NANYANG TECHNOLOGICAL UNIVERSITY

Laboratory Manual

DC-Motor Speed Controller Design using Simulink

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1. Introduction

1.1 Background

In most of the industrial applications, more than half of the controllers are PID controllers. Due to advancement in micro-controllers and electronics, modern day controller employ a digital control system for high reliability and minimal cost. The digital control system is designed such that the closed-loop control system to produce desired output or satisfies the controller specifications. One can easily determine the PID controller gain, if the mathematical model of the system is available. Otherwise, PID controller parameters are determined using experimental study. Further, it can be tuned to minimize the error between the measured variable of the process and its set point.

1.2 Motivation and Objectives

This lab aims to provide you an understanding of PID controller design for a simple DC Motor speed control. We will discuss both Ziegler Nichols Open Loop and Closed Loop tuning methods to design the PID controller. We use Simulink to simulate and understand the DC Motor System and test the controller performance on it.

1.3 Resources

MATLAB-Simulink software is required to understand the speed controller design.

2. Related Theory

2.1 DC Motor Working Principles

The electrical circuit of the DC-Motor considered is shown in Fig. 1 below:

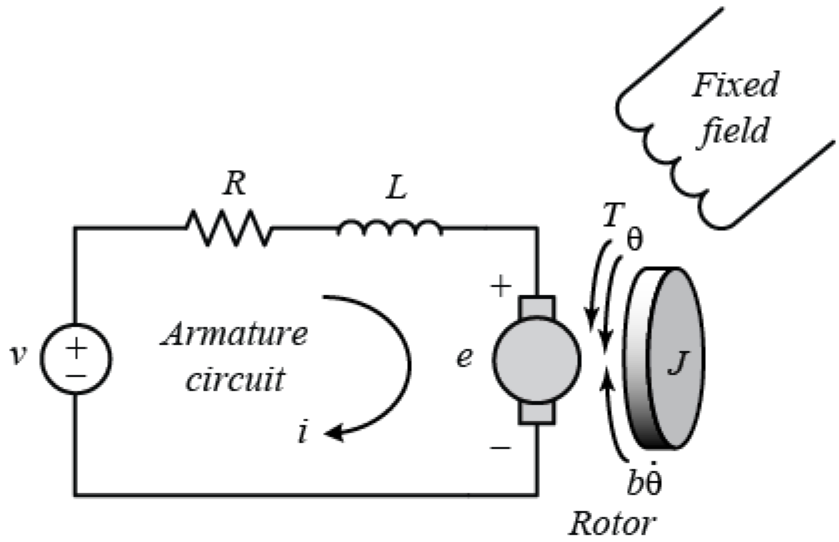

Fig. 1. A Schematic diagram showing the electrical circuit and mechanical forces in a DC motor.

Note that DC motors are often used as actuators. The rotory motion coupled with wheel can be used as a translatory motion in two-wheel robots. DC motor is supplied with source voltage of V and it produces rotational speed of the shaft $\theta^{\cdot}$. We assume that the rotor and shaft are rigid and friction torque proportional to shaft angular velocity. The motor parameters can be obtained from the data sheet and are given below:

(J) moment of inertia of the rotor 0.0009 kg.m^2

(b) motor viscous friction constant 0.1 N.m.s

(Ke) electromotive force constant 0.00008 V/rad/sec

(Kt) motor torque constant 0.01 N.m/Amp

(R) electric resistance 0.008 Ohm

(L) electric inductance 0.005 H

By applying the Newton's law and Krichoff's law, we can derive the transfer function between voltage and rotor speed as,

$$P(s) = \frac{\dot{\theta}(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \quad [\frac{rad/sec}{V}]$$

The above model has been incorporated in the DC Motor subsystem in Simulink. For more details on MATLAB realization, one should refer to [1].

2.2 DC Motor Speed Control System

The closed-loop control system for DC motor is shown in Figure Fig. 2. Note that the physical system is DC motor, which produces specific speed for a given current (u). The controller is the proportional-integral-derivative (PID) controller, which produces necessary current for the given error (e). The error is the deviation between actual speed and set speed.

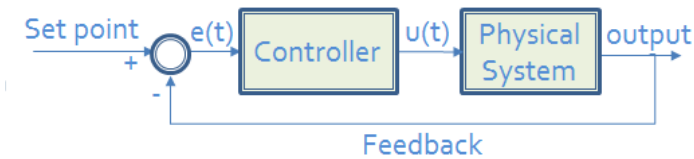

Fig. 2. Schematic diagram for closed-loop control system.

PID Controllers are widely used controllers that minimize the error between the desired set point and actual output of any system. There are other controller designs for specific purposes, but PID is the most general and a simple controller to implement. The PID minimizes the error by generating an output as per the following equation :

$$u(t) = K_P * \mathrm{e}(\mathrm{t}) + K_I * \int_0^t e(\tau)d\tau + K_D * \frac{de(t)}{dt}$$

Fig. 3. PID Controller Control Equation

Thus the PID controller gives a high output if either the error is high, integrated-error is high or rate of change of error is high. These individually aim to improve the transient response of the system by minimizing the rise time, steady state error and overshoot of the system output respectively. The values of Kp,Ki,Kd play an important role in determining the efficacy of the PID controller. These values are known as the 'PID gains'.

The influence of changing these gains on the system closed loop performance is tricky to estimate but the following table is a rough reference to go by:

CL RESPONSE	RISE TIME	OVERSHOOT	SETTLING TIME	S-S ERROR
K_p	Decrease	Increase	Small Change	Decrease
K_i	Decrease	Increase	Increase	Eliminate
K_d	Small Change	Decrease	Decrease	No Change

http://ctms.engin.umich.edu/

Table 1. Effect of changing PID gains on the closed loop response

There are many methods to determine the PID gains for any given system. Ziegler Nichols Open Loop and Closed Loop methods are two such methods which will be discussed below.

3. MATLAB-Simulink based PID Design

3.1 Design Criteria

For a 1-rad/sec step reference, the design criteria are the following.

- Settling time less than 1 seconds
- Rise time less than 0.5 seconds
- Overshoot less than 15%
- Steady-state error less than 1%

3.2 Ziegler-Nichols Open Loop Method

The following steps are required to determine the PID parameters:

a. To understand the DC-Motor System, run the simulation 'ZN-OpenLoop.mdl' in Simulink.

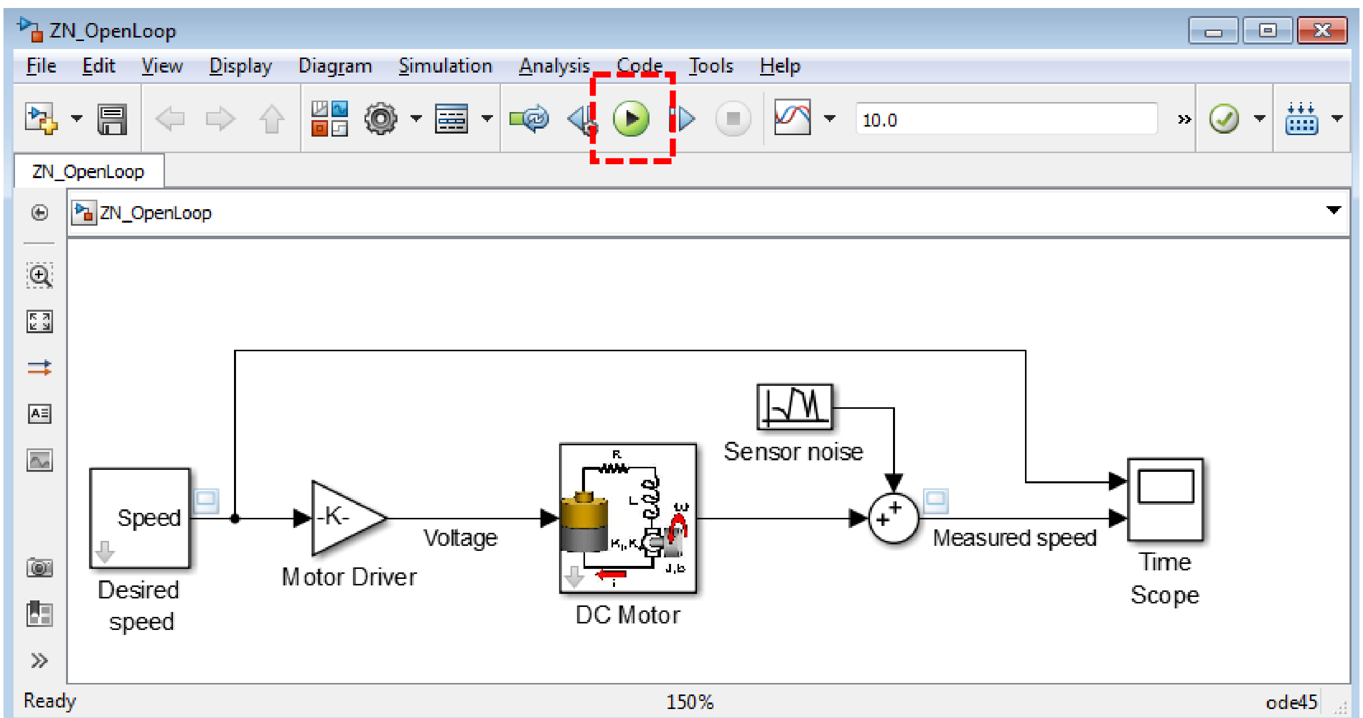

Fig. 4. Schematic diagram of Simulink for observing DC Motor system in open loop

The step response should resemble the following figure. From the time scope, determine approximately K, τ_s, τ_d by fitting the graph to an ideal first-order response shown below

Note 1: To determine K, you can evaluate by using - K = (y2-y1)/(u2-u1)

Note 2: To determine τ_s, *draw a tangent through the estimated maximum slope and find its intercept on 'y = y2'.*

Note 3: τ_d will be given by the time difference between change in 'u' and tangent intercept on 'y=y1' For more details, refer [2].

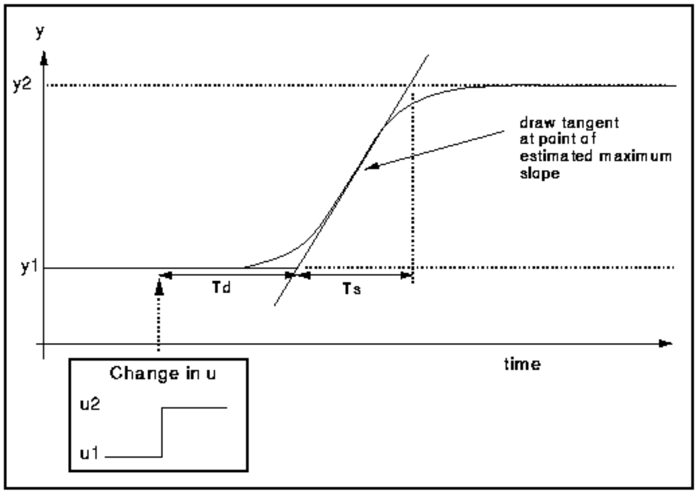

Fig 5. Step Test Response of a First-order plus time delay system

From the model constants above, refer to the Ziegler-Nichols Open Loop tuning table to compute Kp,Ki,Kd for the PID controller

3.3 Ziegler Nichols Closed Loop Method

a. To evaluate the ultimate-gain and ultimate-period of the DC-Motor system needed for Ziegler Nichols Closed Loop Tuning Method, run the 'ZN_ClosedLoop.mdl' in Simulink.

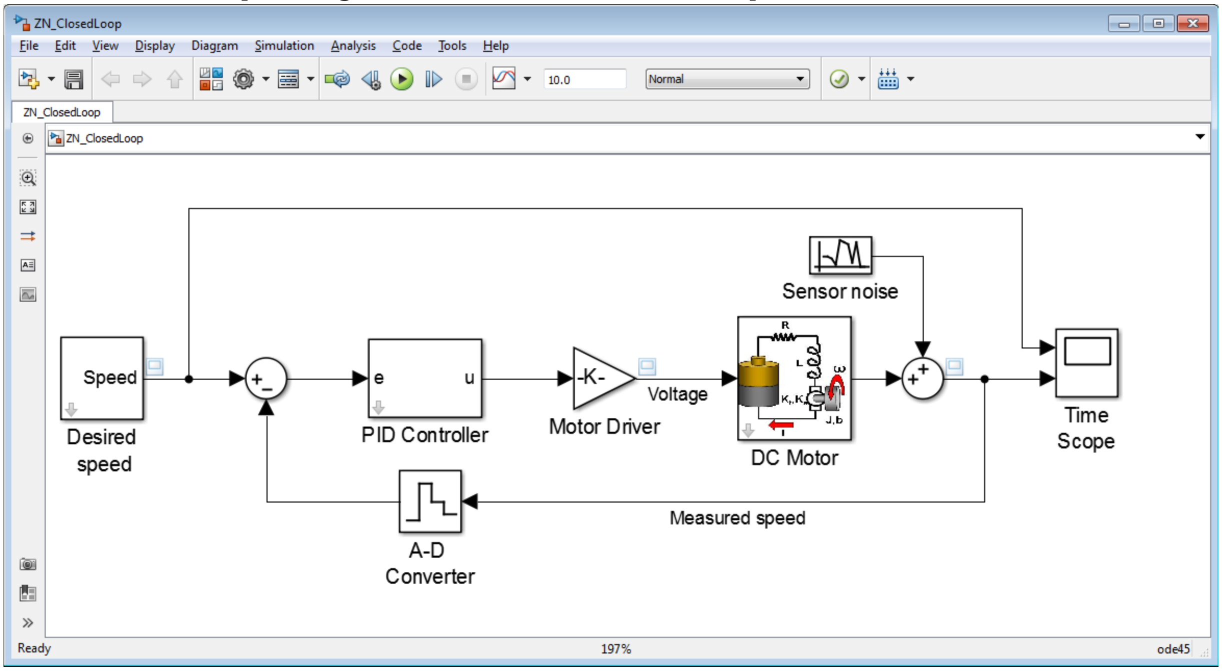

Fig. 6. Schematic diagram of Simulink for performing Ziegler Nichols Closed Loop Test

You will obtain the closed loop performance of the DC-motor with purely proportional controller. Increase the proportional gain 'Kp' in the PID controller until you get a sustained oscillatory response for the measured speed.

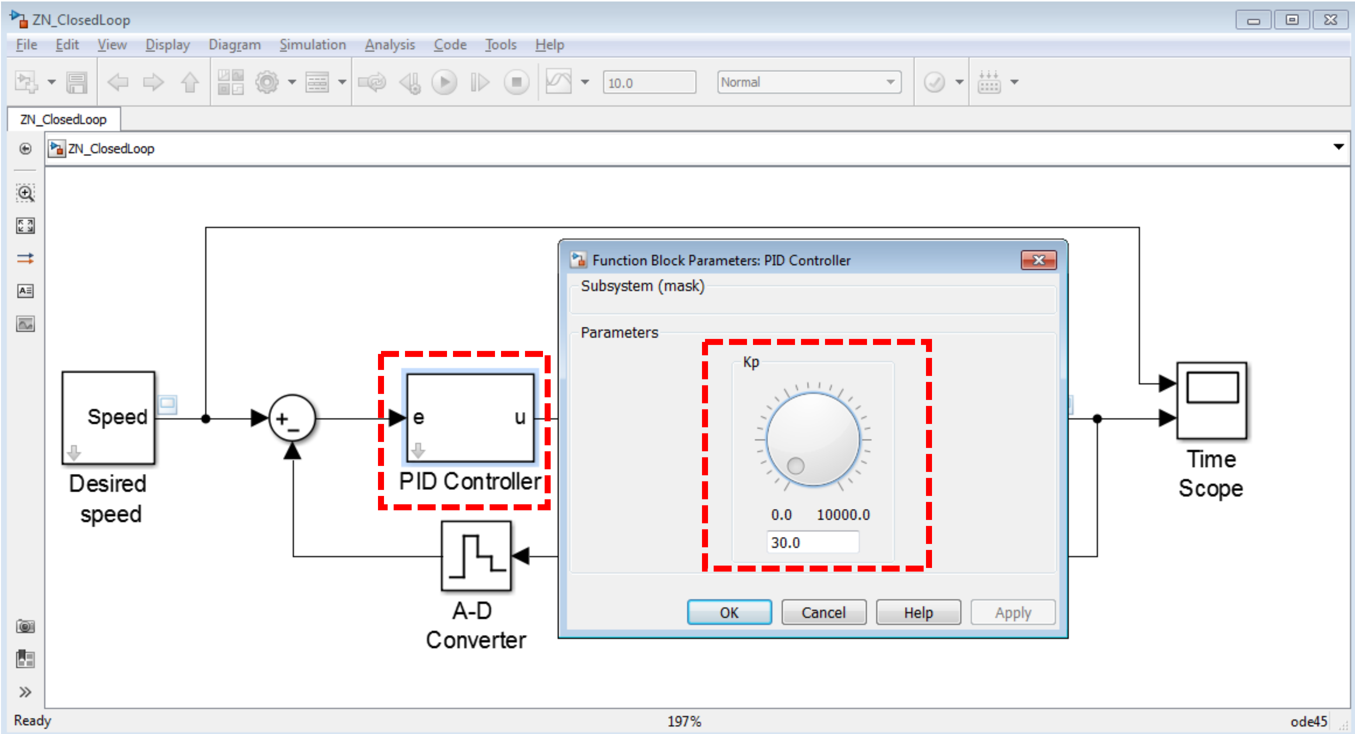

Fig. 7. Schematic diagram of Simulink for changing Kp for Ziegler Nichols Closed Loop Test

b. The response should look like the figure below. Record the Ultimate-gain 'K_u' and Ultimate Period 'T_u' from the response by referring to :

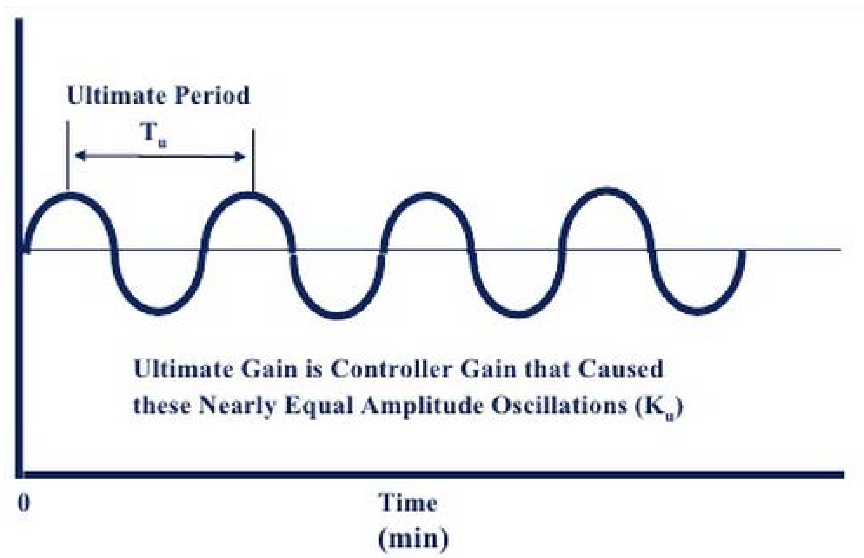

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Fig. 8. Ziegler Nichols Ultimate Gain and Ultimate Period Calculation

c. Compute the PID tuning parameters Kp, Ki, Kd from the Ziegler Nichols Closed Loop Tuning Table.

3.4 PID Control Performance Evaluation

After computing the PID parameters using the above two methods, we can evaluate the closed-loop system behavior.

a. To evaluate the controller performance, set the tuning parameters in the PID Controller block in 'PID_Realization.mdl'.

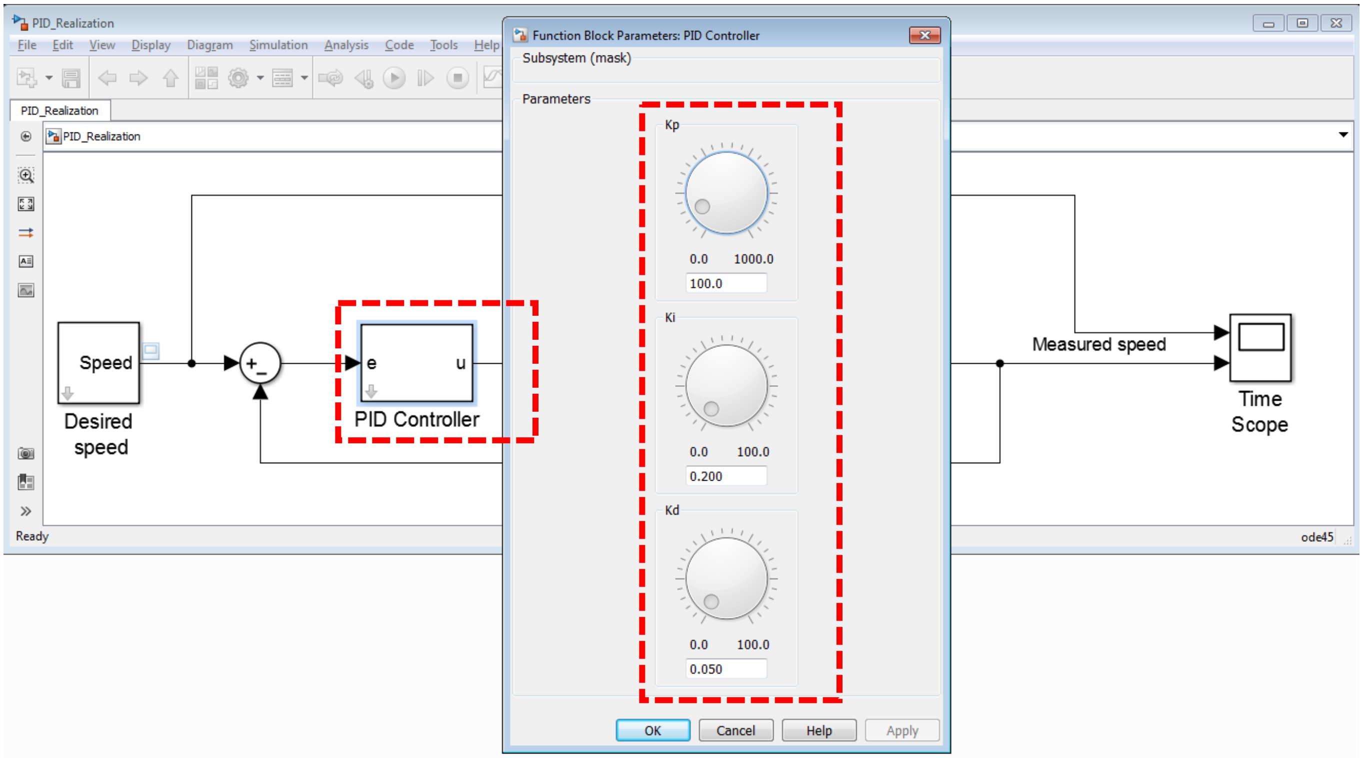

Fig. 9. Schematic diagram of Simulink for for observing system in closed loop

b. Run the simulation file 'PID_Realization.mdl' to evaluate the closed loop performance.

c. Fine-tune the PID tuning parameters with the design criteria in section 3.1. Use table 1 to guide you on how the closed loop performance changes when the tuning constants are changed.

4. Summary

Record your observations in the following table:

	Open-loop		Closed-loop	
Method	Nominal	Tuned	Nominal	Tuned
PID Parameters	K_p = K_i = K_d =	K_p = K_i = K_d =	K_p = K_i = K_d =	K_p = K_i = K_d =
Overshoot				
Rise Time				
Settling Time				
Steady State Error				

Table 2. System closed loop performance with different values of gains

Comment on the methods and your observations.

5. References

[1] http://ctms.engin.umich.edu/CTMS/index.php?example=MotorSpeed&section=SystemModeling

[2] Seborg, Edgar, Mellichamp; Process Dynamics and Controls, Second Edition.