Modeling and validation of brushless DC motor

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Abstract

A black box modeling for a Brushless Direct Current motor is developed and simulated based on real-time data. Taking a discrete time form for the system model, an ARX model structure was selected in this work. The real-time data acquired using a Contact Multimeter Probes via NI data acquisition system from a Brushless Direct Current motor. A Pseudo-Random Binary Sequence has been used as the input signal to determine the open-loop model of brushless motor at determined speeds. Input signal and measured data were interfaced to the plant via Matlab programming. Matlab toolbox was used to obtain the estimates model. The model validation was produced by model output plot which is comparing the input output and gives the percent best fit.

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1. Introduction

Brushless DC (BLDC) motors are one of the electrical drives that are rapidly gaining popularity, due to their high efficiency, good dynamic response and low maintenance. Since the late 1980's new design concept of permanent magnet brushless motors has been developed [1]. The permanent magnet brushless motor can be classified upon to the back-EMF waveform, where it can be operated in either brushless AC (BLAC) or brushless DC (BLDC) modes. Usually the BLAC motors have a sinusoidal back-EMF waveform and BLDC motors have a trapezoidal back-EMF [2]. In modern electrical machines industry productions the brushless direct current (BLDC) motors are rapidly gaining popularity. BLDC motors are used in industries such as Appliances, HVAC industry, medical, electric traction, road vehicles, aircrafts, military equipment, hard disk drive, etc. Comparing BLDC motors with DC motors, the DC motor have high starting torque capability, smooth speed control and the ability to control their torque and flux easily and independently. In the DC motor, the power losses occur mainly in the rotor which limits the heat transfer and consequently the armature winding current density, while in BLDC motor the power losses are practically all in the stator where heat can be easily transferred through the frame, or cooling systems can be used specially in large machines. In general the induction motor has many advantages as: their simplest construction, simple maintenance, low price and reliability. Furthermore, the disadvantages of induction machines make the BLDC motors more efficient to use and become more attractive option than induction motors. Some of the disadvantages of induction machines are poor dynamic characteristics, lower torque at lower speeds and lower efficiency.

The purpose of this paper is to derive a mathematical model based on ARX structure of a BLDC motor using a black-box modeling technique. Recursive Least Square technique will be used to estimate the parameters of the model. Finally the model is validated by plotting the output predicted by the model and comparing it with the measured output for the validation data set. The difference between the predicted model and the measured output is compute to determine its accuracy.

A simple modeling structure intended for control purposes that will be implemented with PID controller in the future work is presented.

2. Plant Description

For the implementation of the online identification, the BLDC plant is set up. The BLDC motor is mounted on a plate in order to position it. The BLDC motor drives by dc power supply of 14 to 32Vdc. It has 0 to 4000 rpm motor speed. 1Vdc is equivalents to 1000rpm. The input is transmitted to the motor through NIDAQ by sending 0 to 4 volt signal. Motor shaft is attached with a round plane with a white sticker to capture speed. Motor speed is captured through the Optical Multimeter Probes. The working optical range is 50 to 1000mm with ±45 degree angle. The overall speed range is 100 to 60 000 rpm. It has an accuracy ± 0.5% with ±1.5mV resolution. All the input and output data is simulated using Matlab toolbox. The BLDC motor plant set up as shown in Figure 2.

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3. Model Development

The System Identification problem is to develop an ideal model of a plant based on observed input-output data. The general procedure to determine a model of a dynamical system from observed input-output data involves three bases;

1. The input-output data
2. The model structure
3. The identification method

.Once all the data have been captured .The data processed using Matlab identification toolbox.

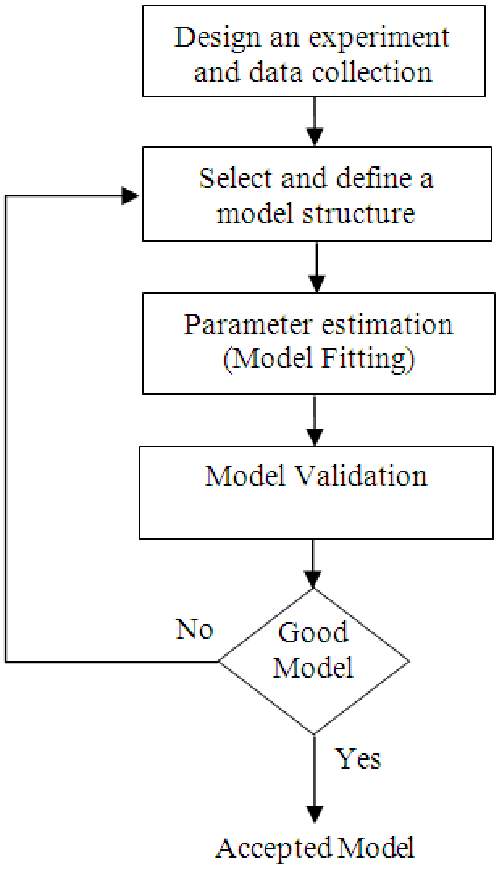


Figure 1: System identification flow chart

1. *Design an experiment and data collection* – the purpose of the experiment is to collect several set of data that describe how the system behaves over its entire range of operating operation. The idea is to vary the input and observe the response of the output.
2. *Select and define model structure* – Select model structure to find the best model structure.
3. *Parameter estimation* – The model fitting used to measured the percent of acceptance and selects the best fit of model.
   Repeat the process and compare it to the second order structure to evaluate the best model.
4. *Model validation* – after a model has been estimated it must be evaluated to investigate whether or not it meets the necessary requirement.
   Repeat the process until good model is achieved.

Excitation Signal

A Pseudo Random Binary Sequence (PRBS) signal with Maximum Length Sequences (MLS) characteristics was selected as the input signal injected to the plant for identification purposes. PRBS state can change only at discrete intervals of time, Δt which is also known as bit interval. PRBS sequence is periodic with period, T=N*Δt where N= sequence length.

Pseudorandom binary sequence can be generated by means of a serial-input shift register with feedback using exclusive-OR gate. The signal is not truly random because the sequence repeats itself every 2^n-1 bit intervals for an n-bit shift register.

The sequence length is related to the number of registers through the following equation:

$$N = 2^n - 1 \qquad (2)$$

where n is the number of registers.

As a rule of thumb in designing the PRBS signal, the clock period Δt is normally chosen to be approximately in the range of a fifth to a half of the output response time constant, i.e.

$$\Delta t = (0.2 \text{ to } 0.5) \times T_C \qquad (3)$$

5. Experimental Set Up

The computer is interfaced to the BLDC motor and the speed sensor captured trough NIDAQ card. A Matlab program is written to generate the PRBS signal that excites the signal send to motor. See Figure 2.

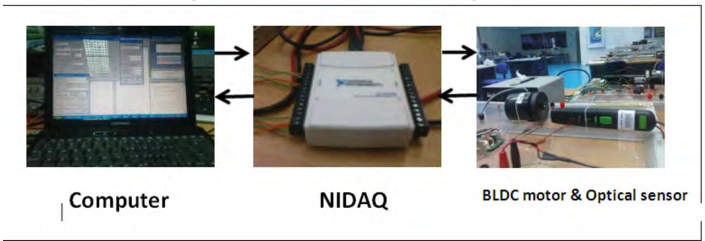


Figure 2: Experiment activities

In this experiment, a PRBS signal used during data collection for BLDC motor modeling at speed 3000 rpm. Figure 3 shows the PRBS signal sent to the BLDC motor from the computer.

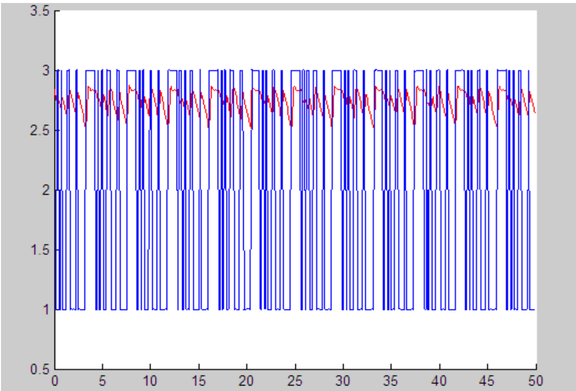


Figure 3: PRBS signal sent to the BLDC motor

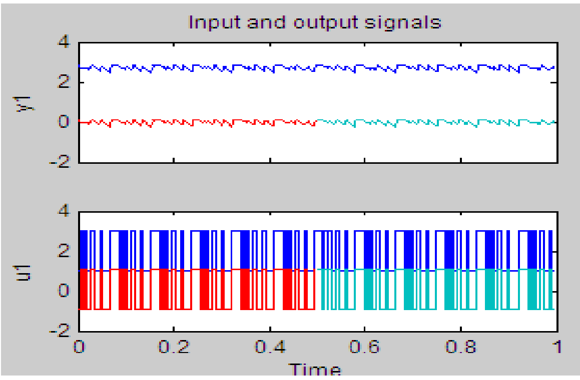


Figure 4: Input and output signal

The data collected being import into Matlab identification toolbox to simulate the model structure.Figure 5 shows the Matlab identification toolbox.

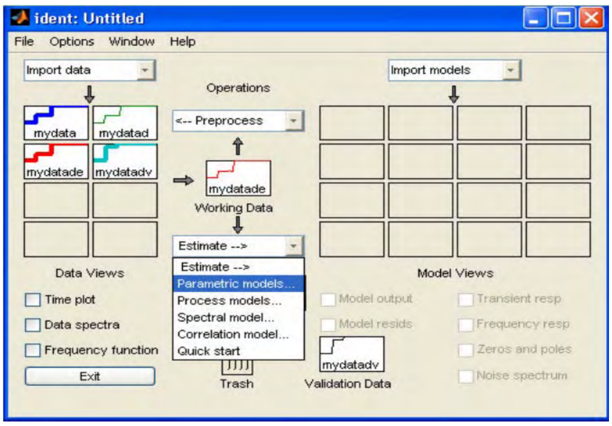
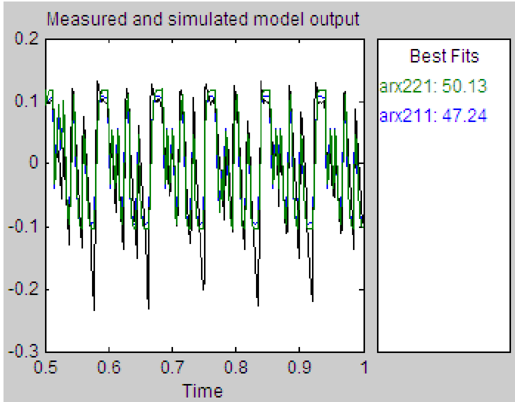


Figure 5 :Matlab IdentificationToolBox

5. Experimental Result

The data used in the toolbox was processed for two model structure.They are [2 2 1] orders represent 2nd order model structure and [2 1 1] orders that represent PID model structure.Figure 6 shows the comparison on model structure fitting.



Figur

figure 6: Model Fitting

Figure 7 shows the final comparison for measured and simulated output.It shows the 2nd order model structure gives 50.13% fit compared to the PID model structure for 47.24% best fit.These show the 2nd order model is better than PID model.The model structure and value obtained from the Matlab data/model toolbox .Figure 6 shows the value and the model structure.

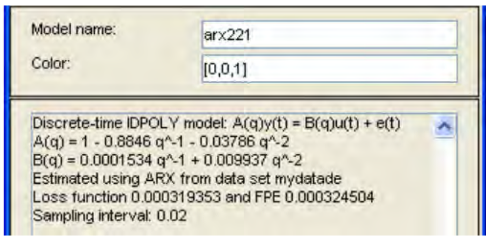


Figure 7: Model structure.

$$y(t) = \frac{0.0001534z^{-1} + 0.009937z^{-1}}{1 - 0.8846z^{-1} - 0.03786z^{-2}} u(t)$$

6. Conclusions

In this work, the development of basic linear model of the BLDC motor has been presented. The model was successfully derived using black-box modeling technique via Matlab toolbox. The model developed will be used in designing the controller for BLDC motor. This is the preliminary study for the recursive PID control system.

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