Lab 7: Pulse Width Modulation PID Motor Controller Design of a Turntable

Ryan St. Pierre, Cameron Esses, Laura Perez, Uriel Salazar Angelini

November 13^{th}, 2017

---

1 Introduction

The relationship between an electrical circuit and its mechanical output may be used to implement a control system that allows for greater flexibility over the dynamics of the mechanical system. For this lab, a proportional-integral-derivative (PID) controller was designed to operate a pulse width modulation (PWM) driven, DC motor within a record player. After building a model PID controller with Simulink, the open loop system was studied by measuring the rotational response of a record player (specifically the static and dynamic friction) as the duty cycle setting on the controller was altered. The Ziegler-Nichols method was used to tune the PID controller for the closed loop system. For this method, the integral and derivative gains were first set to zero. Then, the proportional gain was adjusted until the system stably oscillated, yielding a critical gain and critical period. This allowed for calculations that determine the optimal values of P, I, and D gain factors and their influence on the closed-loop system.

2 Experimental Procedure

Using a modified Victrola 3-Speed Turntable, CUI AMT102V digital optical encoder, and the dSPACE control system, this lab designed a custom PWM based electronic circuit. The first component needed was the PWM generator. This generator takes an input and a repeating sequence block into a summing junction. The resulting signal travels through a relay function and a Gain block to a DA converter. The signal output into the converter is the signal generated from the PWM system.

The next step was to create the control part of the circuit. Again, using Simulink, the control component was designed to contain three constant blocks, a Multiport switch, a duty cycle, and a reference rps value. With the addition of sum and gain blocks controlling the critical gain parameter, the resulting signal travels to the PWM generator. The next part of the lab was to create an encoder signal and control loop. These signals are used as feedback in a closed loop system. The encoder subsystem created took a signal and manipulated the data rates through a rate transition block. The signal returned from this subsystem provided a real time rps reading for the encoder. The final component was to create a PID controller. For both Integral and Differential control an Integrator Limited block and Derivative block were added to a gain block. A sum block was then placed to the start of PID subsystem to supply the system with a negative loop signal generated form the encoder and appositive signal from a different sum block related to a reference value constant.

Once the model was built its functionality was experimented with and its parameters were tuned. First, the rotational response of the turntable was analyzed - specifically the static and dynamic frictions). To do such the proportional gains to get the turntable to turn smoothly from rest and to get the turntable to stop once moving were determnined. Lastly, the parameters of the PID controller in the model were tuned using the Ziegler-Nichols method. This method entailed altering the proportional gain, at a set rps (with integral and derivative gain set to zero), until the system stable oscillated.

3 Results and Discussion

3.1 Dry friction model

Voltage at start	0.264 V
Voltage at stop	0.119 V

Table 1: Average voltage measurements for starting and stopping conditions due to dry friction

There was a difference between the voltage required to start the motor (static friction) and the voltage required to keep the motor moving (dynamic friction). At the lowest voltage possible to get the motor to move, the motor would sputter and eventually come to a stop, overcome by static friction. It would take approximately 0.05 to 0.15 V above this value to get the motor to move smoothly.

3.2 PID tuning

Control type	Proportional (K_p)	Integral (K_i)	Derivative (K_d)
P	5.250e−02	-	-
PI	4.725e−02	1.134	-
PID	6.300e−02	2.520	3.974e−04

Table 2: Values of PID coefficients determined by Ziegler-Nichols method for low rps (rps = 18)

The PID coefficients in Table 2 were determined using the Ziegler-Nichols method for a low rps (motor reference rps = 18). To find these values the gain K_c was first set to zero and then gradually increased. The plotter in ControlDesk and the oscilloscope were used to determine at which K_c value the system stated to oscillate around the set rps value. For the low rps value K_c was determined to be 0.105.

The oscilloscope was used to read the period of oscillations at this value of K_c. The period, P_u, was determined to be 50 ms. From there a MATLAB Script called "GetPIDVals.m" was used to calculate all of the PID values.

The tables for mid and high rps values were determined in the same manner as above, but with rps values equal to 32 and 55 respectively. These tables are given in the Appendix.

3.3 Controller comparison

Throughout the ranges of rps values, the P control mode would constantly undershoot the desired step response and have a substantially large steady-state error (modeled by a exponential decay function). Using the PI control mode produced more accurate and consistent results. While there was virtually no steady-state error within this control mode, any change in the input would yield a response that would overshoot the desired value before settling along the desired response. Meanwhile, the PID control mode did not add anything significant to the study.

In theory, PID control should be the best, however, this lab demonstrates there can sometimes be no difference from PI control. While the K_p and K_i coefficients change substantially from PI control, PID control adds a coefficient K_d that is so small that *Simulink* would just automatically round it to zero. Therefore, the PID controller simply resembled a PI controller with different coefficients from the original. Meanwhile, the effects of rps value demonstrated almost negligible changes between control modes. There was, *qualitatively*, slightly better tracking. However, changing rps did slightly alter K_c and some of the variables, yet did not alter the period. Refer to Tables 2-5 for these observations.

With respect to PI and PID control, Ziegler-Nichols appears to be accurate, straightforward, and an effective method overall as a tuning process (as long as it does not produce a redundant PI controller). Tuning did not only improve the performance of the record player and the quality of the music it, but also minimized some lag that was present during the song. This can be due in part to the mechanical portions of the system (the dry friction, possible air drag, internal friction) or the electrical portions (circuit and tolerances). As seen with the dry friction model, the inertial characteristics can both be a deterrent and the reason for the rotation of the record. DC motors normally depict a low inertia, but also accompanying at low rpm / torque / voltage.

A Appendix

A.1 Middle RPS

ref rps	32
K_c	0.138
Period	50 ms

Table 3: K_c and Period Values

Control type	Proportional (K_p)	Integral (K_i)	Derivative (K_d)
P	6.900e−02	-	-
PI	6.210e−02	1.490	-
PID	8.280e−02	3.3120	5.1750e−04

Table 4: Values of PID coefficients for middle rps (rps = 32)

A.2 High RPS

ref rps	32
K_c	0.183
Period	50 ms

Table 5: K_c and Period Values

Control type	Proportional (K_p)	Integral (K_i)	Derivative (K_d)
P	9.150e−02	-	-
PI	8.235e−02	1.9764	-
PID	1.098e−01	4.34	6.863e−04

Table 6: Values of PID coefficients for high rps (rps = 55)