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Journal of EngineeringSciences

Model Verification For A Brushed DC Motor Running In Closed Loop With Speed Feedback

Hız Geri Beslemeli Kapalı Döngüde Çalışan Bir Fırçalı DC Motor İçin Model Doğrulama

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ÖZET

Bu çalışmada sabit mıknatıslı fırçalı bir dc motora kapalı çevrim hız kontrolü uygulanmıştır. Çalışmanın ilk kısmında, dc motorun modeli oluşturulmuş ve bu model kullanılarak Matlab/Simulink'te geri beslemeli hız kontrol sisteminin simülasyonu yapılmıştır. Sonrasında ise sistem, ED Laboratuarı dc motor seti kullanılarak deneysel olarak gerçeklenmiştir. Elde edilen deneysel verilerin simülasyonla elde edilen verilerle örtüştüğü gösterilmiştir.

Anahtar Kelimeler: SMDC, Kapalı Çevrim Hız Kontrolü

ABSTRACT

In this study, a closed loop speed control of a permanent magnet brushed dc motor is developed. In the first part of the study, the model of the dc motor is obtained and used to simulate a closed loop speed control system using Matlab/Simulink. In the second part, ED laboratory dc motor set is used to implement the simulated system experimentally. The data obtained from experimental study is used to verify simulation results.

Keywords: PMDC, Closed Loop Speed Control

1. INTRODUCTION

Electrical machines are an important part of our daily life since middle of 19th century. There are mainly 2 types of electrical motors: AC and DC. AC motors are generally utilized in industrial environments where heavy work load need to be carried out. DC motors, on the other hand, are used mainly in house hold appliances and places where DC voltage is available without any rectification such as PV panels related source existancy. There are two broad categories of dc motors: Brushless and brushed. Brushed DC motors have also several kinds such as separately excited, shunt, series, compounded, permanent magnet etc (Chapman 2005 ; Kingsley and Fitzgerald 2014) .

There are many studies conducted on DC motors. We briefly summarize 2 of them below. Kose et all conducted a comparison analysis of speed control algorithms on a brushed dc motor using PID and fuzzy logic methods. They utilized ST Microelectronics STM32F407 Discovery kit. For a reference speed of 120 rpm, it is shown that PID control performs better in terms of settling time. For steady state error, both methods gave the same result. In terms of percent overshoot corresponding to different values of step inputs, PID controller seemed toper form better than fuzzy logic controller.

Carroll and Dawson introduced a backstepping with full state feedback and backstepping with partial state feedback approaches to design high performance motor controller for a brushed dc motor. They demonstrated that the Global Exponential Stability (GES) result is better for position control with the partial state feedback. Backstepping with the partial state feedback performed better in terms of both less noise in motor armature voltage and less position error criteria's.

In this study, we implemented a closed loop speed control system for a permanent magnet brushed dc motor. The dc motor used in this study is a part of ED laboratory DC motor set. A simulation study is performed first using Matlab/Simulink software. Experimental study is conducted next to verify correctness of the model.

2. BRUSHED DCMOTOR THEORY

A separately excited brushed dc motor mainly consists of a field winding that generates flux in the machine and a cylindrical rotating part called armature or rotor. The armature of a dc motor has coils located at places called slots which are regularly distributed around the rotor. These coils are connected to conducting plates called commutator. Depending on number of poles of the rotor, even numbers of brushes are connected to the commutator to provide electrical connections from supply voltage to coils. The figure 1 shows an equivalent circuit of a dc motor.

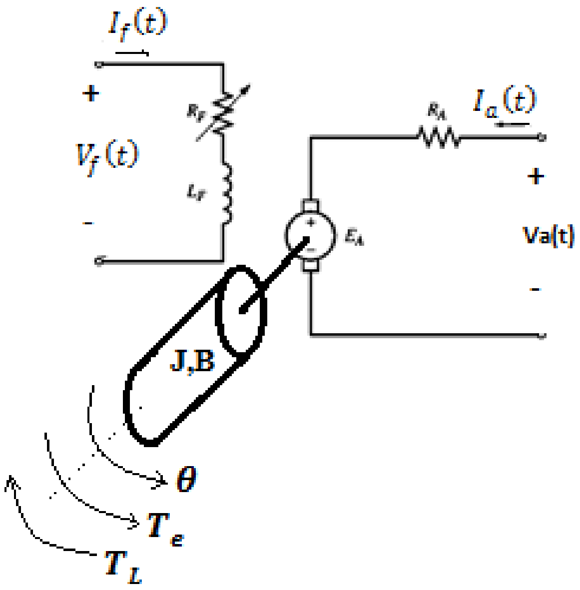

Figure 1. An Equivalent circuit of a separately excited brushed dc motor.

Terminal characteristic of a separately excited dc motor is given as:

$$V_a(t) = R_a I_a(t) + L_a \frac{dI_a(t)}{dt} + E_b(t) \tag{1}$$

$$E_b(t) = K\emptyset(t)w(t) \tag{2}$$

$$\emptyset(t) = f\left(I_f(t)\right)$$

where

$R_a = Coil\ \ Resistance\ (\Omega)$

$L_a = Coil\ Inductance\ (H)$

$K = Motor\ Constant\ (volts - sec/rad)$

$\emptyset(t) = Flux\ in\ the\ machine\ (Weber)$

On the mechanical side, equations for generated torque and mechanical rotation of the rotor are given as:

$$J\frac{dw(t)}{dt} + Bw(t) + T_L - T_e(t) = 0 \tag{3}$$

$$T_e(t) = K\emptyset(t)I_a(t) \tag{4}$$

where

$J = Motor\ Inertia\ (kg * m^2/sec^2)$

$B = Friction\ Coefficient\ (N * m * sec)$

$w = Angular\ Velocity\ (rad/sec)$

$T_e = Electrical\ Torque\ (N)$

$T_L = Load\ Torque\ (\ N\ )$

For the case of permanent magnet dc motor, the flux in the machine is provided by a permanent magnet. Since flux is constant, the terminal characteristic of this kind of motors is the same except that K*Ø(t) term replaces with a single constant $K_b$in related equations.

3. A CLOSED LOOP DC MOTOR SPEED CONTROL SYSTEM

Block diagram of a closed loop speed control of a dc motor is given in the Figure 2. A speed feedback obtained from a tacho generator is used to obtain speed feedback. A type P controller is used in the forward path. There is a class B push-pull type power amplifier in the forward path which is used to drive the motor. The transfer function for the motor driver is shown to be a constant in the block diagram because it merely converts voltage requirement supplied by the P controller into current requirement needed by the motor with a close to unity voltage gain.

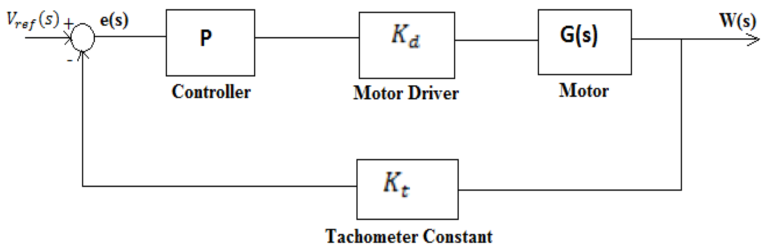

Figure 2. Block diagram of a closed loop speed control of a dc motor

When modeling the motor, it is assumed that no load is applied to the shaft and hence motor runs in no-load condition. It can be shown that the transfer functions of the dc motor for the no load case can be obtained as (Dorf and Bishop, 2014):

$$G(s) = \frac{\frac{K_b}{L_a J}}{s^2 + s\left(\frac{L_a B + R_a J}{L_a J}\right) + \frac{R_a B + K_b^2}{L_a J}} \quad (5)$$

The feedback path is generated with a simple speed to voltage conversion using a tachometer and represented by a gain $\boldsymbol{K_t}$.The remaining parameters needed to model the dc motor are obtained as specified in the Table 1.

Table 1. DC motor parameters

B	R_a	L_a	K_b	J	K_t
$(Nm*sec)$	(Ω)	(H)	$(V/(rad/sec))$	$(kg*m^2/sec^2)$	$(V/(rad/sec))$
2e-5	4	5e-3	0.022	33e-5	0.021

Based on the above given facts, a dc motor speed control system with feedback can be constructed in Simulink as given in the Figure 3.The simulation program outputs values of the reference voltage and the shaft speed of the motor versus time. The plot of these output values are given in the Figure 4.

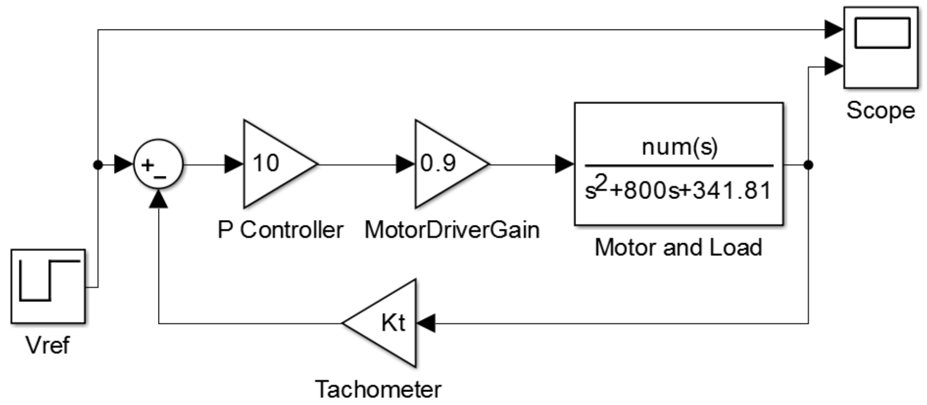

Figure 3. Simulink model of the closed loop dc motor speed control system.

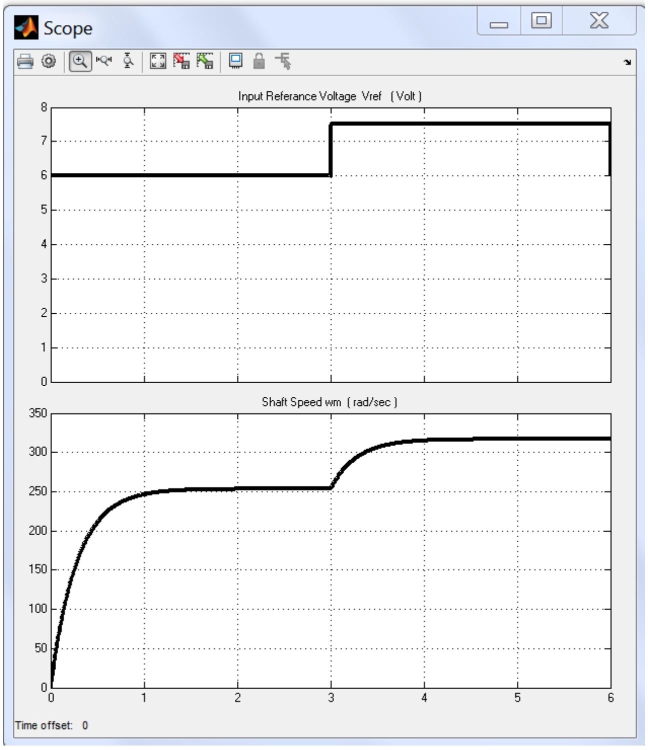

Figure 4. Output values of reference voltage and shaft speed generated by the Simulink.

4. EXPERIMENTAL STUDY

The feedback system given in the Figure 3 is implemented using ED Laboratory DC Motor set. The block diagram of the system is given in the Figure 5 and a snapshot of the experimental setup is given in the Figure 6. The dc motor used in this experiment is a permanent magnet brushed dc motor. Maximum input voltage that can be applied to the motor is 12 V with 0 to 4.5 W applicable power range. There is tacho generator embedded on the motor which is used to perform speed feedback as well as to display shaft speed of the motor on an rpm meter.

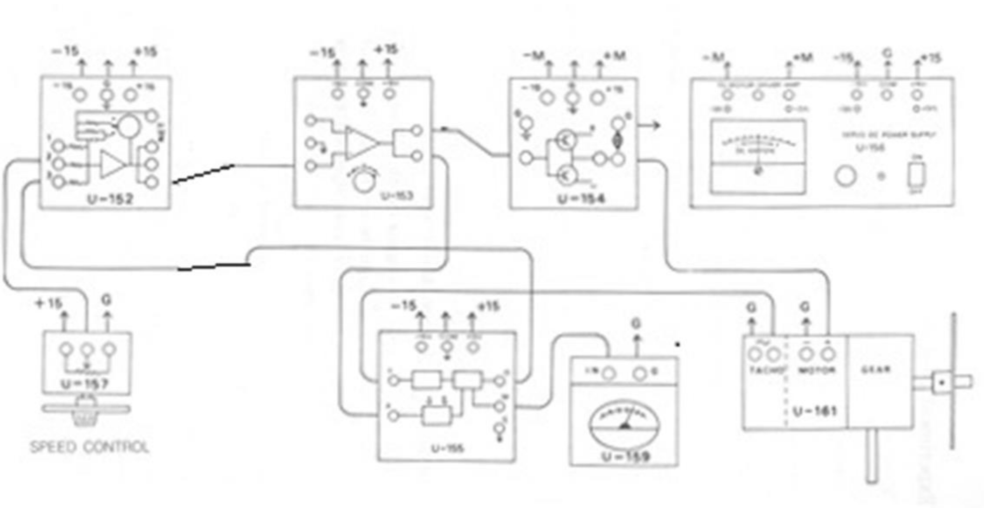

Figure 5. The block diagram of the feedback system.

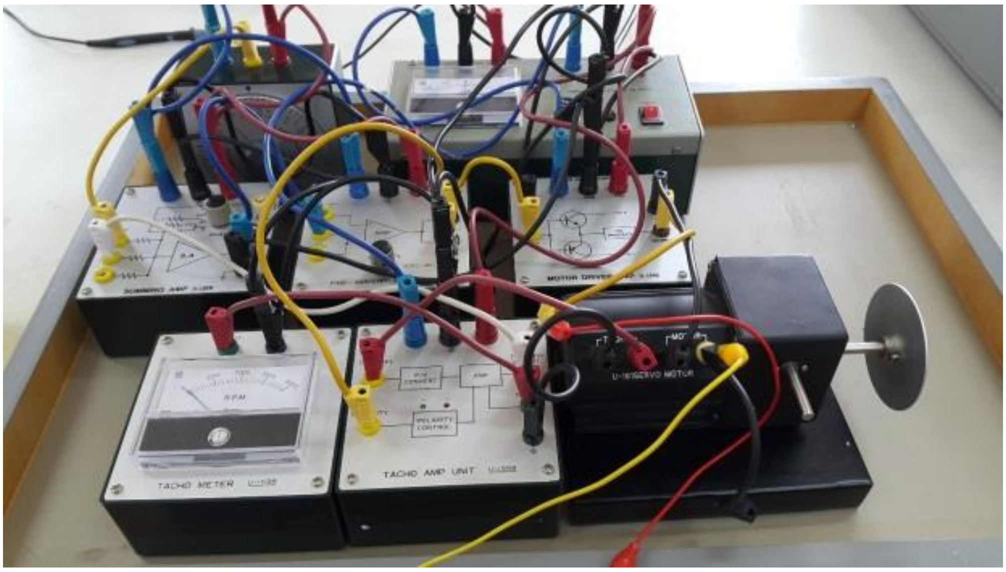

Figure 6. A snapshot of the dc motor speed control system with feedback.

In order to verify correctness of our modeling, steady state values obtained from experimental study for the reference voltage V_{ref}, the motor armature current I_a and the shaft speed w are given in the Table 2.

Table 2. Values of parameters for reference voltage, motor armature current and shaft speed obtained from experimental study

$V_{ref}(V)$	$I_a(mA)$	$w\ (\frac{rad}{sn})$
6	300	256.56
7.5	325	324.63

As it's seen from the Table 2, the shaft speed of the motor for the reference voltages of 6 V and 7.5 V are 256.56 rad/sec and 324.63 rad/sec. These values are approximately same values obtained from the simulation which are given in the Figure 4.

5. CONCLUSIONS

We have implemented a dc motor speed control system with feedback using the ED Laboratory DC Motor set. The system is modeled for the case of no-load condition. The simulation of the feedback control system is performed in Simulink followed by the experimental study. Data obtained from the simulation is verified by experimental work to demonstrate the correctness of the dc motor model.

In future studies, we'll study the behavior of the system under a specified load condition.

6. REFERENCES

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