LAB 5 – VELOCITY CONTROL OF A DC BRUSHED MOTOR

University of New Hampshire

30. November 2017

Jesse Feng  
Simon Popecki  
Reilly Webb

******

***VELOCITY CONTROL OF A BRUSHED DC MOTOR***

|  |  |
| --- | --- |
| **Course Number and Name:**  ME 747 – Senior Lab | |
| **Semester and Year:**  2017 semester 2 | **Name of Lab Instructor:**  **Alireza Ebadi** |
| **Lab Section and Meeting Time:**  2b 14:00 | **Report Type:**  **External Group Report** |
| **Title of Experiment:**  **Velocity Control of a DC Brush Motor** | |
| **Date Experiment Performed:**  14. November 2017 | **Date Report Submitted:**  1 December 2017 |
| **Names of Group Members:**  Jesse Feng Simon Popecki Reilly Webb | **Grader's Comments:** |
| **Grade:** |

# Cover Letter

Jesse Feng  
Simon Popecki  
Reilly Webb  
33 Academic Way  
Durham, NH 03824

Alireza Ebadi  
33 Academic Way  
Durham, NH, 03824

Dr. Ebadi,

The following document contains an analysis of control systems for a DC brushed motor. DC motors are generally controlled via pulse width modulation and a microprocessor, however for the purpose of demonstration, we controlled DC motors with power op-amp driven proportion control, integral control, and proportional-integral control.

These control systems were compared against each other in terms of functionality- the motor parameters have been determined through experimentation.

The body of this report comprises of the results of inputs to the system and recorded system response.

Best Regards,

Jesse Feng

Simon Popecki

Reilly Webb

# Contents

[Cover Letter 3](#_Toc499912667)

[Contents 4](#_Toc499912668)

[Objectives 5](#_Toc499912669)

[Executive Summary 6](#_Toc499912670)

[Theory and Experimental Methods 7](#_Toc499912671)

[Results and Discussion 8](#_Toc499912672)

# Objectives

The objective of this experiment was to compare different methods of control using a power operational amplifier. Proportional, Integral, and Proportional-Integral control systems controlled a motor under load to be measured by a second motor. The parameters of the motor were calculated, and the system response determined from experimental data. The motor back EMF, open-loop, and closed-loop response were analyzed in particular. Quantitative analysis was performed and interpreted. All relevant values are tabulated/listed. Gain values were confirmed by root locus analysis.

# Executive Summary

In this experiment three types of power op-amp control systems were used to control the speed of a DC brushed motor. Proportional control, Integral control, and Proportional-Integral control systems were used. PID control was not used in this experiment. Motors were controlled by voltage, rather than the conventional method of pulse width modulation. The objective of the control systems was to maintain motor speed regardless of the load placed on the motor. Motor speed was measured by a tachometer.

This experiment assumes that the electrical time constant was much less than the mechanical time constant – so that it may be neglected in the analysis.

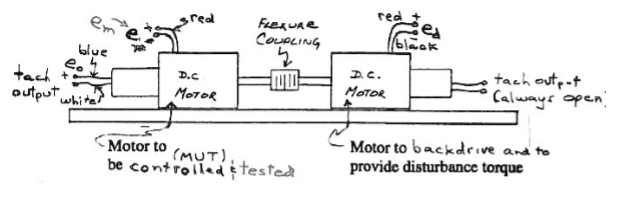
The DC motor’s back EMF constant was found to be #. This value was determined by back driving another motor, referred to in this report as the MUT (motor under test). The torque constant Kt was calculated to be # - it was assumed that Kt = Ke. The resulting motor torque value was calculated to be # oz\*in/A. This value matches the specifications provided by the motor manufacturer.

The motor’s open-loop response for a disturbance torque and input voltage step was recorded and analyzed. The time constant and system gain were calculated – a disturbance load was implemented with a switch to measure steady state error – the steady state error is the difference between the motor’s no-load speed and speed under load. The motor time constant was found to be #, and the motor gain value was found to be #. The stall torque of the motor was calculated to be #. The moment of inertia and damping constant of the system were calculated to be # and # respectively.

Closed-loop motor response to a voltage step input and disturbance torque was recorded with a tachometer in the same way as the open-loop response. The power op-amps were controlled by a 741 op-amp – proportional, integral, and proportional-integral control were implemented and analyzed. SHOW SPEEDS OF EACH CONTROL SYSTEM. In a purpose-built closed-loop system the magnitude of each control element (P,I,D) is modified such that it has a larger or smaller role to fit the individual needs of the system. Generic control parameters were used for this experiment (non-optimized).

# Theory and Experimental Methods

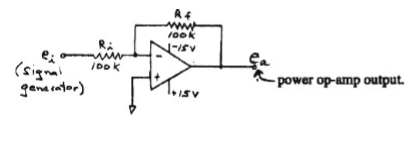
The experimental setup for the open-loop response is shown in Figure 1 below.



Figure

The motor left most is the MUT – the motor under test, and the motor on the right is the motor which is back driven and used to provide a load for the MUT. The two motors are coupled with a flex-coupling to allow for minor shaft misalignment. The MUT was supplied with power from a power op-amp. The MUT was connected to a tachometer, which outputted a voltage proportional to the rotational velocity.

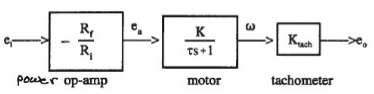
Figure 2 below shows the schematic describing the power op-amp setup.



Figure

The gain of the power op-amp is -1, which means the motor spins the opposite direction (not relevant to the results). Voltages of +15 and -15 volts. The power op-amp was supplied by BK Precision, it provides the power for the motor. Both resistors are 100 kΩ.

The open-loop block diagram of the motor is shown below in Figure 3.



Figure

The time constant of the electrical system is much shorter than the time constant of the mechanical system, it is therefore neglected. In this case, the mechanical pole is dominant.

For the open-loop DC motor analysis, the Ke value was found by back driving the MUT with a motor of identical model and manufacturer (assuming that the motor parameters are going to be similar). Different motor rotational speeds were analyzed to find the response at different voltages. Since motors have different efficiencies at different rotational speeds, the results of this test are important. Voltages were inputted between 1 V and 10 V, but it was found that the motor did not spinning until it was supplied almost 3 V. The frequency of the inputted signal was .001 Hz – the waveform was a square wave.

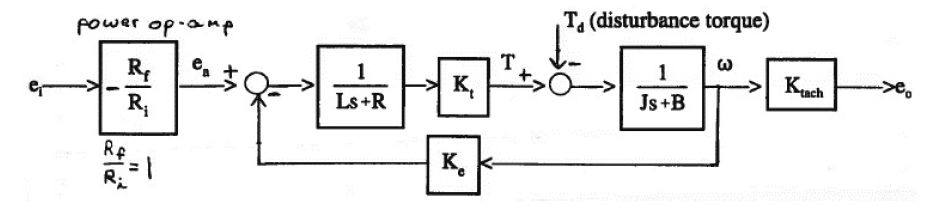
The motor voltage constant is shown in equation 1 below.

Eq.1:

It is assumed that Ke = Kt, where Ke in units V\*s/rad equals Kt in N\*m/A. This value is converted to oz\*in/A (the desired units for this lab) with a conversion factor Cf (see Eq. 2).

Eq. 2:

Step response was analyzed for the open-loop system

The MUT in the open-loop set-up is still connected to the back-drive motor, therefore it would experience both motor’s moment of inertia as well as damping conditions. Assuming both motors are the same, the system equations of the MUT can be derived from the following schematic:

From the circuit, Kirchhoff’s loop law:

The voltage drop is proportional to the resulting angular velocity of the mechanical system, and the current is proportional to the resulting torque by:

Using and , the mechanical system equation is:

Since the inductance is three magnitudes less than the resistance, the inductance term is neglected. Laplace transform and combine the equations:

The transfer function is then:

b) From the block diagram, when the disturbance torque is equal to the motor torque , the output velocity would be zero, and would equal to the stall torque of the motor at the input voltage.

For input voltage, , at stall torque:

Where from experimental data, from information given, for step input, and assuming and converted to the proper units:

The negative sign indicates an arbitrary direction.

c)

The gain , and the time constant , where , the values are found to be:

Which is the motor’s velocity constant .

The moment of inertia term is double the amount given on the spec sheet since the MUT also drives the back-drive motor:

Convert to the correct units:

The matches the expected value for the motor.

d) The recorded data is from the tachometer. Therefore, the motor’s gain would need to multiply by Ktach:

Solve for :

Use and to solve for :

e) Setting time from data:

Steady-State Error:

# Results and Discussion