Laboratory Experiment 2: Implementation of a Speed Controller

MTRN3020 Modelling and Control of Mechatronic Systems

the statement: I verify that the contents of this report are my own work

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1. Introduction

The purpose of this experiment is to use the direct analytical design method to design a speed controller for manipulating a motor-generator combined system. No matter of the loads changing, this controller is required to maintain the motor speed at a specified speed with given time constant and sampling time. The first part is to verify the veracity of the speed controller design. And the second part is to simulate the system with disturbances.

2. Aim

1) Design speed controller under some given conditions.
2) the Simulate the designed system for the two parts.
3) Compare the simulation results with the experimental data.

3. Experimental Procedure

Controller Design

1) By forming the plant transfer function that relates voltage to counts, to obtain a gain value and time constant.
2) Combining amplifier, ZOH and transfer function, converting this equation from s-domain to z-domain.
3) By applying the direct method, get the controller transfer function.

System Simulation

1) Build the block diagram in Simulink.
2) Change the set speed and the resistor load corresponding to the specified part.
3) Plotting the simulation and the experimental results.

4. Controller Design Calculation

From the figure 4.1, it is clear that the steady state value of angular velocity in counts per second is nearly 75000. When a transfer function is known and a constant voltage input of 24 volts is applied, the angular velocity can be presented in s-domain.

$$\Omega(s) = \frac{A}{1 + \tau s} \times \frac{24}{s} \tag{1}$$

By using final value theorem,

$$\lim_{t \to 0} \Omega(t) = \lim_{s \to 0} s\Omega(s) = \lim_{s \to 0} \frac{24A}{1+\tau s} = 24A = 750000 \tag{2}$$

So, the gain A is equal to $\frac{75000}{24} = 31250.$

Besides, through inverse Laplace transforming function in MATLAB, the angular velocity in time domain is

$$\Omega(t) = 24A \times \left(1 - e^{-\frac{t}{\tau}}\right) \tag{3}$$

When the time t is equal to time constant, the time constant can be obtained from the figure 4.1.

$$\tau = 0.041$$

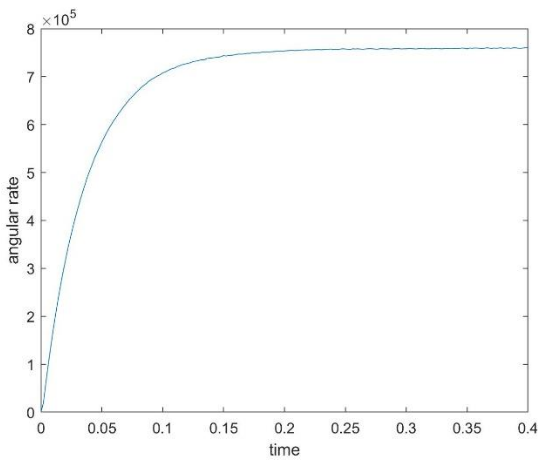


Figure 4.1 angular rate vs time

Hence, the transfer equation with integrator can be determined as

$$G_p(s) = \frac{A}{s(1+\tau s)} = \frac{31250}{s(1+0.041s)} \tag{4}$$

Combing all components in the plant transfer function, it can be separated into two parts,

$$G_p(z) = A(z)\left(\frac{z-1}{zT}\right) \tag{5}$$

$$A(z) = \frac{24A}{126\tau s^2 + 126s} \tag{6}$$

A(z) can be figured out by c2dm function in MATLAB, so it can be stated as

$$A(z) = \frac{3.363(z+0.9447)}{(z-1)(z-0.8430)} \tag{7}$$

Bring the equation (7) into (5), the plant transfer function is

$$G_p(z) = \frac{480(z+0.9447)}{z(z-0.8430)} \tag{8}$$

The system transfer function is

$$z = e^{sT} = e^{-\frac{T}{\tau}} = e^{-\frac{0.007}{0.0041}} = 0.8430$$

$$F(z) = \frac{b(z+0.9447)}{z(z-8430)} \tag{9}$$

For zero steady state error, F(1) has to be equal to 1

$$F(1) = \frac{b(1+0.9447)}{1-0.8430} = 1$$

$$b = 0.08073$$

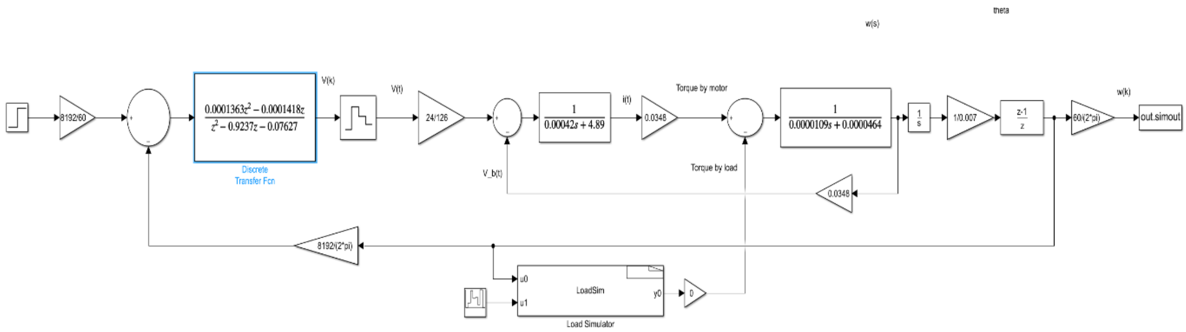
$$F(z) = \frac{0.08073(z+0.9447)}{z(z-0.8430)} \tag{10}$$

Finally, the controller transfer function can be obtained

$$G_c(z) = \frac{1}{G_p(z)} \times \frac{F(z)}{1-F(z)} \tag{11}$$

$$G_c(z) = \frac{0.0001363z^2 - 0.0001418z}{z^2 - 0.9237z - 0.07627} \tag{12}$$

5. Block Diagram



6. Part A – Design Verification

The following plot shows the variation of motor speed while the set speed is changed from 1000rpm to 2000rpm. The experimental data is provided by the data file on Moodle.

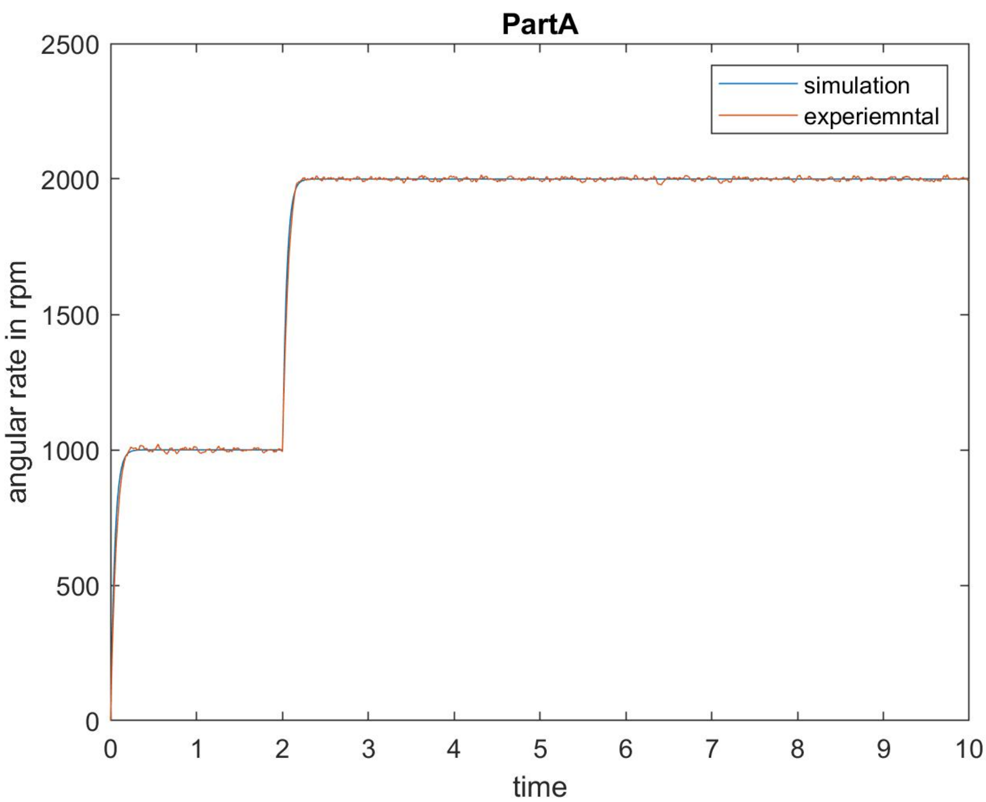


Figure 6.1 Part A plotting

Discussion: Apparently, the simulation graph highly corresponds to the data measured from experiment. Although there are still oscillations with small amplitudes on the experimental graph, these may be resulted from the noises of the encoder and the system model. Undoubtably, both of two graphs have a short response time and instantly ramp up to steady state without no more large oscillations or overshoot.

7. Part B – Disturbance Rejection

With a constant set speed of 2000 rpm, the disturbance to the system is generated from the different load patterns. The load pattern depends on the student ID, 5146927, so the specified load pattern for this report is [0 4 14 8 9 2 15 0]. The graph is shown below.

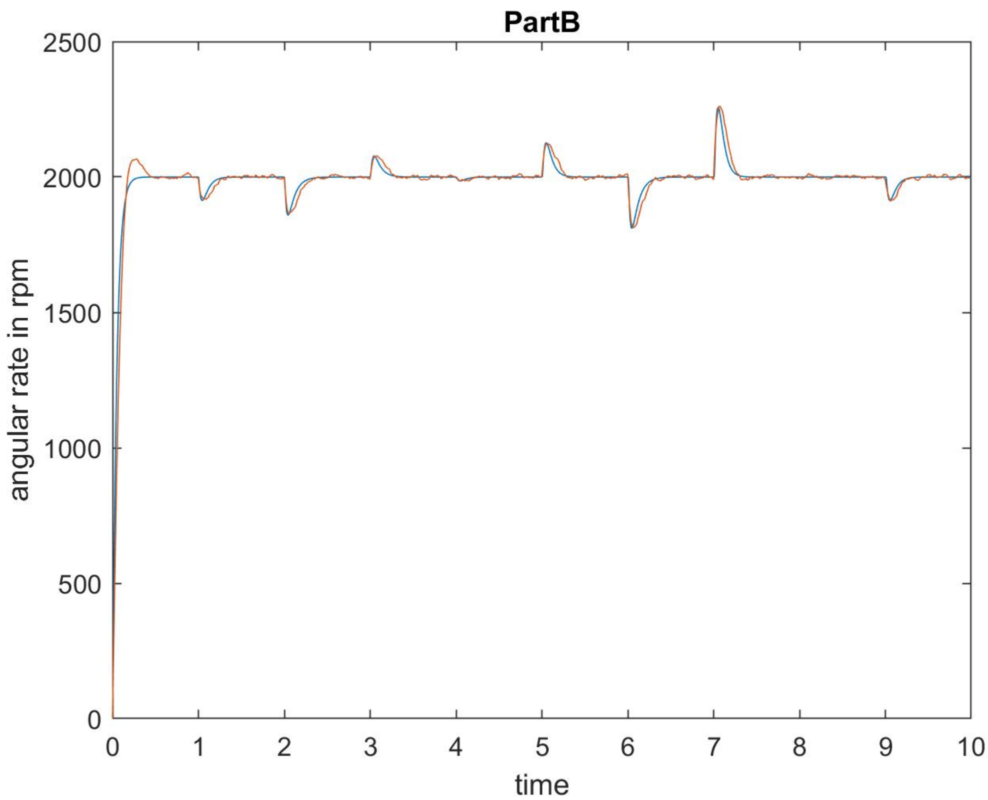


Figure 7.1 Part B Plotting

Note: blue line is from simulation, orange line is from experiment

Discussion: It is clear from the above graph that the simulation graph highly matched up to the experimental one during the test time. There are two points worth to be discussed.

Firstly, it can be viewed on the graph that the overshoot exists at the initial time in the experimental data. Because the controller design has eliminated the zeros or poles which may cause ringing or oscillations, this overshoot may be caused by the experimental error. One of the possible reasons is excessive voltage applied to the motor at the start stage in order to rotate a stationary motor.

Secondly, compared with the simulated data, the experimental data has a longer response time to the new steady state when the load pattern changes. This may be produced by the delaying in the components of the discrete time system, like ZOH. Meanwhile, the controlling computer with low operation speed could also slow down the computation.

8. Conclusion

Although the experimental data is not exactly same as the data simulated on the computer, the performances of controller designed by the direct method is a reliable in a certain extent. This system has appeared zero steady state error and maintained the motor speed at the specified value regardless of loads changing. It can be furtherly improved by adopting more accurate apparatus in the lab or advanced algorithm in the control system.