Model-based Analysis for Experimental Parameter Identification of Micro DC Motor

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Abstract

For effective designs of a servo state controller with a observer of a micro DC motor, a mathematical model with its parameters is to be known precisely under operating conditions. A deep understanding of system parameters and how they affect dynamical performance is crucial. This paper deals with theoretical analysis and experimental simulation of the micro DC motor in real-time environment by using Simulink/xPC target toolbox. The work focuses on the system integration aspect of a mechatronic system and emphasizes this with hands-on laboratory exercises in high-speed data acquisition of millisecond scale. Theoretical analysis reveals parameter determination of the micro DC motor. The micro DC motor dynamics identified in this paper is experimentally verified from incorporation in the modeling and parameter identification of a motion system.

Keywords: Parameter Identification, micro DC motor, State Controller/observer, xPC Target/Simulink

1. Introduction

In recent years, it can be obviously seen that micro DC motors have become a viable choice for various motion control applications from electrical appliances to robots in industry. Therefore, the servo performance of the micro DC motor is required tightly. To fulfill this obligation, the control design is crucial. Servo state feedback control with state observer is one of the most effective and practical methods in modern control design [1]. For example, the research of Leephakpreeda[2] shows challenging attempts to implement a servo state feedback controller with observer for a sensorless DC motor drive. Furthermore, much active research in this area has been interested in this servo control method [3,4]. However, this method requires a mathematical model including its system parameters, which represent the actual dynamics of the micro DC motor around operating conditions. Unfortunately, all/some quantitative system parameters of the micro DC motor may be unknown or even if they are given, they may be, at different operating conditions from the specification sheets from manufacturing companies.

This main work intensively contributes on the model-based analysis for the parameter identification of the micro DC motor at desired operating conditions via implementing a commercial data acquisition package with Simulink/xPC target toolbox in laboratory exercises. This concept can be applied practically and economically for other research and development of micro DC motors in general.

It should be noted that there are other relevant identification algorithms of modeling dynamic systems from experimental data. However, those model structures are commonly based on the differential (or difference) equations of input/output data only [5-7]. Therefore, those goals are to approximate the unknown black box with a mathematical model.

For example, The first-order plus integrator and delay transfer function was used as the mathematical model of the servo DC motor[8]. In [9], the technique used a recursive least square to identify the Auto Regressive Moving Average (ARMA) parameters of the transfer function of the DC motor. On the other hand, the mathematical model in this study has been derived from the physical principles including parameters of physical properties.

2. Experiment setup

In real time implementation of Simulink/xPC target toolbox [10], there are two computers required for "host" and "target" as shown in Fig. 1. The host computer is used for programming/embedding design while the target computer is used for performing data acquisition according to such predetermined command. In aspect of software, Simulink, developed by The MathWorks™, provides a graphical block diagramming environment interfaced with a customizable set of block libraries such as xPC target. The xPC target yields the I/O driver blocks, which are connected to sensors and actuators. In this work, the data acquisition board in the target computer was implemented from PCI-DAS 1200 A/D board of Computer Boards, Inc. Fig. 2 shows the experiment setup with a micro DC motor. The rotor speed was measured by built-in tachometer and the armature current was measured by non-contact milliammeter of F. W. Bell Inc.

3. Methodology

Micro DC motors are widely used to convert electrical energy into mechanical work. Fig. 3 depicts a schematic diagram of a typical micro DC motor in terms of electromechanical components where v is the terminal voltage, i is the armature current, ω is the angular speed of the rotor, R is the armature resistance, L_i is the armature inductance and J is the rotor inertia. This study assumes that the magnitude of the back electromotive force (EMF) is proportional to the angular speed of the rotor and the magnitude of the torque of the micro DC motor is proportional to the armature current.

The governing differential equations describing the dynamic behavior of a micro DC motor [1] is written as:

$$L_i \frac{di}{dt} = -Ri - K_v \omega + v \qquad (1)$$

$$J \frac{d\omega}{dt} = K_\tau i - D\omega - \tau \qquad (2)$$

where K_v is the back EMF constant, K_τ is the torque constant, D is the damping constant and τ is the external torque.

From Eq. (1) and (2), the parameters R, D, K_v and K_τ can be determined by freely running the micro DC motor in steady state at desired operating conditions. With this, Eq. (1) and Eq. (2) can be reduced to:

$$v = Ri + K_v \omega \qquad (3)$$

$$K_\tau i = D\omega \qquad (4)$$

Eq (3) can be solved for two unknowns, R and K_v, from measurement data of armature current i and angular speed ω, which are observed at different supply voltages v. However, under noise disturbance, if more than two experiments may be needed, then the leasts square technique can be implemented instead. It is a fact that the value of the back EMF constant K_v equals the value of the torque constant K_τ in SI units. Finally, the value of the damping constant D can be obtained by solving Eq. (4).

The values of the armature inductance L_i and the rotor inertia J dictate the transient responses of the micro DC motor. In order to determine these parameters, the following procedures C1 and C2 have been done as:

C1: Let the rotor to be camped $(K_v \omega = 0)$ and the resistance R_o is added in order to obtain its voltage measurements v_o so that the step response can be obtained. Fig. 4 shows the electrical schematic diagram of the micro DC motor in this condition.

Hence, Eq. (1) becomes:

$$v = L_i \frac{di}{dt} + Ri + v_o \qquad (5)$$

The analytical solution of Eq. (5) is:

$$\ln\left(1-\frac{v_o(t)}{v_o(\infty)}\right) = -\left(\frac{R+R_o}{L_i}\right)t \qquad (6)$$

where $v_o(\infty)$ is the value of v_o at steady state.

It should be noted that the value of the armature inductance L_i can be determined from the slope of linear function in Eq. (6).

C2: The circuit of the micro DC motor is open suddenly after the DC motor is free running. This action causes a decay of the angular speed of the rotor. Eq. (2) can be expressed as:

$$J\frac{d\omega}{dt} + D\omega = 0 \qquad (7)$$

The analytical solution of Eq. (7) is:

$$\ln(\frac{\omega(t)}{\omega(0)}) = -\frac{D}{J}t \qquad (8)$$

where $\omega(0)$ is the angular speed of the rotor at initial state.

The slope of the linear model in Eq. (8) yields the value of the rotor inertia J.

4. Results and discussion

In this work, measurements of the rotor speed ω, the terminal current i and the voltage v_o are required to identify the parameters of the micro DC motor. Programming commands in Simulink with xPC target toolbox on Windows was implemented as shown in Fig. 5.

First, the micro DC motor in steady conditions was tested by regulating the different terminal voltages. The corresponding angular speeds and the armature currents were recorded in Table 1.

By applying the least squared error technique to Eqs (3)-(4), the values of the armature resistance, the back EMF constant, the torque constant, and the damping constant were obtained and reported in Table 2.

Experimental results of the condition C2 is presented with the plot of angular speed of the rotor against time in Fig 6. The terminal voltage was set at 2 V, 3 V and 4 V before it was cut off. It was observed that the speed of the rotor reduces to zero magnitude within a few seconds. Fig. 7 shows the linear relations given in Eq. (8) with experimental data in Fig 6. From Eq. 8, the slope can be used to determine the moment of inertia. The result of calculation for the rotor inertia is given in Table 2.

In the condition C1, the rotor of the DC motor was camped as mentioned earlier. The additional voltages v_o were measured when terminal voltages were supplied at 2 V, 3 V and 4 V. However, it was observed that the transients of the additional voltage occurred very shortly even through the sampling time of the data acquisition system is 0.1 ms. As results, there were only a few data points. Therefore, the Simulink block of the first-order linear filter with the passband edge frequency of 5 rad/s was used to obtain more points of data. The plots of the additional voltages against time are illustrated in Fig. 8. As expected, the additional voltage v_o increases and approaches the steady state condition accordingly.

The data of the plots in Fig. 8 were substituted in Eq. (6). The linear relations can be obtained as shown in Fig. 9.

The value of the armature inductance can not be directly determined from the slope of the linear relation in Fig. 9 since the influences of the first-order linear filter was incorporated into the transients of the additional voltage. However, the value obtained can be used as initial guessed value of the armature inductance. To obtain the actual value, an iterative optimization technique in Simulink was performed by searching the value of the armature inductance in Eq. 6 and then passing the results through the same filter in Simulink. Sequentially, the value of the armature inductance can be determined from the best fits of the simulation of plots as seen in Fig. 10. The smooth curved lines indicate the resultant performance of the proposed model with obtained parameters and the non-smooth curved lines are represented as the actual measurements of the additional voltage in Fig. 8. Simulation results show the fitted curve of the responses with the corresponding armature inductance obtained and listed in Table 2.

The obtained parameters in Table 2 with the mathematical model from Eqs. (1)-(2) are verified with the actual responses of the micro

DC motor in Fig. 11. The simulation results are fitted very well to the actual responses of the micro DC motor.

5. Conclusion

The proposed model-based analysis for parameter identification can be implemented to determine the parameters of the micro DC motor via data acquisition package of Simulink/xPC target toolbox. The viability of the methodology is confirmed by reliable agreement between the simulation results and the experimental measurements of the responses of the micro DC motor.

It is challenging for future research that the values of the parameters can be changed once other operating conditions are specified. The adaptive approach to parameter identification may be introduced, then.

6. Acknowledge

Author would like to thank Iddhi Thansuriya for assistance on experiments.

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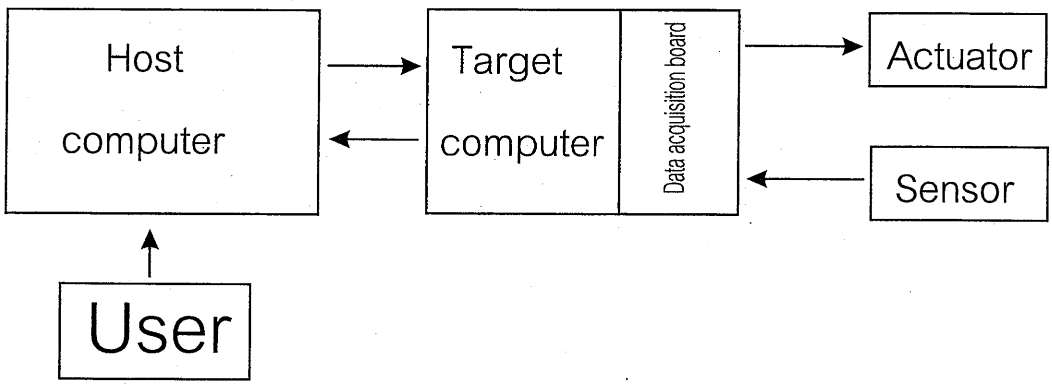

Fig 1. Diagram of host-target connection.

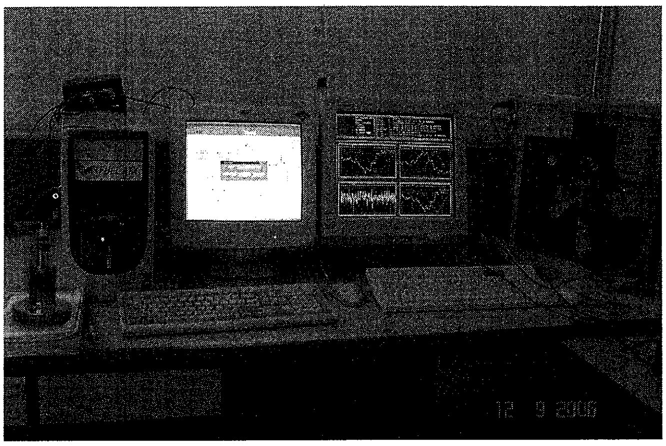

Fig 2. Experiment setup.

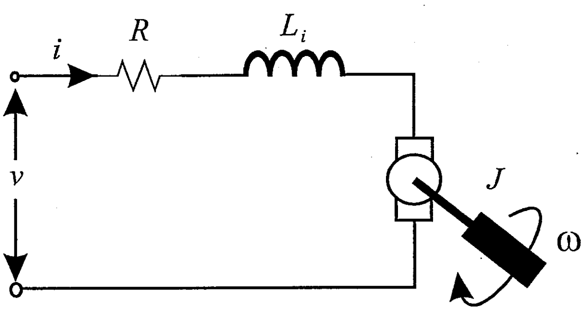

Fig 3. Schematic diagram of micro DC motor.

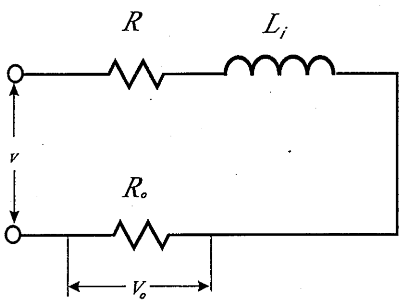

Fig 4. Circuit diagram with additional resistance.

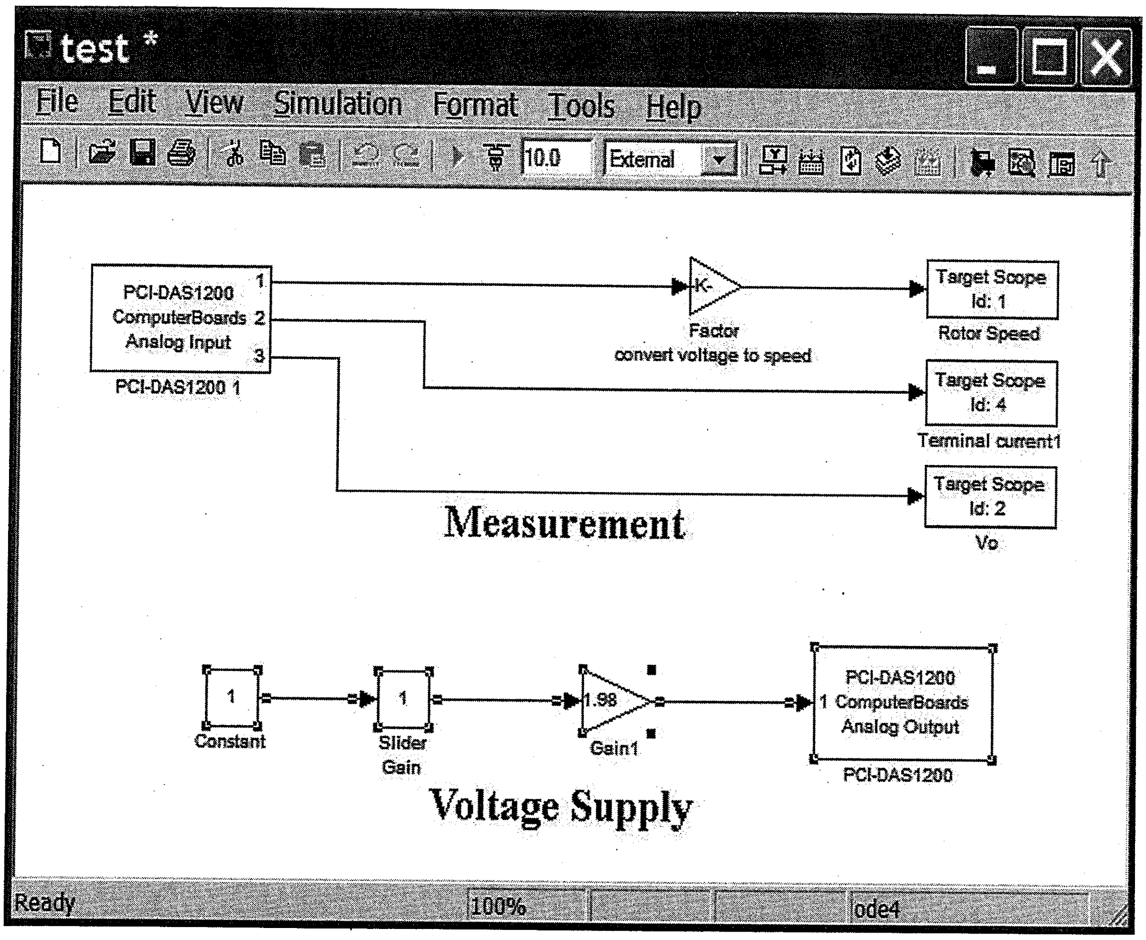

Fig 5. Flow diagram in Simulink/xPC target toolbox.

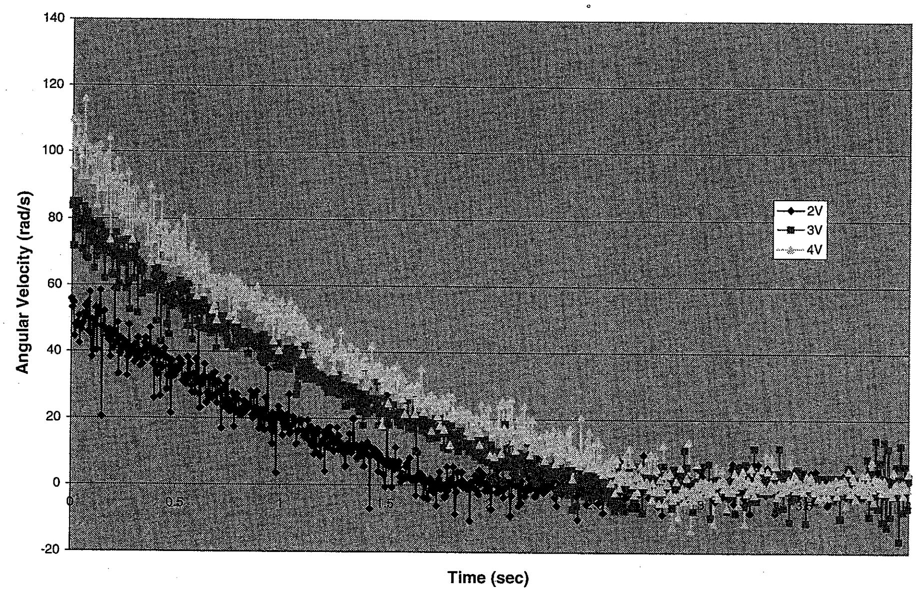

Fig. 6 Plots of angular speed against time.

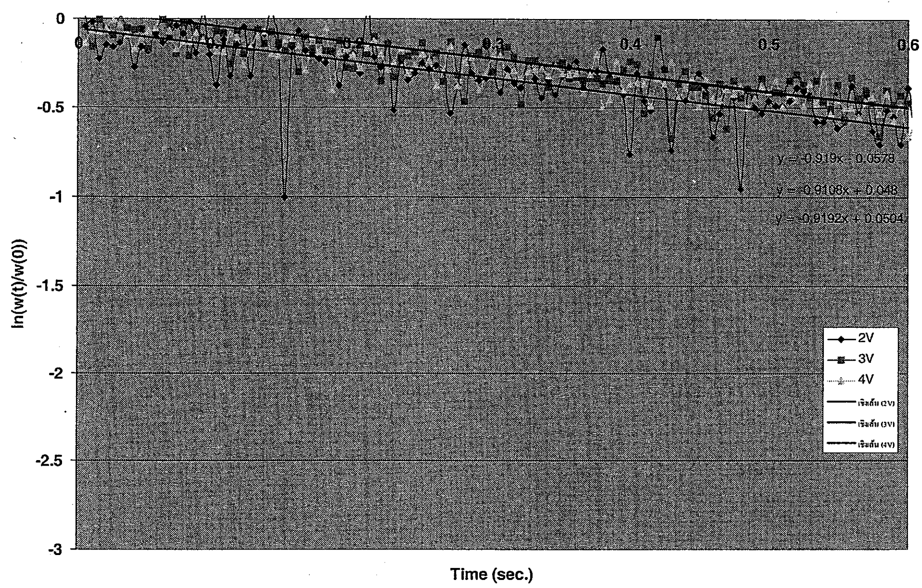

Fig 7. Linear relations based on Eq. (8).

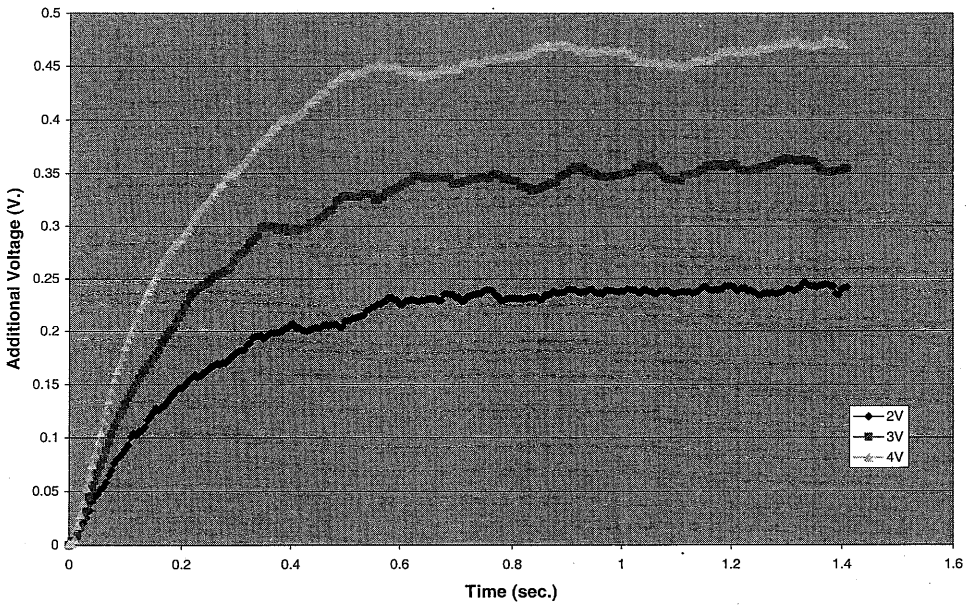

Fig 8. Plots of additional voltage against time.

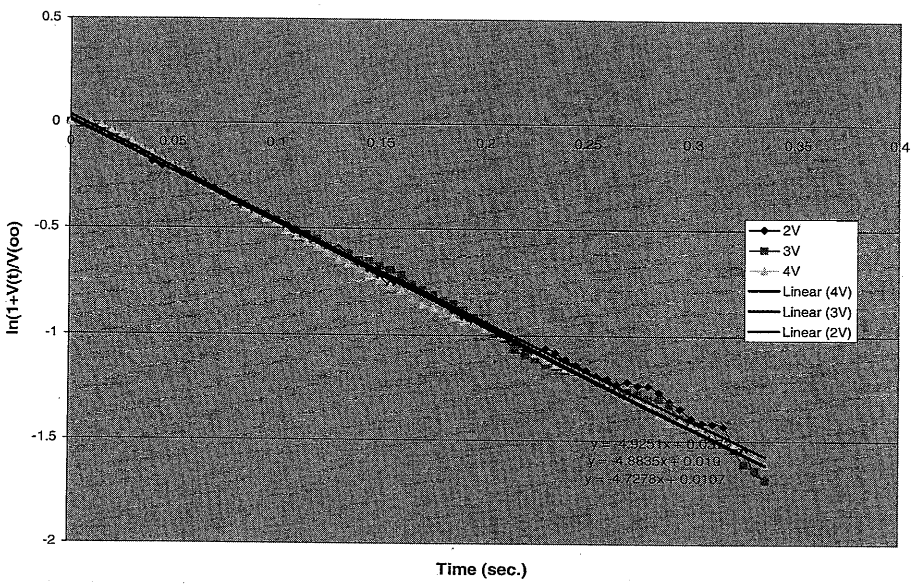

Fig 9. Linear relations based on Eq. 6.

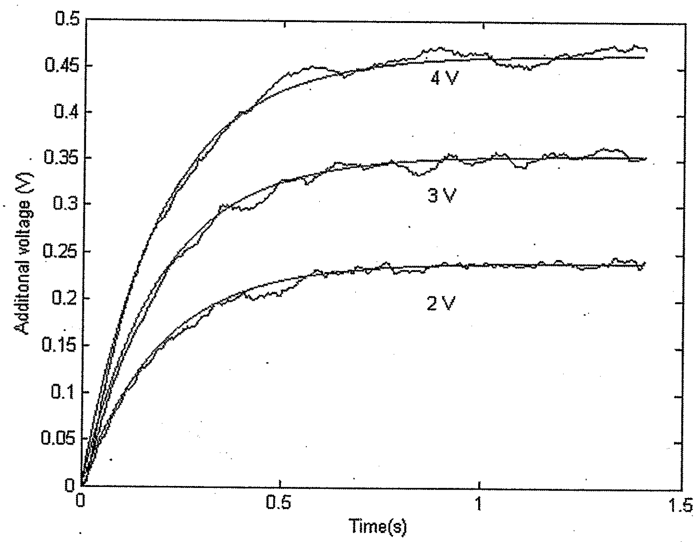

Fig 10. Simulation results of additional voltages compared with actual voltages.

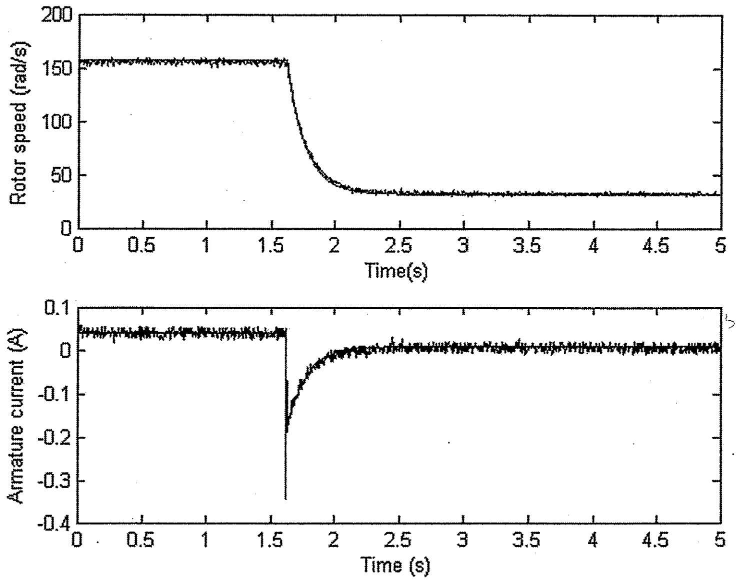

Fig 11. Simulation results fitted to actual step responses.

Table 1. Experiments at steady state conditions.

Terminal voltage(V)	Speed (rad/s)	Current (A)
1	31.5756	0.0080
2	63.1512	0.0159
3	94.7268	0.0239
4	126.3024	0.0318
5	157.8780	0.0398

Table 2. Micro DC motor parameters.

Parameter	Numerical value
Armature resistance (Ω)	16.956
Armature inductance (H)	1.049×10^{-3}
Back EMF constant (V/(rad/s))	0.0274
Rotor inertia (Kgm^2)	7.528×10^{-6}
Damping constant (Nm/(rad/s))	6.900×10^{-6}
Torque constant (Nm/A)	0.0274