs into angular movement-step, number of steps is equal to the number of control pulses. The above mentioned advantages have lead to their wide application in control systems and robotics and have made them irreplaceable moving force of industrial processes [3].

2. Hybrid stepper motor-construction and principle of operation

Hybrid stepper motors have magnetic core which is excited by combination of electrical windings and permanent magnet. Electrical windings are placed on stator while rotor is made of permanent magnets (Fig. 1). Number of poles at stator are usually eight and each pole has two to sex teethes. Per pair of poles are placed two excitation windings for example one winding for pole 1,3,5 and 7 and another for pole 2,4,6 and 8 [1].



a) side view b) cross-section view

Fig. 1 Construction of hybrid stepper motor

Length of each step can be calculated if number of rotor teethes are known-p. For hybrid stepper motor length of one seep is calculated from:

$$\text{Steep length}=\left(\frac{90}{p}\right)^{\circ} \tag{1}$$

Hybrid steeper motor has small steep, typically 1.8° and larger torque compared to variable-reluctance stepper motor. These two parameters can have a decisive advantage when there is an application with limited operating space.

3. Simulink Model Of Hybrid Stepper Motor

Hybrid stepper motor is operating due to electronically commutated magnetic field which enables rotor movement. All excitation windings are placed at stator while motor rotor is constructed of permanent magnet or soft magnetic material. In Fig. 2 is presented block diagram of motor simulation model constructed of three basic blocks: controller, driver and motor.

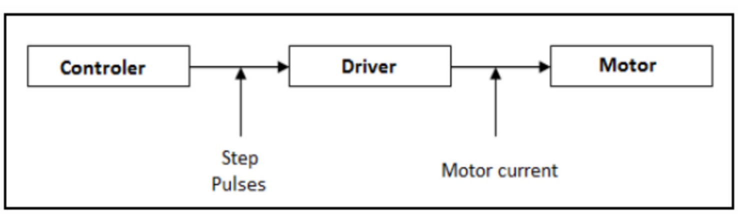


Fig. 2 block diagram of stepper motor

Simulink model from Simulink demo library is presented in Fig.3 and it is consisted of two sections: electrical and mechanical [4]. According to Simulik model motor input parameters are: phase voltage (A_+, A_-, B_+ and B_-) and mechanical load $-T_L$.

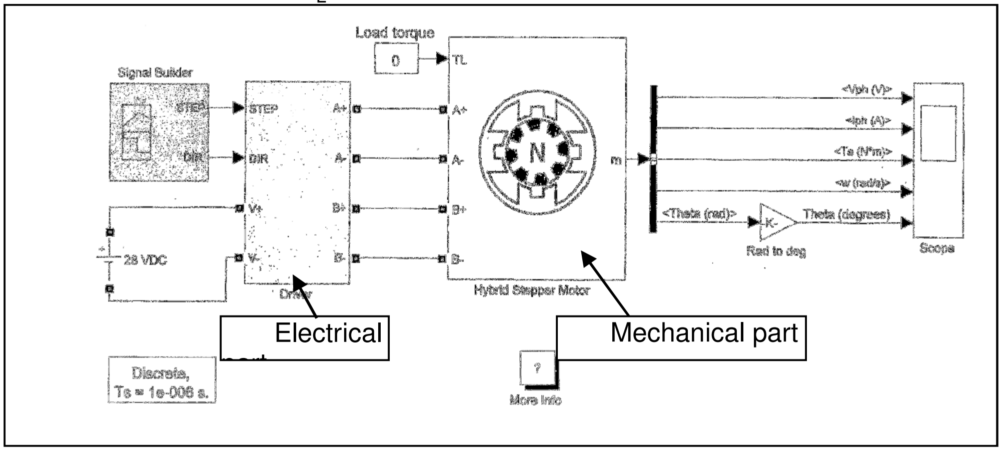


Fig.3 Simulink model of hybrid stepper motor

Output parameters from motor model are: phase current-I_{ph}, electromagnetic torque-T_e, rotor speed-w and rotor position-theta. Electrical part or motor control circuit is consisted of three functions entities: control block, hystersis comparator and MOSFET PWM converter (Fig. 4).

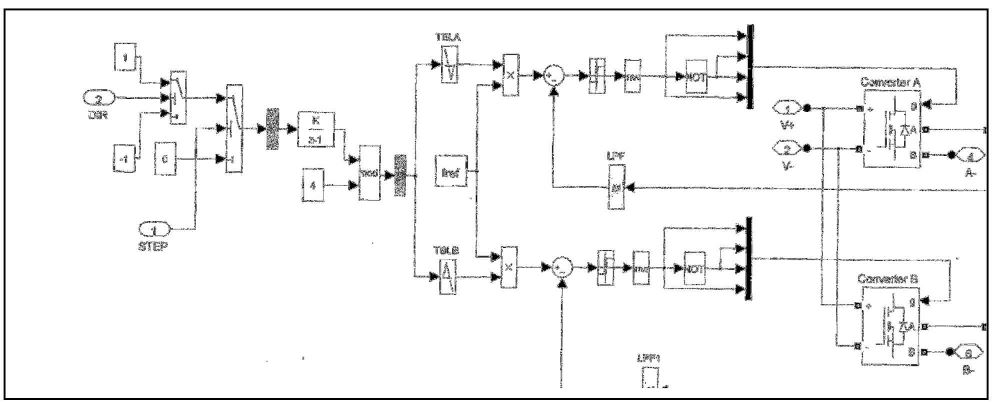


Fig. 4 Simulink model of control circuit

Motor movement is controlled by two signals: STEP and DIR which are output signals from block Signal Builder. Positive value (value of ‘1’) of signal STEP enables motor rotation while value ‘0’ stops the rotation. DIR signal controls the direction of motor rotation. Positive value (value of ‘1’) enables rotation in one direction while value of ‘0’ reverses the direction of rotation. Converter bridges “A’ and “B’ are H bridges consisted of four

MOSFET transistors. Bridges are supplied by 28 V DC and their outputs supply the motor windings with excitation current and enable the motor movement.

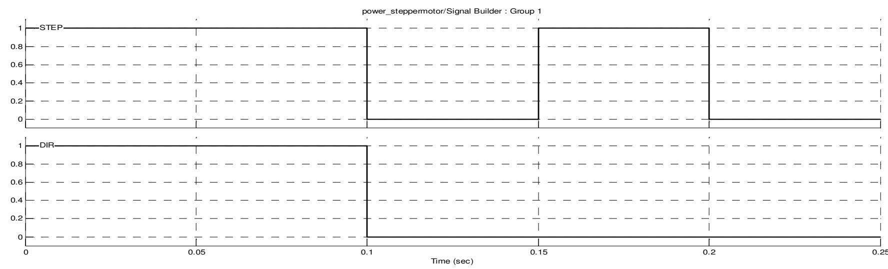


Fig. 5 Output signals from Signal builder block

4. Simulation results

After all motor parameters are input in motor model simulation is run. Time for simulation execution in is defined to be 0,25 seconds according to the signals from Signal Builder block and set time in Simulink model. First simulation is run at no-load operation or motor is running without any load. From the simulation results presented in Fig. 6 it can be concluded that motor is moving in one direction for 0,1 seconds (STEP=1 and DIR=1), stops in period from 0,1 to 1,5 s (STEP=0, DIR=0) 0,05 seconds is rotating in opposite direction (STEP=1, DIR=0) and again it stops for 0,05 seconds (STEP=0 and DIR=0). Motor transient performance characteristics are presented in Fig. 6 for no load operation.

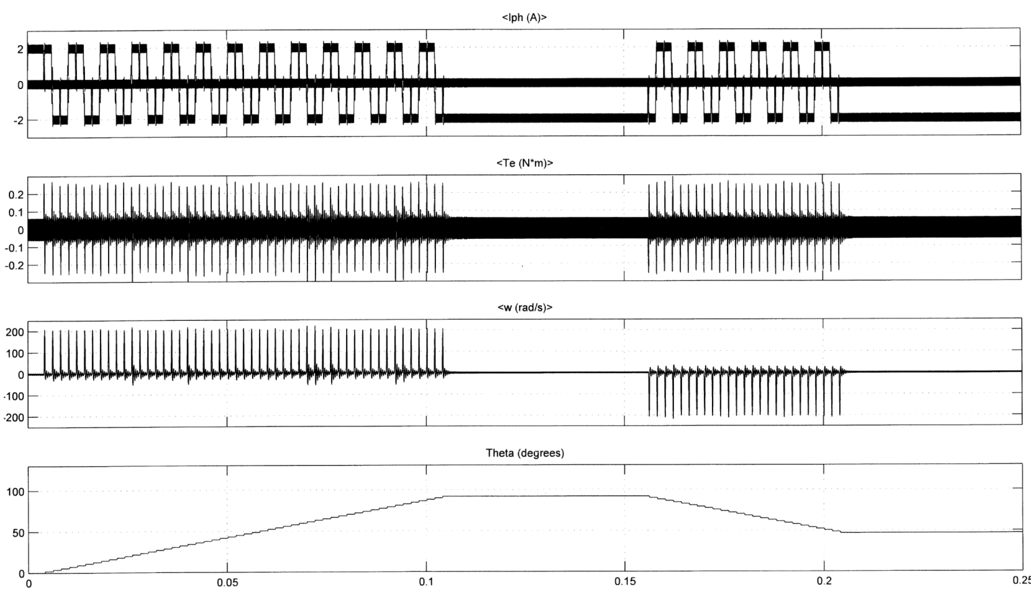


Fig. 6 Motor transient performance characteristics at no-load

With adequate zooming of presented results in Fig. 6 it can be noticed that motor has reached the speed of 200 [rad/s] and have moved from position 0° to 98 degrees. It remains in that position for 0.052 seconds before it starts for time of 0,156 to move in opposite direction and it stops for time of 0.204 seconds on position 47°. For case that load torque is increased to value of 0.1 Nm motor transient characteristics are presented in Fig. 7. In the same time motor moving sequence is changed by changing the values of step signal to 1 for 0-0.15 s, and from 0.2 to 0.25 s. In the interval between 0.15 and 0.2 its value is zero.

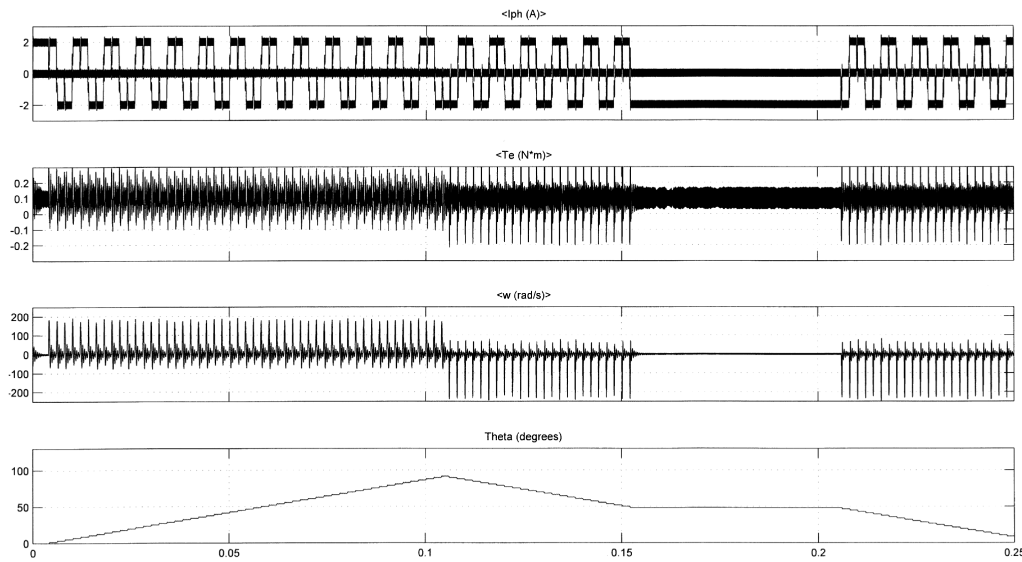


Fig. 7 Motor transient performance characteristics for load 0.1 Nm

From presented results in Fig.7 as it is expected there is a change in motor transient characteristic of electromagnetic torque. Its value is increased near to 0.1 Nm in order to be able to drive the load torque. For case that load is further increased to 0.4 Nm simulation results are presented in Fig. 8.

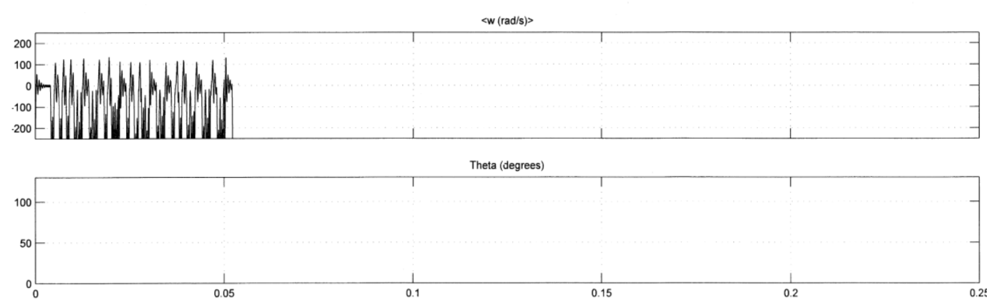


Fig. 8 Motor transient performance characteristics for overload of 0.4 Nm

Since applied external load is bigger than then motor electromagnetic torque motor is not capable to move the shaft coupled with the load so motor speed-w very shortly after the motor start is going to zero (0.05 seconds) and motor angle of movement is zero. In case that number of motor steps are changed from 500 steps/second into 150 steps/second at no-load operation, simulation results are presented in Fig. 9. From Fig.9 it can be concluded that steep length is bigger due to decreased number of steps, final step position is 25° in one direction and 13° in opposite direction.

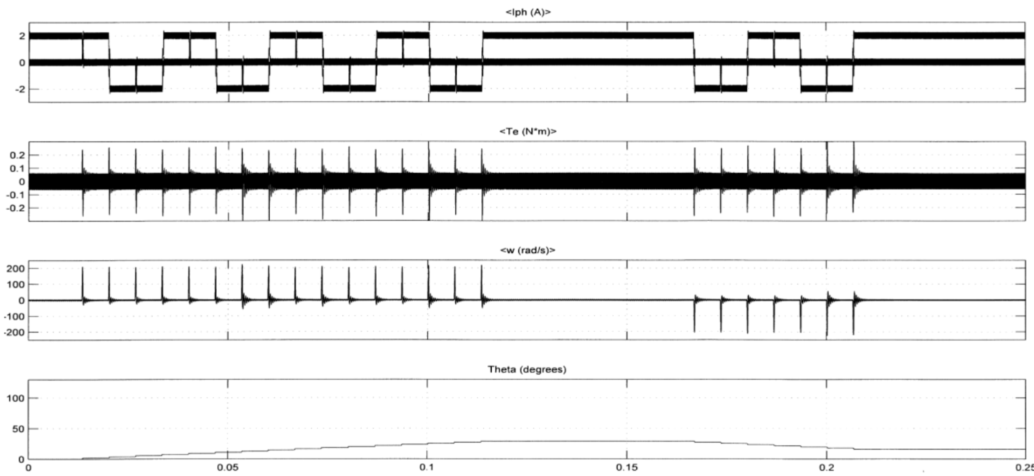


Fig. 9. Motor transient performance characteristics for 150 steps /second

5. Conclusion

Different simulation software packages during recent years have proved itself as a useful tool in analyses of electro engineering problems. Simulink with its extensive block libraries enables wide possibilities for electrical machines simulation. In this paper is analyzed simulation of hybrid stepper motor transient performance characteristics under different operating regimes: no-load, rated load and overload. Simulation results proved that motor is running in forward and backward direction according to the applied signals from PWM inverters to the excitation windings and only in case when applied load is smaller than motor electromagnetic torque. In case when external load is bigger than motor electromagnetic torque no rotor movement is achieved and motor speed is rapidly going to zero very shortly after motor start. Application of simulation packages has considerably improved electrical machines analysis replacing the expensive laboratory equipment and enabling performing of different experiments easy and with no cost.

5. References

[1] D.P. Atherton, G.W. Irwin, “Stepping Motors a guide to theory and practice”, 4th Edition, The institute of Enginering and Technology, 2007.

[2] Q.B. Al-Sabbagh, A.S. Mahdi, “ Pulse width modulation for high performance hybrid stepper motor, Journal of Engineering, Nr. 4, Vol.16, December 2010, p.p. 6028-6047

[3] W.H. Yeadon, A.W. Yeadon “Handbook of small electric motors”, McGraw Hill,2003

[4] Matlab/Simulink , User’s Manual, Mathworks 2007