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STUDY ON MODELLING AND SIMULATION OF PERMANENT MAGNET STEPPING MOTOR BY MATLAB/SIMULINK

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Abstract

The evolution of digital electronics and microcontroller systems has led to development of electrical motors capable to tee digitally controlled. These motors are widely known as stepper motors and the enable transformation of pulsed electrical excitation into mechanical energy. A model of the permanent stepper motor is simulated using Matlab/Simulink simulation software. The software is used as a simulation tool for bipolar permanent 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. The achieved results are in good accordance with the theoretical expectation and with the results of analytical computations. Adequate conclusions regarding motor performance characteristics are presented.

Key words: modelling, simulation, permanent magnet bipolar stepper motor, simulink, steping mode

1. Introduction

The stepper motor is an electromechanical actuator which converts the input pulse train into a precisely defined increment in the shaft position. Each pulse moves the shaft through a fixed angle, called step angle. Stepper motors have emerged as cost-effective alternatives for DC servomotors in high-speed, motion control applications, where the high torque is not required, with the improvements in permanent magnets and the incorporation of solid-state circuitry and logic devices in their drive systems. These motors are commonly used in measurement and control applications, such as positioning systems for NC machines, ink jet printers, robotics, computer peripherals, automotive devices and small business machines[1][2]. 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 [18] 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.

2. Permanent magnet stepper motor construction and principle of operation

A permanent magnet stepper motor has a cylindrical permanent magnet rotor. The stator usually has two windings [3] [4] [5]. The windings could be centre tapped to allow for a unipolar driver circuit where the polarity of the magnetic field is changed by switching a voltage from one end to the other of the winding. A bipolar drive of alternating polarity is required to power windings without the centre tap. A pure permanent magnet stepper usually has a large step angle. Rotation of the shaft of a de-energized motor exhibits detent torque: if the detent angle is large, say 7.5^o to 90^o, it is likely a permanent magnet stepper rather than a hybrid stepper. The construction of a permanent magnet stepper motor is considerably different from the drawings above. It is desirable to increase the number of poles beyond that illustrated to produce a smaller step angle. It is also desirable to reduce the number of windings, or at least not increase the number of windings for ease of manufacture.

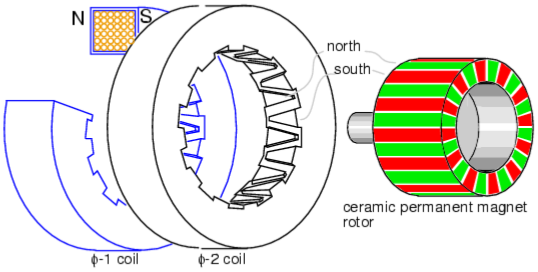

Fig. 1: Permanent magnet stepper motor, 24-pole can-stack construction

The permanent magnet stepper motor shown in Fig.1 , only has two windings, yet has 24-poles in each of two phases[6][7]. This style of construction is known as can stack. A phase winding is wrapped with a mild steel shell, with fingers brought to the centre. One phase, on a transient basis, will have a north side and a south side. Each side wraps around to the centre of the doughnut with twelve interdigitated fingers for a total of 24 poles. These alternating north-south fingers will attract the permanent magnet rotor. If the polarity of the phase were reversed, the rotor would jump $360^o/24 = 15^o$. We do not know which direction, which is not usefully. However, if we energize φ-1 followed by φ-2, the rotor will move 7.5^o because the φ-2 is offset (rotated) by 7.5^o from φ-1. See below for offset. And, it will rotate in a reproducible direction if the phases are alternated. Application of any of the above waveforms will rotate the permanent magnet rotor. Note that the rotor is a gray ferrite ceramic cylinder magnetized in the 24-pole pattern shown. This can be viewed with magnet viewer film or iron filings applied to a paper wrapping. Though, the colours will be green for both north and south poles with the film.

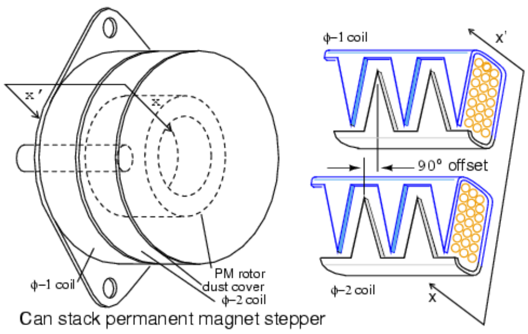

Fig. 2 : (a) External view of can stack, (b) field offset detail

Can-stack style construction of a permanent magnet stepper is distinctive and easy to identify by the stacked "cans" shown in Fig. 2. Note the rotational offset between the two phase sections. This is a key issue in making the rotor follow the switching of the fields between the two phases. Permanent magnet stepper motors require phased alternating currents applied to the two (or more) windings. In practice, this is almost always square waves generated from DC by solid state electronics. Bipolar drive is square waves alternating between (+) and (-) polarities, say, + V to - V. Unipolar drive supplies a (+) and (-) alternating magnetic flux to the coils developed from a pair of positive square waves applied to opposite ends of a centre tapped coil. The timing of the bipolar or unipolar wave is wave drive, full step, or half step.

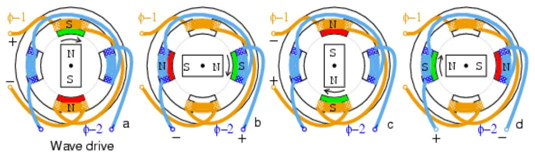

Fig. 3: PM wave drive sequence (a) φ_1+ , (b) φ_2+ , (c) φ_1- , (d) φ_2-

Conceptually, the simplest drive is wave drive [8] [9] shown in Fig.3. The rotation sequence left to right is positive φ-1 points rotor north pole up, (+) φ-2 points rotor north right, negative φ-1 attracts rotor north down, (-) φ-2 points rotor left. The wave drive waveforms below show that only one coil is energized at a time. While simple, this does not produce as much torque as other drive techniques.

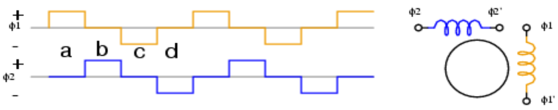

Fig. 4: Waveforms, bipolar wave drive

The waveforms shown in Fig.4 are bipolar because both polarities, (+) and (-) drive the stepper. The coil magnetic field reverses because the polarity of the drive current reverses. Full step drive provides more torque than wave drive because both coils are energized at the same time. This attracts the rotor poles midway between the two fields[10] [11].

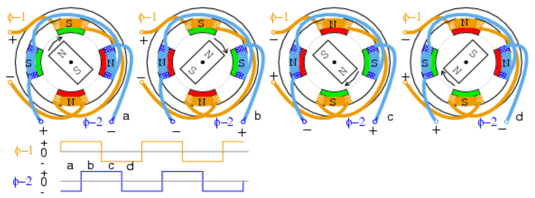

Fig. 5: Full step, bipolar drive

Full step bipolar drive as shown in Fig. 5, has the same step angle as wave drive[12][13][14]. The additional cost of bipolar drive is justified when more torque is required. The step angle for a given stepper motor geometry is cut in half with half step drive. This corresponds to twice as many step pulses per revolution. Fig. 6 shown half stepping provides greater resolution in positioning of the motor shaft [15][16]. For example, half stepping the motor moving the print head across the paper of an inkjet printer would double the dot density.

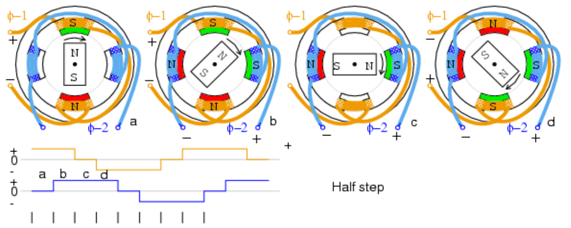

Fig. 6: Half step, bipolar drive

Half step drive is a combination of wave drive and full step drive with one winding energized, followed by both windings energized, yielding twice as many steps. The rotor aligns with the field poles as for wave drive and between the poles as for full step drive. Microstepping is possible with specialized controllers. By varying the currents to the windings sinusoidal many micro steps can be interpolated between the normal positions.

3. Permanent magnet stepper motor model

The permanent magnet stepper motor driver is simulated using MATLAB/Simulink`s SimPowerSystems simulation engine [17][18]. In Fig.7 is presented the block diagram of a permanent magnet stepper motor simulation model constructed of basic blocks: controller, driver and stepper motor.

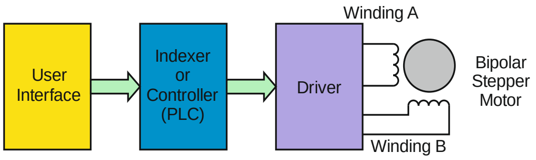

Fig.7: Block diagram of stepper motor simulation model

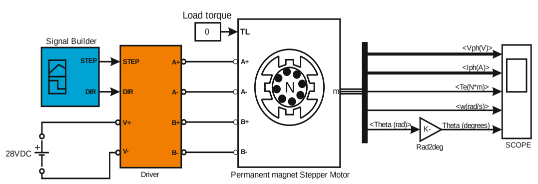

Fig.8: Simulink model of permanent magnet stepper motor

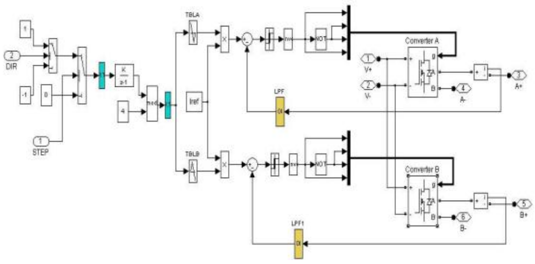

Fig. 9: Simulink model of control circuit

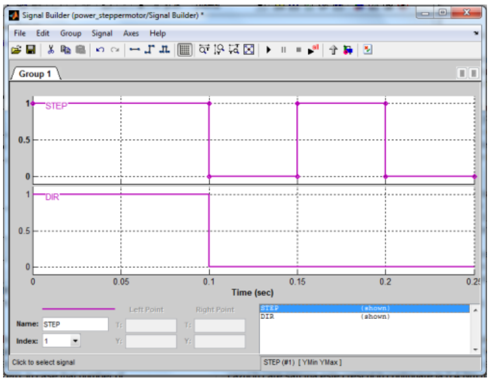

Fig. 10: Output signals from Signal Builder block

Simulink model from Simulink demo library is presented in Fig. 8 and it is consisted of two section: electrical part and mechanical part [17][18]. The electrical section is represented by equivalent circuit, configuration of which depends on the motor type. The equivalent circuits have been built with the supposition that the magnetic circuit is linear (no saturation) and the mutual inductance between phases is negligible. The mechanical section is represented by state-space model based on inertia moment and viscous friction coefficient. According to Simulink model motor input parameters are: voltage per phase – V_{ph} [V] (A_+, A, $B_{+,}$ B) and mechanical load torque – T_L[N·m]. Output parameters from 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 control circuit is shown in Fig.9.
Electrical part or motor control circuit is consisted of three functions entities: control block, hysteresis comparator and MOSFET PWM converter. The motor phases are fed by two H-bridge MOSFET PWM converters connected to a 28 V DC voltage source. The motor phase currents are independently controlled by two hysteresis-based controllers which generate the MOSFET drive signals by comparing the measured currents with their references. Square-wave current references are generated using the current amplitude and the step frequency parameters specified in the dialog window. Motor movement is controlled by two signals: STEP and DIR which are output signals from block Signal Builder. Positive value (value of "l") of signal STEP enables motor

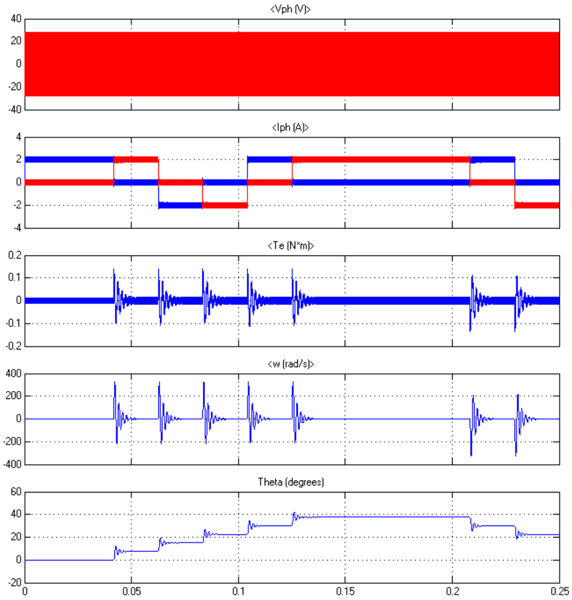

Fig. 11: Motor transient performance characteristics at no-load, up=7,5°, 48 steps / sec

rotation while value "0" stops the rotation. DIR signal controls the direction of motor rotation. Positive value (value for "l") 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. Output signals from signal Builder Block is shown in Fig. 10.

4. Simulation results

After all permanent magnet stepper motor parameters are input in permanent magnet stepper 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 stepper motor is running without any load. From the simulation results presented in Fig. 11 it can be concluded that stepper motor is moving in one direction for 0,1 seconds (STEP=1 and DIR=1), stops in period from 0,1 to 0,15 seconds (STEP=0, DIR=0), 0,05 seconds is rotating in opposite direction (STEP=1, DIR=0) and again it stops for 0,1 seconds (STEP=0, DIR=0). Permanent magnet stepper motor transient performance characteristics are presented in Fig.11 for no load operation. With adequate zooming of presented results in Fig.11 it can be noticed that motor has reached the speed of 48 [rad/s] and have moved from position 0° to 37,5 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 22,5°. For case that load torque is increased to value of 0,2 Nm stepper motor transient characteristics are presented in Fig.13. Motor transient perfprmance characteristics for 200 steps/second , no-load , is shovn in Fig. 12.

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 permanent magnet stepper motor transient performance characteristics under different operating regimes: no-load, rated load and overload. Simulation results proved that stepper 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 stepper motor electromagnetic torque no rotor movement is achieved and stepper motor speed is rapidly going to zero very shortly after motor start. All the obtained results for diverse regimes are in good accordance with the theoretical expectations and also with the results of analytical computations. 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.

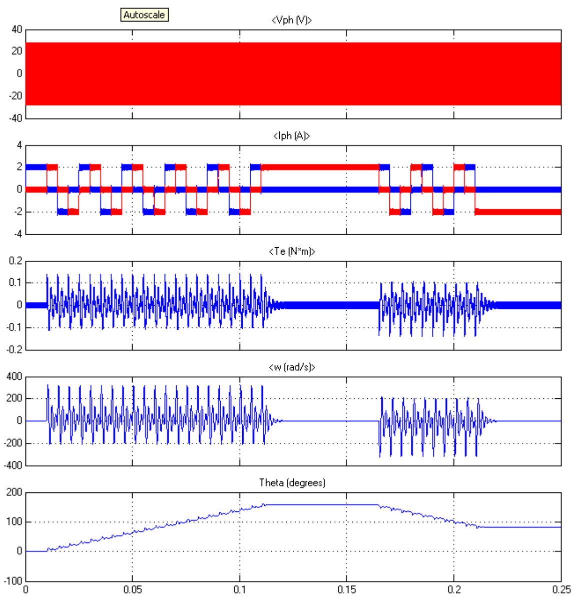

Fig. 12: Motor transient performance characteristics at no-load, θp=7,5°, 200 steps / sec

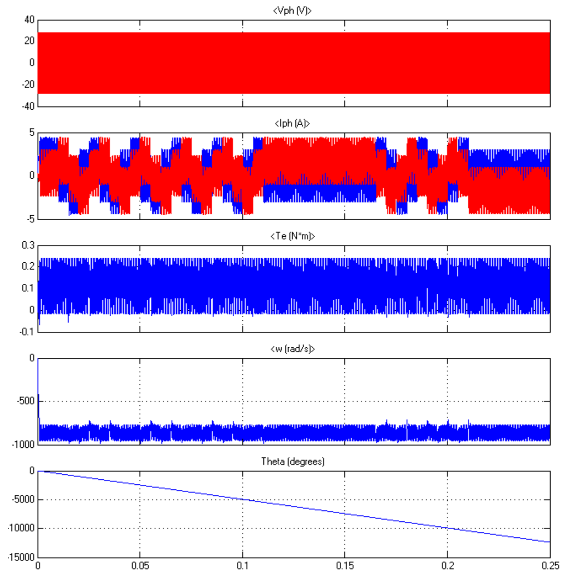

Fig. 13: Motor transient performance characteristics at 0.2 Nm load, θp=7,5°, 200 steps / sec

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