Karadeniz Technical University
Faculty of Engineering

Department of Electrical and Electronics Engineering

EEE 3003

System Dynamics and Control

Separately Excited DC Motor Speed Control

With PID Kontrols

Group (G1-75)

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PREFACE

We aimed to improve our teamwork and project management capabilities with the project, we implemented in the report. The project aims to learn the most frequently used PID controllers by control engineering which are one of the sub-branches of electrical and electronics engineering. In the report, the speed control of the free excitation dc motor was recognised and the response results of the system are clarified.

SUMMARY

DC motors are divided into 4 types in modelling. These are Separately Excited, Shunt, Series and Cumulatively compound. Today, studies are carried out on the control of these motors in many areas, especially in robots.

The project aims to learn speed control of separately excited DC motor with PID controllers. The topics of PID conrollers and separately excited DC motor used during process are explained. According to dc motor speed control is realized with PID controllers.

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Fair and accurate assessment is essential in an educational setting. As a student, any action that you engage in that gives you or another student an unfair advantage over any other student as it relates to assessment is a form of academic dishonesty. Copying someone else's work and claiming it as your own is academic dishonesty.

This is called plagiarism.

Allowing someone to copy your work and submit it as their own is also dishonest. We all have a role in ensuring fairness and a lapse by one member of the community does not excuse misconduct by another. Rationalization such as "everybody does it" or "the bar was set too high" does not justify or excuse dishonesty.

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I believe in that everything written above is correct in the frame of ethics. I promise to act with the understanding of ethics duing my education in this institute and afterwards.

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Contents

1. What is PID? (Proportional Integral Derivative)

PID is a commonly used feedback controller method in digital control systems. The main purpose of the PID method is to measure the error value continously thus, it calculates the difference between the intended state of the system and its current state.The controller tries to minimize the error by adjusting the process control input. PID method provides control of the system with three parameters it uses.

Closed loop system is widely used in control systems. Command is given to controller in closed looop system. After the given command, the signal sent by the controller is applied to the system. The system reacts with the input signal. The resulting response is measured with the help of sensors and sent to the controller. The controller updates itself according to the feedback and applies a new input to the system.

1.1 Properties of Proportional Integral and Derivative Terms

Proportional control is the easiest feedback control system to implement. In proportional control, the error signal is multiplied by the controller's signal. The ideal K_P value varies from system to system.

1.2 Integral Control

The integral operation is the addition of the area under the curve. This property of the integral is also taken as basis in integral control. Difference between feedback signal and input signal is calculated as area. The next input signal to be sent from the controller is such that it dampens the calculated area. In systems, the difference between the target value and the instantaneous value is large. Due to the large difference, the system in integral mode increases rapidly. After this increase, oscillation is observed in the system. The system needs a settling time to rest the error.

1.3 Derivative Control

With the derivative control, the time dependent variation of the error is calculated. By analyzing past error rates, future error rates are calculated. The rate of increase in error and the effect of the derivative on the system are directly proportional. However, since the derivative reacts by calculating the rate of change in the error, it cannot be used alone in the system. Also, although the derivative control is effective, noise is a problem fort his mode.

Based on what we explained above, the effect of K_P, K_i, K_D values on the system can be categorized as follows.

CL RESPONSE	RISE TİME	OVERSHOOT	SETTLING TİME	SS ERROR
Kp	Decrease	İncrease	Small Change	Decrease
Ki	Decrease	İncrease	İncrease	Decrease
Kd	Small Change	Decrease	Decrease	No Change

(CL: Controller , SS:Steady State:)

2. Separately Excited DC Motor

The main pole windings are not directly connected to the excitation windings. Excitation windings form an excitation field by being fed from an independent direct current source. For this reason, independent direct current sources are needed in the system.

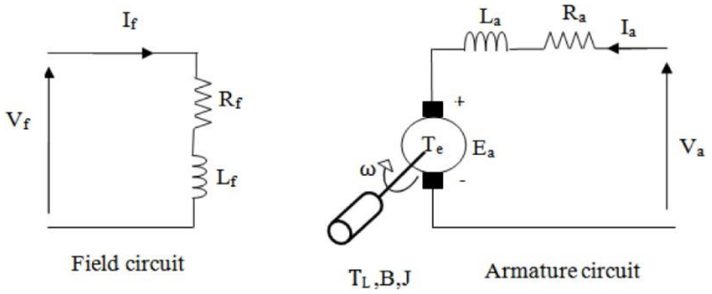

Figure 1 – Model of Separately Excited DC Motor

Block diagram of this system is below

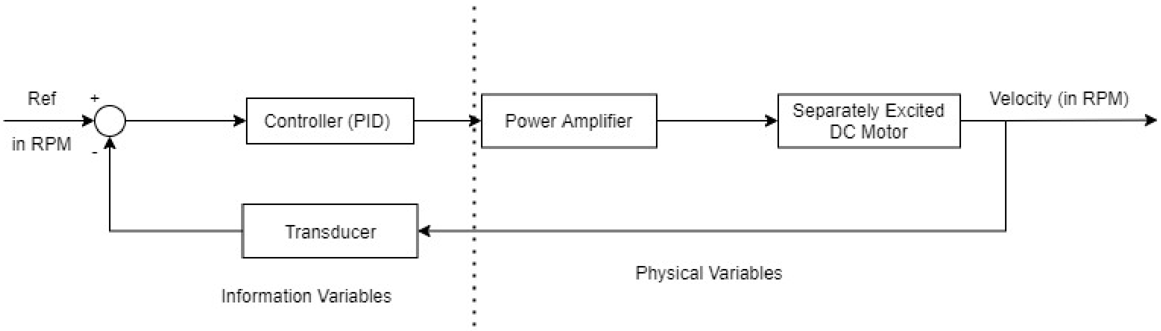

Figure 2 – Block Diagram of The Designed System

Here, armature voltage is used for motor speed control. Based on this, the following mathematical operations can be written:

2.1 Electrical Modeling

$$L_a \frac{di_a}{dt} = V_a - R_a i_a - e_a \quad , e_a = BlNr \frac{d\Theta_m}{dt} = k_m \Theta_m \, , k_m = BlNr$$

2.2 Mechanical Modeling

$$J_m \frac{d^2\Theta}{dt^2} = T_e - f_m \frac{d\Theta}{dt} - T_L \ , \qquad T_e = k_m i_a$$

Here,

Te = Torque generated by the motor

TL = Load torque to be exceeded (neglected in transfer function and block diagram.)

ea = Electromotive force (back emf) generated in motor windings

ia = Current in the armature.

La = Armature inductance

km = Motor torque constant

fm = Friction coefficient

The transfer function of the model was created over the block diagram, using the reduction methods learned in the course.

Block diagram drawn in MATLAB / Simulink environment according to these equations:

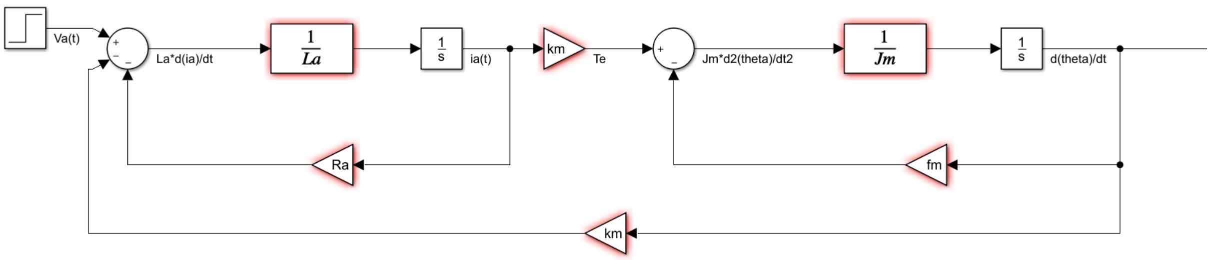

Figure 3 – Modeling of Armature Voltage Controled Separately Excited DC Motor

We use reduction methods and we obtained the following schemes:

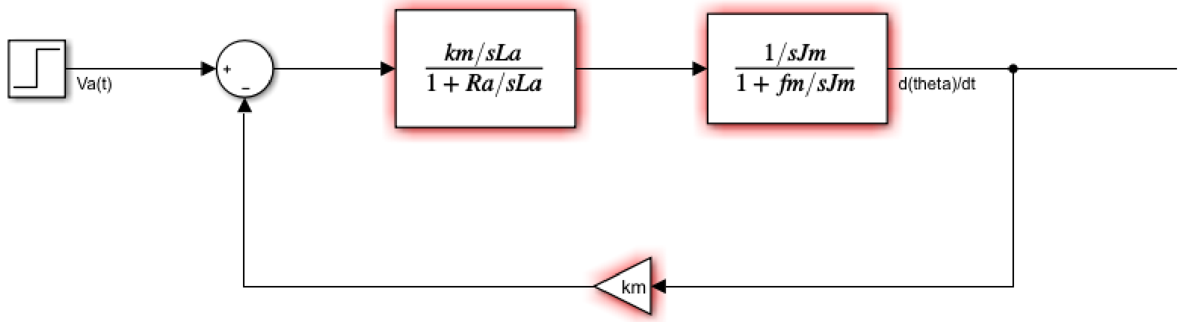

Figure 4 - Block Diagram Obtained by Using The Reduction Method

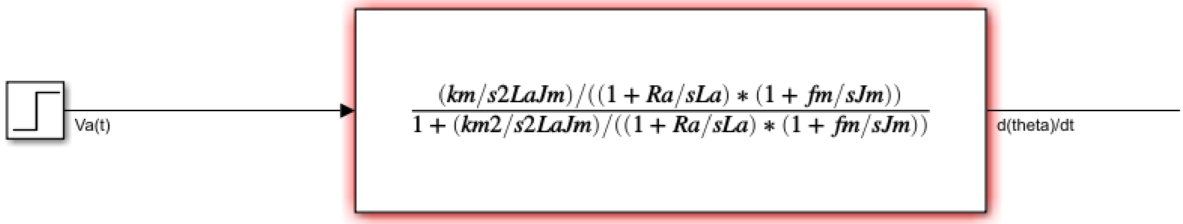

Figure 5 – Transfer Function Obtained by Using The Reduction Method

Transfer function of the system that is reduced through the block diagram:

$$\frac{Y(s)}{U(s)} = \frac{\dfrac{\dfrac{k_m}{s^2 L_a J_m}}{\left(1+\dfrac{R_a}{sL_a}\right) * \left(1+\dfrac{f_m}{sJ_m}\right)}}{1+\dfrac{\dfrac{k_m^2}{s^2 L_a J_m}}{\left(1+\dfrac{R_a}{sL_a}\right) * \left(1+\dfrac{f_m}{sJ_m}\right)}}$$

In order to realize the purpose of the experiment and simplify the equation, the following values are given to the variables in the equation.

L_a = 0.5H

R_a = 1Ω

k_m = 0.01(N.m/A),

J_m = 0.01(kg.m^2)

f_m = 0.1 (N.m.s)

Transfer function according to these values is below.

$$G(s) = \frac{2}{s^2 + 3s + 20.02}$$

Using the characteristic polynomial of the system, the parameters of the system has calculated as follows.

$$\boldsymbol{w_n} = \sqrt{20.02} = 4.474\ Hz\ (\boldsymbol{Natural\ Frequency})$$

$$\boldsymbol{\xi} = \frac{3}{2\mathrm{w_n}} = 0.335\ (\boldsymbol{Damping\ Ratio})$$

The damping ratio of the system (ξ) is between 0-1, indicating that the system is **underdamped**.

Poles of the characteristic polynomial

$$s_1, s_2 = -\xi w_n \pm j w_n \sqrt{1 - \xi^2}$$

according to this

s_1 =-1.499 +j4.215

s_2 =-1.499 -j4.215.

$$\tau = \frac{1}{\xi w_n} = 0.677\ (\boldsymbol{Time\ Constant})$$

$$t_s = 4\tau = 4 * 0.677 = 2.668(sn)\ (\boldsymbol{Settling\ Time})$$

and

$$w_d = w_n\sqrt{1-\xi^2} = 4.215\ Hz\ (\boldsymbol{Damped\ Frequency})$$

$$t_p = \frac{\pi}{w_d} = 0.745\ sn\ (\boldsymbol{Peak\ Time})$$

We get results.

The impulse and step responses of the system are as follows, respectively.

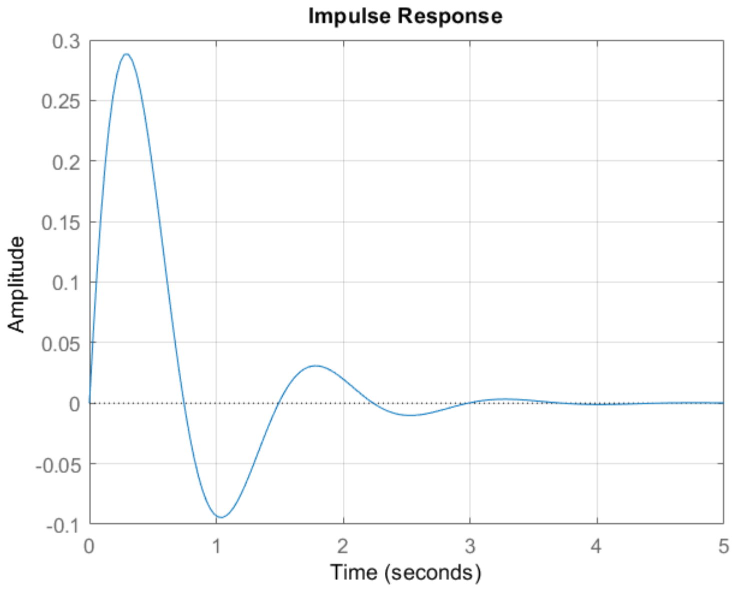

Figure 6 - Impulse Response of the Motor

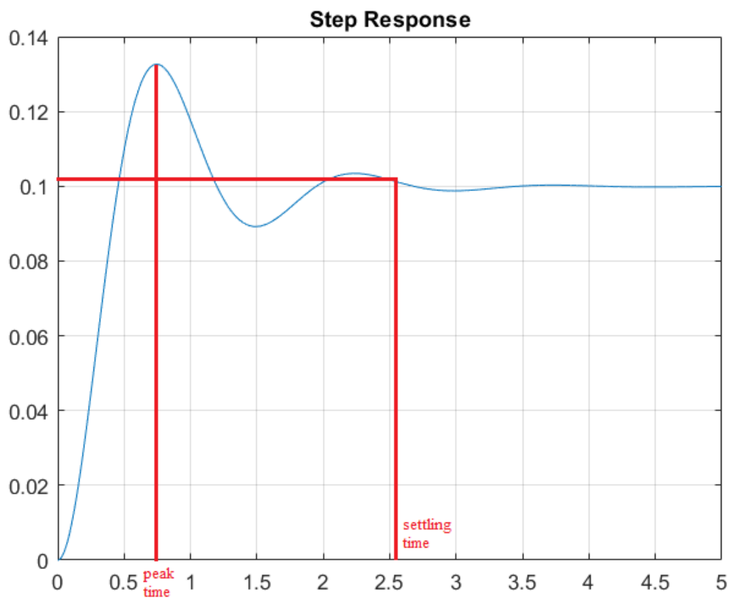

Figure 7 - Step Response of the Motor

Previously calculated peak time and settling time values were plotted on Figure 7.

Components and features of the PID controller explained. Block diagram of the system with this controller added:

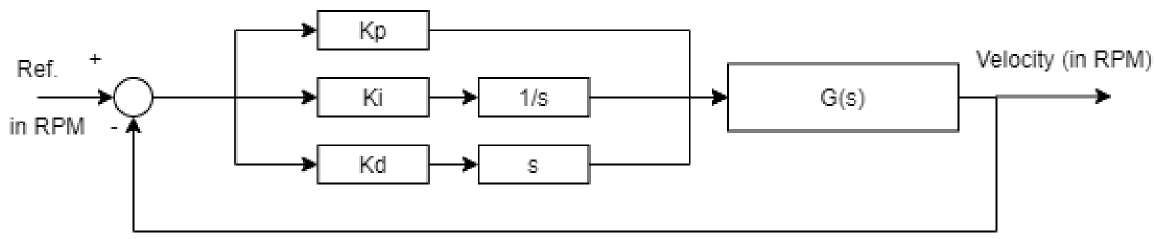

Figure 8 - Block Diagram Created by Adding a PID Controller to the Modeled Motor

The resulting block diagram was created in MATLAB / Simulink environment as shown in Figure 9.

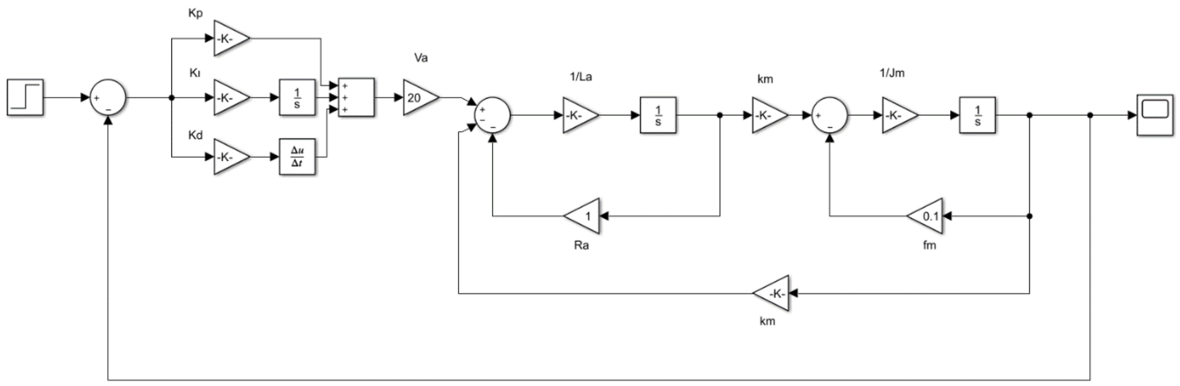

Figure 9 - Explanation of the Diagram in Figure 8

So far, we have observed the oscillation that the motor makes by calculating the settling time and peak time. By adding a PID controller to this designed system, it was aimed to extend the residence time of the system and reduce its oscillation.

K_P, K_I and K_D values in the PID controller have determined using the tuner in the PID block. Values determined accordingly are included in Figure 10.

Controller Parameters

	Tuned	Block
P	0.91109	20
I	2.5664	1
D	0.047877	10
N	37.2193	1

Performance and Robustness

	Tuned	Block
Rise time	0.419 seconds	0.0346 seconds
Settling time	1.55 seconds	4.07 seconds
Overshoot	7.12 %	54 %
Peak	1.07	1.54
Gain margin	Inf dB @ Inf rad/s	Inf dB @ Inf rad/s
Phase margin	69 deg @ 3.55 rad/s	20.3 deg @ 33.9 rad/s
Closed-loop stability	Stable	Stable

Figure 10 - Controller Parameters

Figure 11 – Step Response Graph Taken on Tuner

K_P, = 20, K_I, = 1 and K_D, = 10 values were given in the designed block to see the PID effect more clearly. As can be seen in Figures 10 and 11, overshoot, settling time and oscillation are quite high in manually entered values. On the other hand, these values, which are not desired to be more than the values determined through the tuner, have been reduced.

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