Faculty of Engineering
Department of Electrical & Computer Engineering (ECE)

Control Systems (ECE 331)

Experiment No: 06

“Servo Motor Position Control using a Proportional Controller”

Submitted By:

University ID No:

Date of Submission:

Signature of Faculty: Marks:

Name of Faculty: Ankit Patel

Control Systems ECE 331

Experiment 06

Servo Motor Position Control using a Proportional Controller

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1 Introduction

DC motors are used extensively in many control applications. Therefore, It is necessary to establish mathematical models for DC motors. The transfer function of a DC motor can be approximated by a first order model with unknown constants.

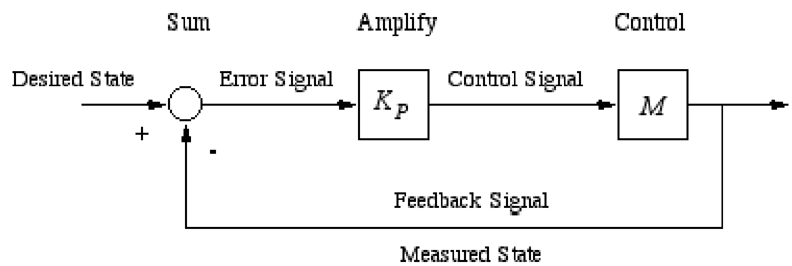

Figure 1: Basic Proportional Controller Model

A proportional control system is a type of linear feedback control system. Two classic mechanical examples are the toilet bowl float proportioning valve and the fly-ball governor.The proportional control system is more complex than an on-off control system like a bi-metallic domestic thermostat, but simpler than a proportional-integral-derivative (PID) control system used in something like an automobile cruise control. On-off control will work where the overall system has a relatively long response time, but can result in instability if the system being controlled has a rapid response time. Proportional control overcomes this by modulating the output to the controlling device, such as a continuously variable valve.

An analogy to on-off control is driving a car by applying either full power or no power and varying the duty cycle, to control speed. The power would be on until the target speed is reached, and then the power would be removed, so the car reduces speed. When the speed falls below the target, with a certain hysteresis, full power would again be applied. It can be seen that this looks like pulse-width modulation, but would obviously result in poor control and large variations in speed. The more powerful the engine; the greater the instability, the heavier the car; the greater the stability. Stability may be expressed as correlating to the power-to-weight ratio of the vehicle.

Proportional control is how most drivers control the speed of a car. If the car is at target speed and the speed increases slightly, the power is reduced slightly, or in proportion to the error (the actual versus target speed), so that the car reduces speed gradually and reaches the target point with very little, if any, "overshoot", so the result is much smoother control than on-off control.

1.1 Limitation of Proportional Controller:

[1] There are many times when you want the output of a system to be equal to the input value.

- The proportional controller amplifies the error and applies a control effort to the system that is proportional to the error.
- P-controller must have some error in order to provide control output.

[2] If you want better error performance, you might want to consider using an integral controller.

- In integral control, the control effort is proportional to the integral of the error.

2 Modeling:

The open loop transfer function for the dc motor is given by,

$$P(s) = \frac{\Theta(s)}{V(s)} = \frac{K}{s((Js+b)(Ls+R)+K^2)} \qquad \frac{rad}{V}$$

The structure of the control system has the form shown in the figure below.

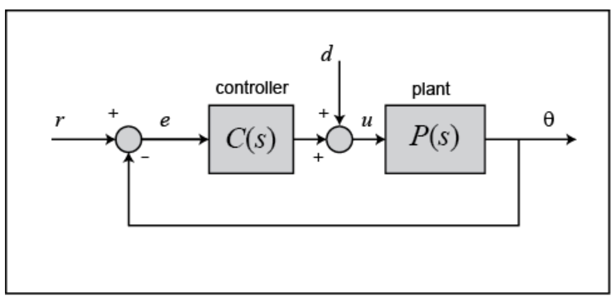

Figure 2: Modeling of DC Motor using Proportional Controller

For a 1 radian/second step reference, the design criteria are the following:

- Settling time less than 0.040 seconds

- Overshoot less than 16%

- No Steady state error, even in the presence of a step disturbance input

Before going to make a *.m* file, please consider the following parameters used in the modeling:

J = 3.2284E-6;
b = 3.5077E-6
K = 0.0274
R = 4;
L = 2.75E-6;
s = tf('s');
Pmotor = $K/(s*(J*s+b)(L*s+R)+K^2)$;

Let's apply Proportional Controller with a gain of 1, that is, C(s) = 1. To determine the closed-loop transfer function, we use the feedback command,

So,

Kp = 1;
for i = 1:3
C(:,:,i) = pid(Kp);
Kp = Kp + 10;
end
syscl = feedback(C*Pmotor,1);

Now examine the output graph for the given proportional controller.

The final script programme as under::

```
clc
clear all

J = 3.2284E-6;
b = 3.5077E-6;
K = 0.0274;
R = 4;
L = 2.75E-6;
s = tf('s');
Pmotor = K/(s*((J*s+b)*(L*s+R)+K^2));

Kp = 1;
for i = 1:3
    C(:,:,i) = pid(Kp);
    Kp = Kp + 10;
end
syscl = feedback(C*Pmotor,1);

t = 0:0.001:0.2;
step(syscl(:,:,1), syscl(:,:,2), syscl(:,:,3), t)
ylabel('Position, \theta (radians)')
```

```
title('Response to a Step Reference with Different Values of K_p')
legend('K_p = 1',  'K_p = 11',  'K_p = 21')
```

The graph for the proportional controller as under:

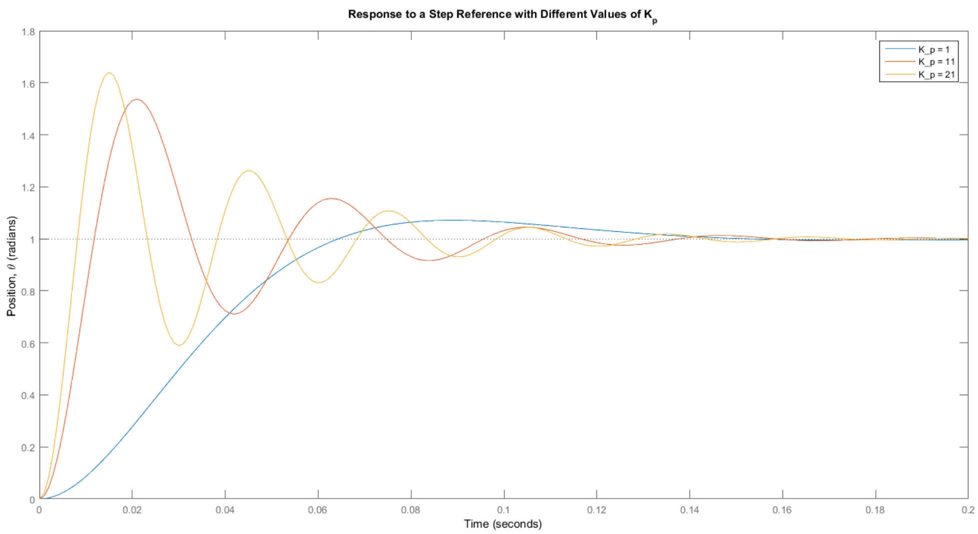

Figure 3: Step input for Proportional Controller

Let's also consider the system's response to a step disturbance. In this case, we will assume a reference of zero and look at the how the system responds to the disturbance by itself. The feedback command can still be employed for generating the closed-loop transfer function where there is still negative feedback, however, now only the plant transfer function P(s) is in the forward path and the controller C(s) is considered to be in the feedback path. Refer back to the block diagram at the top of this page to see the structure of the system. Add the following to the end of your m-file and run it in the command window. You should generate the plot shown in the figure below.

```
distcl = feedback(Pmotor,C);
step(distcl(:,:,1), distcl(:,:,2), distcl(:,:,3), t)
ylabel('Position, \theta (radians)')
title('Response to a Step Disturbance with Different Values of K_p')
legend('K_p = 1', 'K_p = 11','K_p = 21')
```

The above plots show that the system has no steady-state error in response to the step reference by itself, no matter the choice of proportional gain Kp. This is due to the fact

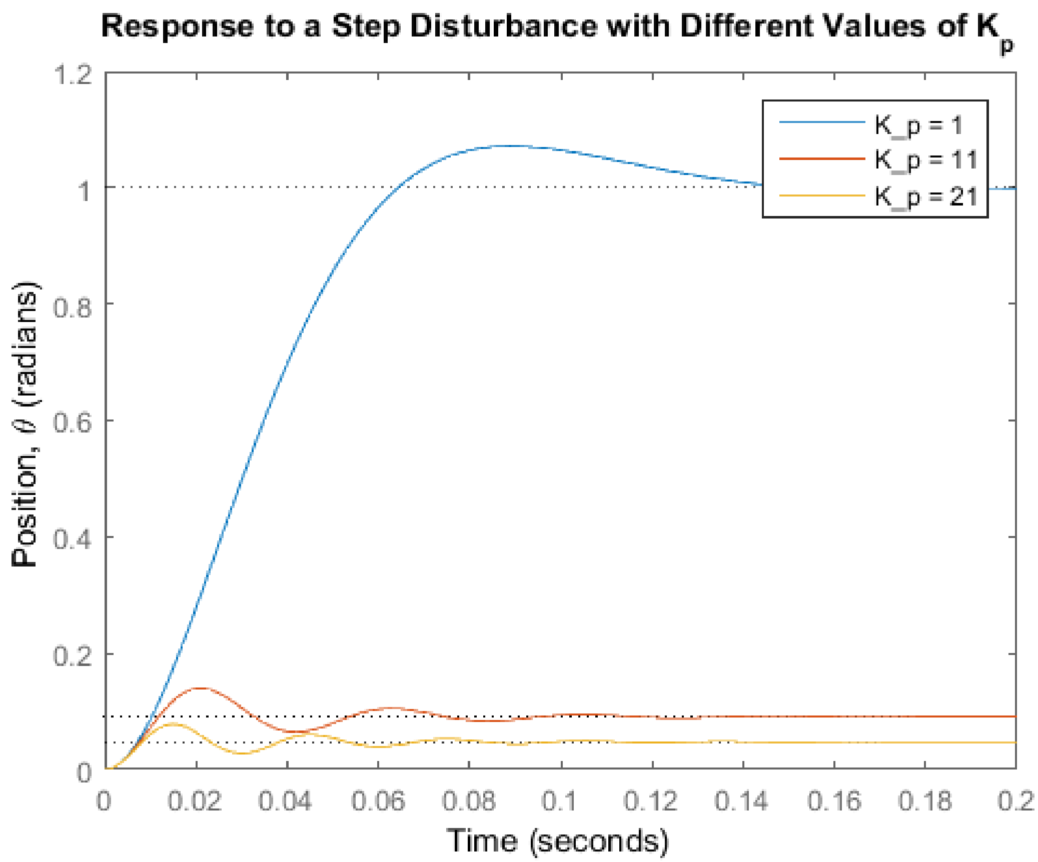

Figure 4: Step input for Proportional Controller with Disturbance

that the plant has an integrator, that is, the system is type 1. However, the system has significant steady-state error when the disturbance is added. Specifically, the response due to the reference and disturbance applied simultaneously is equal to the sum of the two graphs shown above. This follows from the property of superposition that holds for linear systems. Therefore, to have zero steady-state error in the presence of a disturbance, we need the disturbance response to decay to zero. The larger the value of Kp the smaller the steady-state error is due to the disturbance, but it never reaches zero. Furthermore, employing increasingly larger values of Kp has the adverse effect of increasing the overshoot and settle time as can be seen from the step reference plot. Recall from the DC Motor Position: System Modeling page that adding an integral term will eliminate the steady-state error and a derivative term can reduce the overshoot and settling time.