
Position Sensorless Drives of Permanent Magnet Motors for Military and Commercial Applications



The University of Michigan-Dearborn
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Annual Progress Report

Position Sensorless Drives of Permanent Magnet Motors for Military and Commercial Applications

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Synopsis

The permanent magnet (PM) motor drive is one of the fastest-growing, adjustable-speed motor control technologies, finding increasing applications in military, automotive, aerospace, computer, and home appliance industries. This is because of the PM motor's high torque, compactness, and high system energy efficiency. To control PM motors, rotor position sensors are used to provide the current commutation instants. However, when the position sensor is in a harsh environment, it can generate a wrong signal or no signal. The problems of the reliability of rotor position sensors need to be solved to enable further military and commercial applications.

Recently, in an effort to replace existing hydraulic and pneumatic devices with electric actuators, PM motors are increasingly being used by global defense companies such as Textron, Northrop Grumman, and Lockheed Martin for their military products. Since the PM motor drive, along with sensorless drive technology, is an important research topic for all electro-mechanical applications of the national defense industry based on the system reliability point of view, the proposed sensorless control scheme can be applied to various other military applications. Therefore, based on the outcomes of the proposed sensorless drive, technology transfers are expected to various electromechanical actuators used in military applications.

The research project has four objectives: (1) developing a complete sensorless PM motor drive test-bed to test new sensorless drive methods and emulate specific system applications to facilitate the implementation of sensorless drives; (2) developing a simulation model to expect and analyze experimental results; (3) providing an experimental platform for students in order to inspire insights into power electronics and motor drive applications; and (4) integrating research and teaching through student participation in research. The outcomes of the proposed research will enhance the university's research and education infrastructure.

1. Background

Among many different types of motors which operate on electro-magnetic principles, permanent magnet (PM) motors have outstanding characteristics for use as actuators in automated equipment; thus they are widely used in the military, aircraft, aerospace, power plants, automobiles, computers, and home appliances. This is because of the permanent magnet motor's high torque, compactness, and system energy efficiency. Recently, in an effort to replace existing hydraulic and pneumatic devices with electric actuators, many U.S defense companies have started to use PM motors for military applications such as aircraft, missile tail actuation systems, and gun turret drives in combat vehicles. However, the PM motor is inherently electronically controlled, and requires rotor position information for proper commutation of currents in its stator windings. Since the position sensors fail in harsh environments such as hot temperature, sophisticated position sensorless drive technology is needed for applications that require reliability. The reliability problems of rotor position sensors need to be solved to enable further military and commercial applications. Therefore, the position sensorless drives became a significant research topic in advanced control technology for various military and commercial applications.

2. Objectives

The main objectives of this project include (1) developing a simulation model to design the sensorless controller and to expect and analyze experimental results; (2) building a sensorless PM motor drive test-bed to test new sensorless drive methods and emulate specific system applications to propel external funding opportunities; and (3) providing an experimental platform for students in the Department of Electrical and Computer Engineering at the University of Michigan-Dearborn to provide insight into power electronics and motor drive applications.

3. Approach

Based on the given duty cycle and load torque characteristics of a specific target application, several sensorless control algorithms were tested to find the most suitable method for achieving the desired level of performance. The possible acceleration and position accuracy for the sensorless drive system with the duty cycle and load characteristics should be analyzed with a simulation first. A sensorless drive simulation model for PM motors should be developed to test the feasibility of the control methods. Then, an experimental test-bed will be built to confirm the simulation results, and to verify the implementation into a target application.

4. Results

The Matlab/Simulink-based simulation model was developed to evaluate the sensorless control scheme. Figure 1 shows the overall block diagram of the Simulink model.

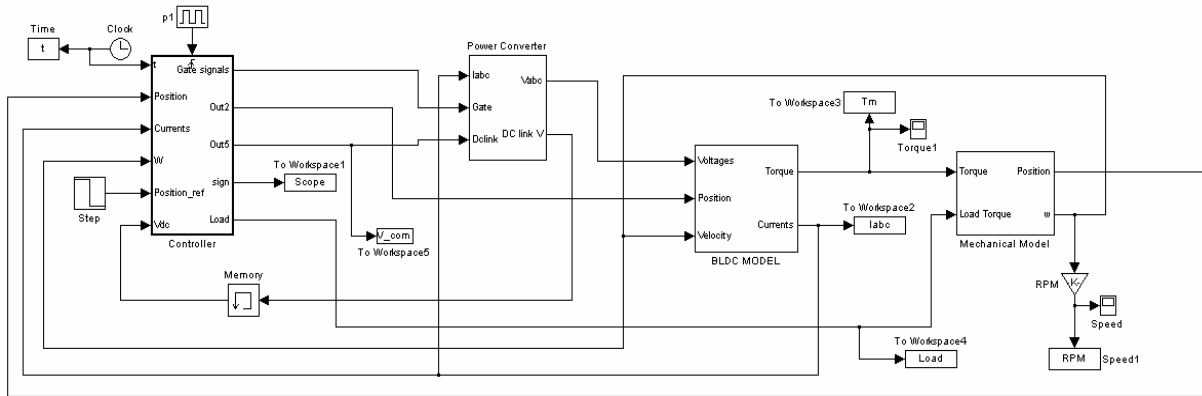


Figure 1. Developed Simulink model for PM motor drive.

The power converter, PM motor model, and mechanical models were created by Simulink blocks. However, the controller block was created using a Matlab function block that contains Matlab codes as illustrated in Fig. 2. The control algorithm developed by the Matlab code in the function block is same as the algorithm which will be implemented into a digital signal processor (DSP) in the experimental system. Figure 2 shows the inside of the controller block shown in Fig. 1. In the controller block, a fixed time step of 50 μ s is used in order to create a fixed sampling frequency of 20 kHz.

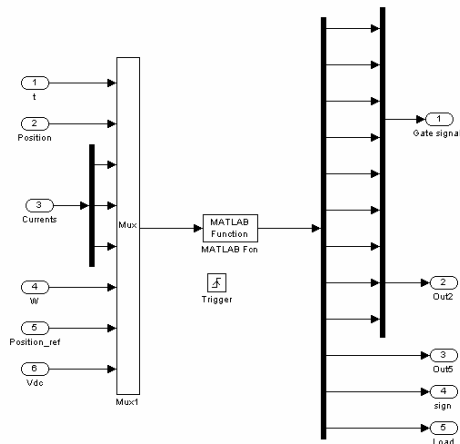


Figure 2. Inside of the “Controller” block.

Figure 3 shows the power converter block for three phase motors. Six switches and diodes are connected to compose a three-phase inverter. The outputs are three voltages which are phase to neutral point voltages. The outputs are used in the motor block as shown in Fig. 4.

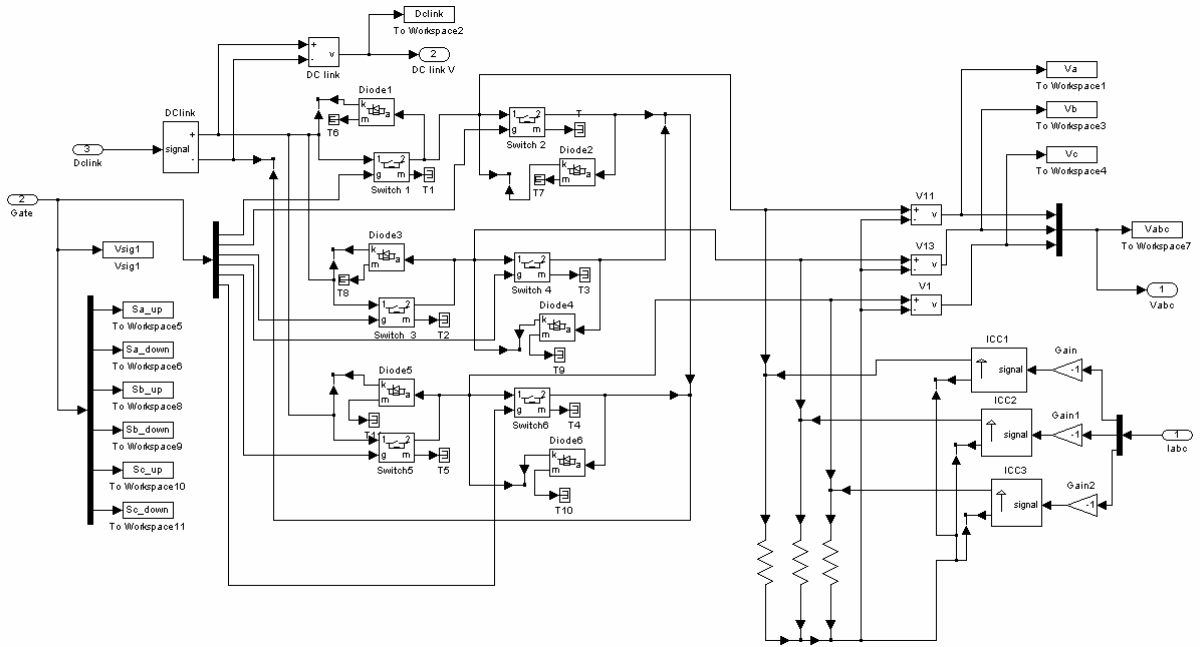


Figure 3. Inside of the "Power Converter" block.

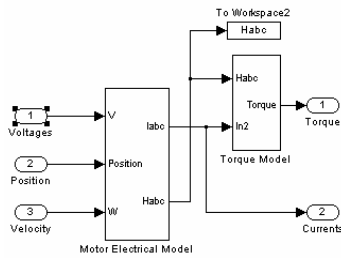


Figure 4. Inside of the "BLDC Model" block.
block.

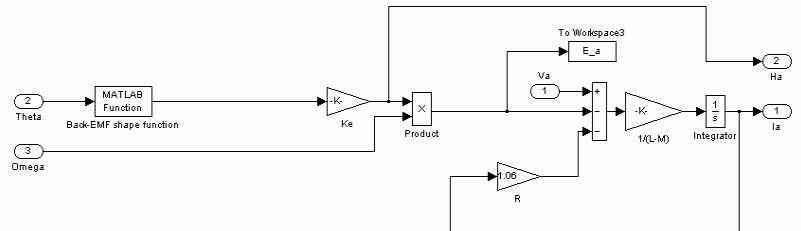


Figure 5. Inside of the "Motor Electrical Model" block.

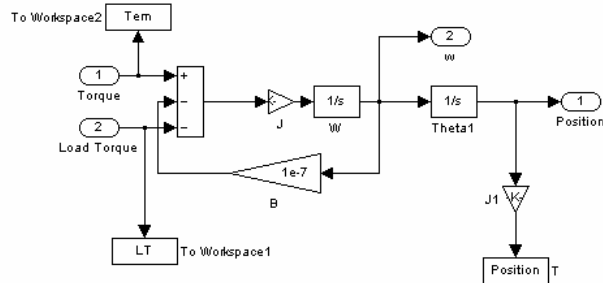


Figure 6. Inside of the "Mechanical Model" block.

In the motor model block, the motor back-EMF (electromotive force) is formulated based on the speed input and a Matlab function that generates the normalized back-EMF shape. The motor back-EMF is formulated using speed input and a Matlab function that generates the normalized back-EMF shape. Figure 6 shows the inside of the mechanical model block. The mechanical dynamic equations for PM machines are formulated using two integrators.

In the Matlab function block illustrated in Fig. 2, position (using the P controller) and speed (using the PI controller) are controlled based on the given position command. With the Simulink model developed, a simulation is performed with a step position command as shown in Fig. 7 to verify the model. Figures 7(a)-(f) show simulation results for motor position, speed, torque, current, and back-EMF waveforms.

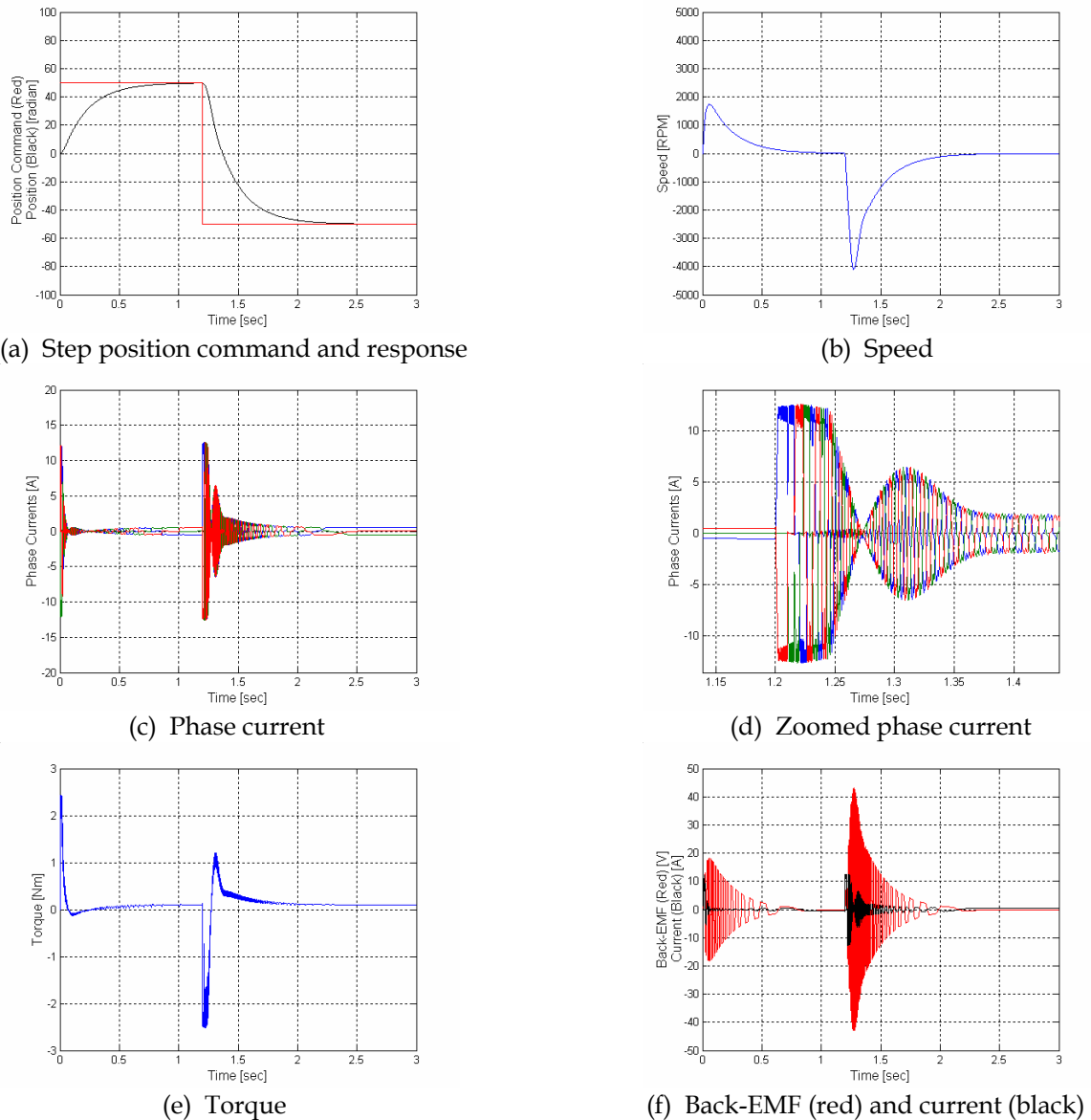
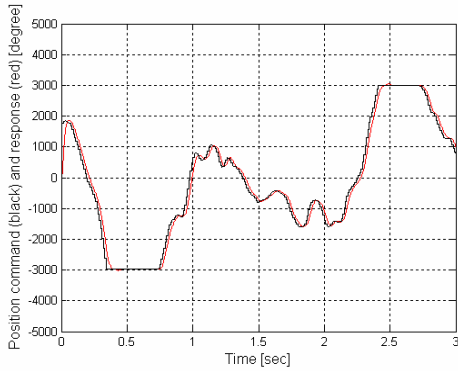
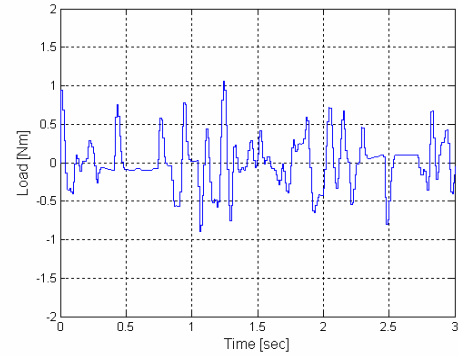


Figure 7. Simulation results with step position command.

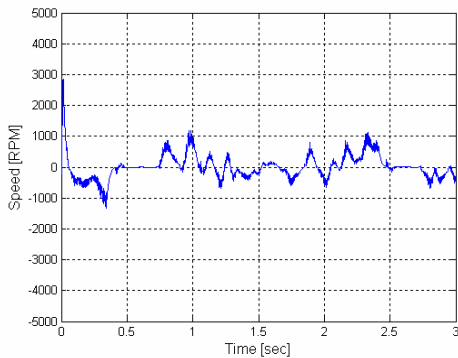
Also, Fig. 8 shows the simulation results with a duty cycle and load torque. It is seen that the motor follows the position command well with the given load. The sensorless algorithm will be implemented in the developed Simulink model for the PM motor drive. Also, the developed Simulink model can be further modified or updated based on experimental results. The experimental test bench and corresponding DSP software codes are being developed.



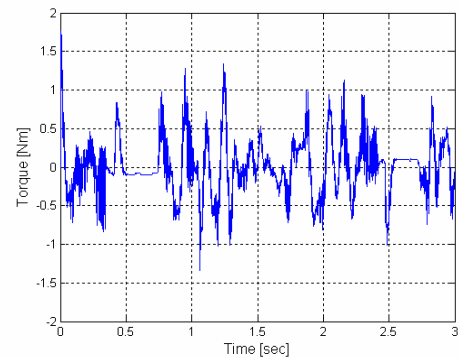
(a) Given position command and response



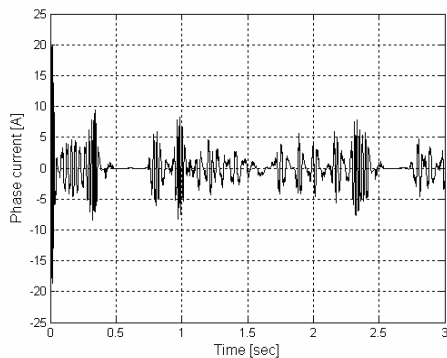
(b) Given load torque



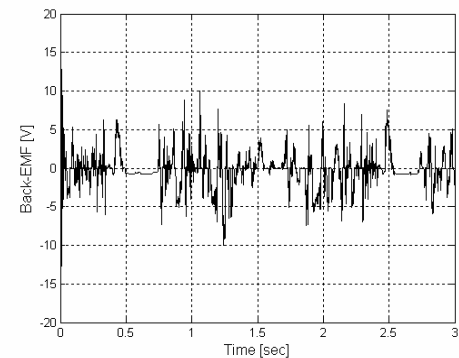
(c) Speed



(d) Torque



(e) Phase current



(f) Back-EMF

Figure 8. Simulation results with step position command.

Figure 9 shows the experimental test-bed built to evaluate the performance of sensorless PM machine drives. The next step of the project is to implement the sensorless control algorithm into the simulation model and prototype test-bed, which will be built during the first year of the project.



Figure 9. PM machine drive test-bed.

5. Conclusions

In this project, the sensorless PM motor drive is proposed. As a first task of the project, the PM machine drive is modeled and simulated. The simulation model can implement the sensorless drive algorithm using Matlab codes in a controller block. Therefore, the same sensorless control algorithm used in this simulation model can be directly implemented into a DSP (Digital Signal Processor) which is utilized in the actual system. This simulation model allows for the easy change of the model and control algorithm to test various sensorless control methods with different loads. The modeling and simulation results show the transient and steady state responses of the PM machine drive. The sensorless algorithm will be tested in the simulation model first for performance comparison, and will then be implemented in the experimental test-bed, which is being developed.

6. Impact

Educational

The proposed research can be integrated into several courses (ECE 415 Power Electronics, ECE 510 Vehicle Electronics, and ECE 532 Automotive Sensors and Actuators) as a good advanced application example. Also, the outcomes will bring new Capstone design projects. As a result, students will better understand advanced motor drives and their applications.

Industrial

In defense companies, the reliability issue is one of the most important research topics. Therefore, sensorless drive control will be a significantly important technology for all electro-mechanical applications in the national defense industry based on the system reliability point of view. As one of the other target applications, based on recent advancements in hybrid synergy drives for hybrid electric vehicles, PM motors are increasingly utilized as a traction motor/generator. The General Motors Corporation is already interested in position sensorless drives for PM motors as a back-up control technology if a position sensor fails during operation. Also, more electric vehicles nowadays need

variable speed electric compressor drives instead of using belts. In this case, due to the structural difficulties and temperature effect, position sensors cannot be implemented, and hence the senseless drive is required. Therefore, the outcomes of proposed sensorless control will attract various U.S. and international companies and agencies.

7. Acknowledgments

The financial support from the Henry W. Patton Center for Engineering Education and Practice at the University of Michigan-Dearborn is gratefully acknowledged. Also, the suggestions and help from Drs. John Cristiano and Roger Shulze are gratefully acknowledged.

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