Modelling and Control of an Open-Loop Stepper Motor in Matlab/Simulink

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***Abstract*—With the advent of increased industrial the automation and microprocessor applications, the interest in digital motion control systems has also expanded. Hybrid Stepper Motors are widely used in open-loop position applications. This article presents a description and a functional model of a hybrid stepping motor. The motor drive methods of full stepping and back stepping are presented in this paper. Test methods for system characterization are described and response characteristics for the simulated and experimental results are compared to verify the model. This paper shows that an open-loop stepping motor can be accurate simulation to predict real hardware performance.**

Keywords — hybrid stepper motor, simulation, model.

I. INTRODUCTION

Stepper motors are very important in process control, industries and instrumentation. The stepper motors enable precise control of the motor speed, angular position and direction of the motor rotation. They are capable of discrete exactly movements i.e. movements in precise steps so they are named as ‘stepper motors’. Stepper motors transform electrical energy into mechanical movement. Stepper motors are constructed as rotating or translating motors. Although stepper motor have been known for a long time, they have achieved their wide popularity in the last thirty years due to the development of electronics which enables the construction of cheap and reliable control circuits capable to satisfy complex requirements regarding a motor speed, torque and angular displacement. In order their transient performance characteristic to be analyzed Matlab/Simulink is chosen as a simulation tool and motor characteristics are analyzed under various 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, the 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 industries, instrumentation and have made them a replaceable moving force of industrial processes [3].

II. HYBRID STEPPER MOTOR CONSTRUCTION AND PRINCIPLE OF OPERATION

Hybrid stepper motors have a magnetic core which is excited by combination of electrical windings and a permanent magnet. Electrical windings are placed on the stator while the rotor is made of permanent magnets (Fig. 1). The number of poles at the stator are usually eight and each pole has from two to six 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].

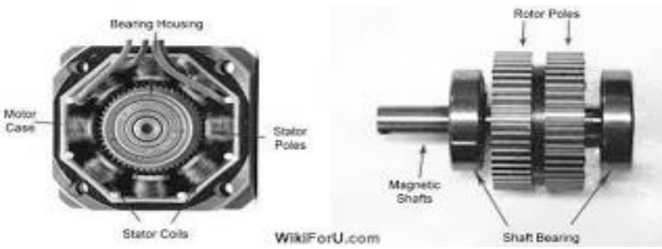

Fig. 1 Image at the hybrid stepper motor

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

$$\text{Steep length}=\left(\frac{90}{p}\right)$$

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

III. SIMULINK MODEL OF A HYBRID STEPPER MOTOR

The mathematical modelling equations for a hybrid stepper motor are given below. This is a dynamical model with differential equations. Equations (1) and (2) are the electrical equations and (3) and (4) are the mechanical equations of the hybrid stepper motor. The change in inductance, detent torque and magnetic coupling between the phases are neglected in this model.

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

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

$$\frac{dw}{dt}=\frac{K_m i_b\cos(N\theta)-T_i-K_m i_a\sin(N\theta)-K_v\omega}{J} \tag{3}$$

$$\frac{d\theta}{dt} = \omega \qquad (4)$$

Where i_b (A) is the current in phase B, i_a (A) is the current in phase A, u_a (V) is the voltage in phase A, u_b (V) is the voltage in phase B, T_L is the load torque(Nm), ω is the rotor speed(rad/sec) and Θ is the rotor position(rad). The subsystem of currents based on the motor equations (1) and (2). The subsystem of the speed and position based on the motor equations (3) and (4).

The hybrid stepper motor operates due to electronically commutated magnetic field which enables rotor movement. All excitation windings are placed at stator the while the motor rotor is made of a soft magnetic material.The block diagram of the motor simulation model consists of three basic blocks: a controller, a driver and a motor is presented in Fig. 2.

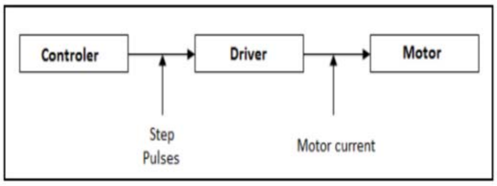

Fig. 2. The block diagram of stepper motor

Simulink model from Simulink demo library is presented in Fig.3 and it consists of two sections: electrical and mechanical [4]. According to Simulink motor model the input parameters are: mechanical load – T_l [N. m] and voltage per phase - V_{ph} [A] (A+, A-, B+ and B-). The output parameters of the motor model are: current per phase - I_{ph} [A], electromagnetic torque- T_e [N. m], rotor speed-w [rad/s] and rotor position –theta [degrees].Simulink model of the control circuit is presented in Fig.4.

The electrical part or the motor circuit includes three functions entities: a control block, a hysteresis comparator and MOSFET PWM converter. The motor phases are fed by two H-bridge MOSFET PWM converters are connected to a 28 V DC voltage source. The motor phase are currented independently controlled by two hysteresis-based controllers which generate MOSFET drive signals by comparing the measure currents and their references Square-wave current references are generated using the current amplitude and the step frequency parameters specified in the dialog window. Any motor movement is controlled by two signals: STEP and DIR which are output signals from a block signal builder. The positive value (value "1") of signal STEP enables motor rotation while value "0" stops the rotation. DIR signal controls the direction of the motor rotation. The position value (value "1") enables the rotation in one direction while value "0" reverses the direction of rotation. Converter bridges "A" and "B" are H bridge consisted of four MISFET transistors. Bridges are supplied by 28 V DC and their outputs supply the motor windings with excitation current and enable the motor movement.The output signals from a signal builder block is presented in Fig.5.

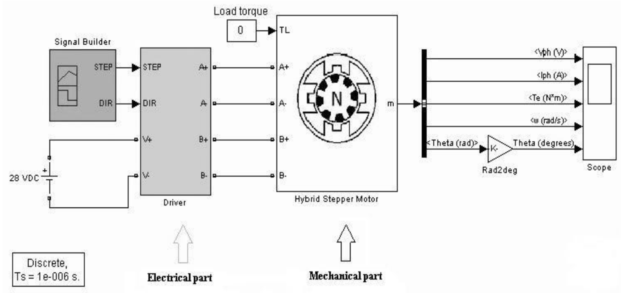

Fig.3. Simulink model of hybrid stepper motor

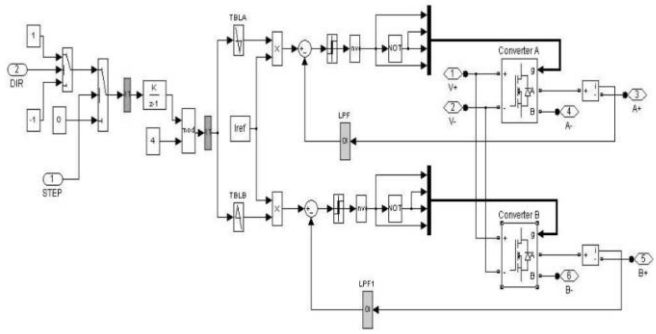

Fig .4. Simulink model of the control circuit

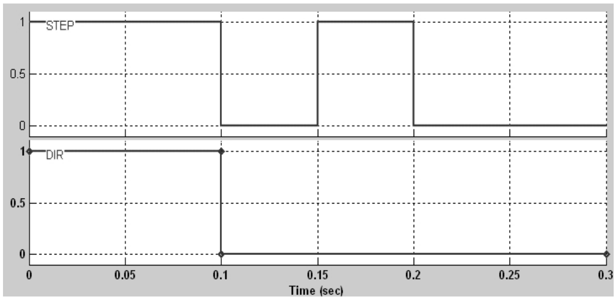

Fig .5 The output signals from a signal build block

IV. Simulation Results

After all hybrid stepper motor parameters are input in hybrid stepper motor model is run in the simulation. Time for simulation execution is defined to be 0, 3 seconds according to the signals from signal builder block and set time in simulink model. The first simulation is run in no-load operation or stepper motor is running without any load. From the simulation results is shown in fig.6 it can be concluded that stepper motor moves in one direction for 0,1 seconds (STEP=1 and DIR=1), it stops in period from 0,1 to 0,15 seconds (STEP=0,DIR=0),0,05 seconds is rotating in opposite direction (STEP=1 and DIR=0) and again it stops for 0,1 seconds (STEP=0,DIR=0). The hybrid stepper motor transient performance characteristics are presented in Fig.6 for no load operation.

The detailed waveforms are shown in Fig.7. With adequate zooming of the results presented in Fig.6 it can be noticed that the motor has reached the speed of 200 [rad/s] and has moved from position 0 to 38 degrees. It remains in that position for 0.05 seconds before it starts for time of 0.155 to move in opposite direction and it stops for time of 0,205 seconds on position 18 degrees. For case that the liad torque is increased to value of 0, 1 Nm stepper motor transient characteristics are presented in Fig 8.For case when the load is further increased to 0.4 Nm simulation results are presented in Fig.9. Motor transient performance characteristics for 150 steps/second are shown in Fig.10.

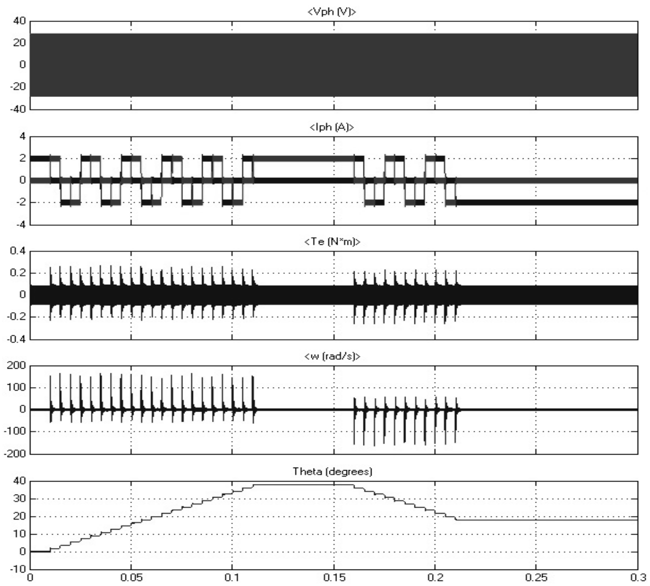

Fig. 6. Hybrid stepper motor transient performance characteristics at no-load

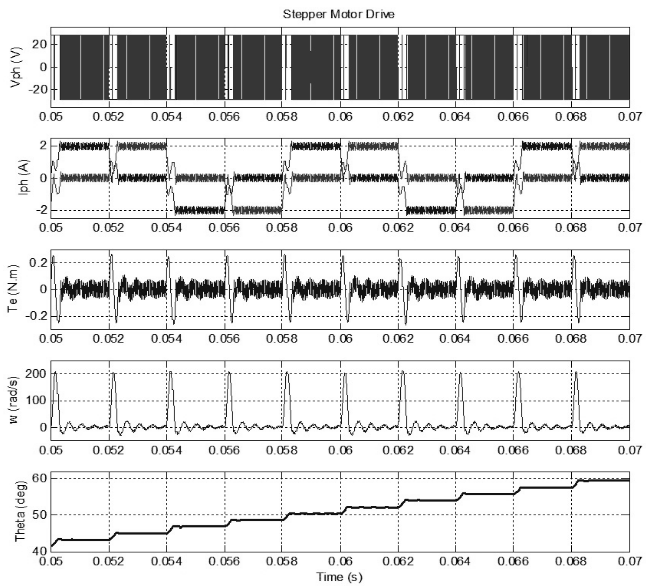

Fig.7. The detailed waveform

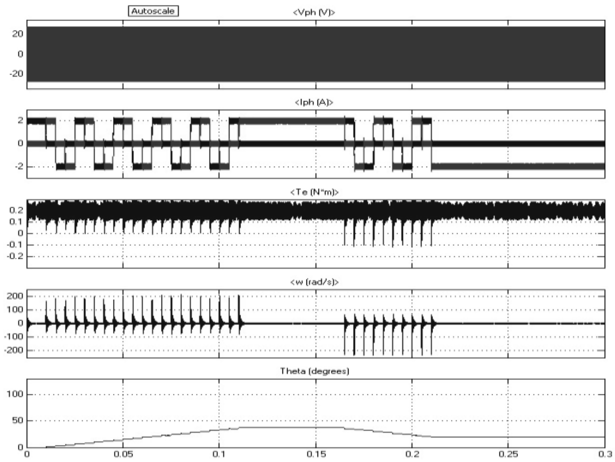

Fig.8. Hybrid stepper motor transient performance characteristics for overload of 0.1 Nm

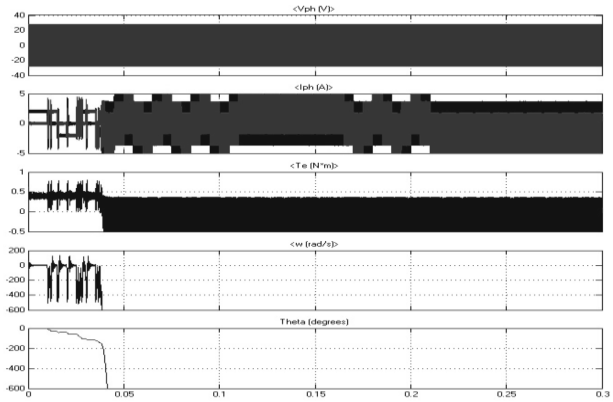

Fig. 9. Hybrid stepper motor transient performance characteristics for overload of 0.4 Nm

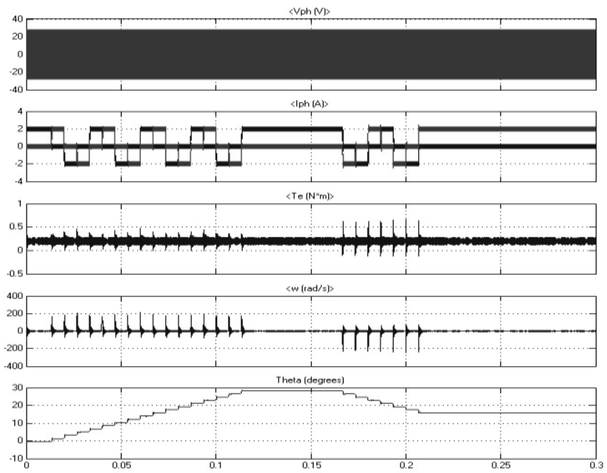

Fig. 10. Hybrid stepper motor transient performance characteristics for 150 steps/second

V. CONCLUSION

An open-loop hybrid stepping motor may be described by a set of equations. Model equations may be used to predict the system response of a stepper.The different simulation of softwares during recent years have proved itself as a useful tool in analysed of electro engineering problems. The simulink with its extensive block libraries enables wide possibilities for electrical machines simulation. In this paper is analyzed the simulation of hybrid stepper motor transient performance characteristics under different operation regimes: no-load, rated load and overload. The simulation results proved that the stepper motor runs 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 the external load is bigger than the stepper motor electromagnetic torque no rotor movement is achieved and the stepper motor speed is rapidly going to zero very shortly after motor starts .

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