

## PARAMETER ESTIMATION OF BRUSHLESS DC MOTOR USING EXPERIMENTAL METHODS

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**ABSTRACT:** Parameter estimation of any physical system is essential in order to simplify the process of designing the controllers and analyzing the system's performance. In many cases, the estimation through an experimental approach is more favorable since the parameters are obtained using the real-world-conditions setup. This is important to validate the result obtained using simulation to ensure the parameter variations is kept within the acceptance limit. Even if there is a variation, one can simply identify the source of the discrepancies. However, without the experimental approach, the outcome from simulation could potentially lead the result to the wrong path, since it only consider the ideal condition and ignores the setup error as well as product variations. Hence, in this paper, it is proposed that, the parameter estimation of BLDC motor is not only obtained experimental method but also compare using simulation and CAD approaches. Such parameters are line-to-line resistance ( $R_{l-l}$ ), line-to-line inductance ( $L_{l-l}$ ), line-to-line back EMF constant ( $K_e$ ), torque constant ( $K_T$ ), viscous friction coefficient  $B$  and rotor's moment of inertia  $J$ . In the experiment the value of  $J$  and  $B$  are filtered using Least Square Method (LSM) and compute the transfer function of the BLDC motor. Finally, the result in a form of transfer function is compared against the simulation and CAD methods and found to be comparable.

**KEYWORDS:** *Parameter estimation; Brushless motor, Least Squares Method and Transfer function*

## 1.0 INTRODUCTION

The fundamental concept of parameter estimation is to determine optimal values of parameters for a numerical model that predicts dependent variable outputs of a function, process or phenomenon based on observations of independent variable inputs (Majoros, W.H, 2008). Parameter estimation provides effective approach to obtain the mathematical models of a complex system that is usually hard to derive based on the physics laws. In the case of brushless direct-current (BLDC) motors (P/N:A2212/13T 1000KV), the physical parameters include line-to-line resistance  $R_{l-l}$ , line-to-line inductance  $L_{l-l}$ , line-to-line back EMF constant ( $K_e$ ), torque constant ( $K_T$ ), viscous friction coefficient,  $B$  and rotor's moment of inertia  $J$ . Those parameters can be obtained either through experimental measurement or simulation using curve fitting technique to obtain the best estimation from the experimental data. Recently, several algorithm based methods for BLDC motor's parameter estimation have been introduced with common aim that is to reduce the estimation error. For example, the Gradient Search (GS) algorithm utilize the steepest descent approach is used to minimize the identification error, the stochastic state estimation requires set of parameters which are considered to be the unknown state of the system and is estimated by using a Kalman filter. Lastly, the Least Squares (LS) algorithm (A. Björck, 1996), is widely used in linear time invariant systems with minimum least square error (S.S. Saab & R.A. Kaed-Bey, 2001). Comparing with simulation based parameter estimation, the result of the experimental approach includes the environment factors with acceptable instrument errors. Hence, the cross-validation between simulation based and experimental based parameter estimation can ensure the parameter variation is keep within acceptance tolerance.

Over the years, many researches has been conducted to compute system parameter experimentally using different methods. In another research (J. Kuo and T. Wang, 2007) torque constant measurement is determined by using a torque test apparatus-based measuring system. However, this approach involving torque test apparatus that are suffering from the well-known noise and offset drift problems that leads to inaccuracy of the results (J. Wu, 2012). Under those circumstances, a rather simple method that utilizes LS estimation can be used which can helps to save cost without compromising the result. Although classic least square approximation method require large numbers of data to interpret, it is selected for its efficiency and simplicity (S.S. Saab & R.A. Kaed-Bey, 2001). Therefore, in this paper we propose that the estimation of BLDC motor parameters using experimental approach in conjunction with LS method.

## 2.0 METHODOLOGY

The experimental approach in determining BLDC motor's parameters is discussed in this paper. The parameters estimated using MATLAB system identification toolbox® as well as modelling using SolidWorks®. The value of  $R_{l-l}$ ,  $L_{l-l}$ ,  $K_e$ ,  $B$ , and  $J$  are found to be 0.40  $\Omega$ , 26 $\mu$ H, 0.0083 V.s/rad, 0.0144 N.m/A, 3.14x10<sup>-6</sup> N.m.s and 2.71 x10<sup>-6</sup> kg.m<sup>2</sup> respectively. Next, those values are substituted into the general form of BLDC motor's transfer function. In this experiment, the speed profile of BLDC motor is obtained when various input voltage are supplied that generates different speeds. From the velocity profile, mechanical time constant,  $\tau_m$  is obtained for the deceleration of the BLDC motor from its initial steady speed to its 36.8% of speed when voltage supply is cut-off. For a no-load BLDC motor, the load torque  $T_L=0$  When current supply is cut-off, the electrical torque becomes zero,  $T_e=0$ , hence. A generic diagram for a BLDC motor is shown in Figure 1 below.

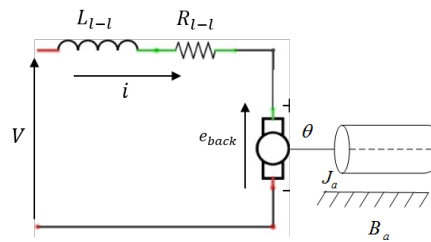


Figure 1 : Schematic diagram of of BLDC motor (single phase).

Using Kirchoff's Voltage Law (KVL) for the circuit and the motor mechanism, the electrical torque,  $T_e$  generated by BLDC motor can be determined using Eq.(1).

$$V = R_{l-l}i + L_{l-l} \frac{di}{dt} + e_{back} \quad \text{and} \quad T_e = B\omega + J \frac{d\omega}{dt} + T_L \tag{1}$$

where  $e_{back}$  = back emf and  $T_L$  = Load Torque

Combining two equations in Eq.(1) and using Laplace transform, a transfer function of the BLDC motor can be obtained as in Eq. (2).

$$G(s) = \frac{\omega}{V} = \frac{K_T}{A \cdot s^2 + B \cdot s + C} \tag{2}$$

(where,  $[A = J \cdot L_{l-l}] [B = R_{l-l} \cdot J + B \cdot L_{l-l}] [C = R_{l-l} \cdot B + K_e \cdot K_T]$

(where,  $K_T$  – torque constant,  $K_e$  – emf constant,  $L_{l-l} \cdot R_{l-l}$  .]

Since  $K_T$ = Torque constant,  $K_e$ = EMF constant,  $L_{l-l}$ = line inductance,  $R_{l-l}$ = line resistance are obtained through calculations, that leaves us with on two variables J and B represents in the state space in Eq.(3)

$$[B \ J]^* = \left[ \begin{matrix} \theta_1 & \ddot{\theta}_1 \\ \theta_2 & \ddot{\theta}_2 \\ \vdots & \vdots \\ \theta_m & \ddot{\theta}_m \end{matrix} \right]^T \left[ \begin{matrix} \theta_1 & \dot{\theta}_1 \\ \theta_2 & \dot{\theta}_2 \\ \vdots & \vdots \\ \theta_m & \dot{\theta}_m \end{matrix} \right]^{-1} \left[ \begin{matrix} \theta_1 & \ddot{\theta}_1 \\ \theta_2 & \ddot{\theta}_2 \\ \vdots & \vdots \\ \theta_m & \ddot{\theta}_m \end{matrix} \right]^T \begin{bmatrix} i_1 \\ i_2 \\ \vdots \\ i_m \end{bmatrix} \tag{3}$$

Rotor's moment of inertia, J and Viscous coefficient, B can be estimated from the mechanical time constant,  $\tau_m$  and  $K_T$  of the speed profile. The setup for this experiment is as shown in Figure 2 below.

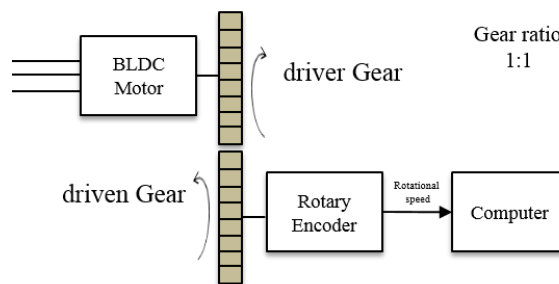


Figure 2 : Experimental setup to determine the BLDC motor's speed ( $\omega = \frac{d\theta}{dt}$ ) measured using a rotary encoder.

The Values of initial rotational speeds, mechanical time constant, viscous coefficient constant, and rotor's moment inertia are listed in Table 1.

Table 1: Values of initial rotational speeds, mechanical time constant, viscous coefficient constant, and rotor's moment inertia

No.	Initial speed, $\omega$ (rad/s)	$\tau$ (s)	$B$ ( $\times 10^{-6}$ N.m.s)	$J$ ( $\times 10^{-6}$ kg.m <sup>2</sup> )
1	261.8	0.333	5.03	1.66
2	285.6	0.333	4.90	1.63
3	349.0	0.422	4.24	1.79
4	392.7	0.538	3.77	2.03
5	448.7	0.714	3.48	2.49
6	486.2	0.809	3.21	2.60
7	523.6	0.863	3.14	2.71

### 3.0 RESULT AND CONCLUSION

Based on th the transfer function obtained from the experiment amd two other methods known as CAD modeling and MATLAB system identification toolbox are as follows.

Experimental using LS method,

$$G(s) = \frac{119.2}{5.83 \times 10^{-7} \cdot s^2 + 0.008976 \cdot s + 1}$$

CAD modelling using Solidwork,

$$G(s) = \frac{119}{4.79 \times 10^{-7} \cdot s^2 + 0.007374 \cdot s + 1}$$

MATLAB System Identification toolbox,

$$G(s) = \frac{120.2}{5.72 \times 10^{-7} \cdot s^2 + 0.00881 \cdot s + 1}$$

The result obtained from the experiment is consider accurate and successful which is very close to the result obtain using MATLAB identification toolbox considering the MATLAB System identification toolbox is the reliable method.

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