

## Prelaboratory Exercise 3

### Objective

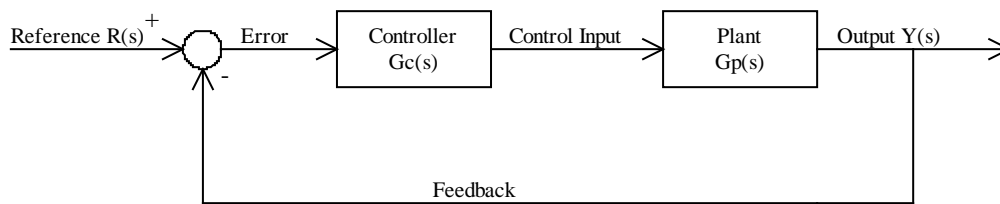
In this Prelab you will familiarize yourself with unity feedback closed loop systems as well as P, PI, and PID controllers.

### Assignment

1.) Read Ogata 5<sup>th</sup> ed., pages 24-25 and 123-129 for a basic understanding of the inner workings of a hydraulic servo valve. (Note that valves, in themselves, can have integral and proportional action. These are mechanical control systems and can surprise the unwary engineer).

2.) Read this Prelab.

### *Unity Feedback Closed Loop Systems – Theoretical Overview*



*Figure 1 Theoretical Unity Feedback System*

Consider the closed loop system in Figure 1. As always,  $G_c(s)$  is the controller,  $G_p(s)$  is the plant, the reference value is denoted by  $R(s)$  and the system's output is  $Y(s)$ . The transfer function  $H(s)$  for the closed loop system can be written using basic block diagram algebra as:

$$H(s) = \frac{Y(s)}{R(s)} = \frac{G_c(s)G_p(s)}{1 + G_c(s)G_p(s)} \quad (1)$$

The mathematics of the system allow the engineer to determine the closed loop response of the controller plus plant system and modify the controller so that the response is one which meets certain design criteria. These calculations are the basis for most academic controls courses. However, for an intuitive understanding of what is going on physically, one must separately look at each of the blocks and connections between the blocks.

The output  $Y(s)$  of some system has value and units. It may be position in meters, velocity in m/s, flow rate in  $\text{cm}^3/\text{s}$ , or temperature in Celsius. Controlling the system refers to forcing the output of the system  $Y(s)$  to some desired reference value  $R(s)$ .  $R(s)$  is presumed to have the same units as  $Y(s)$ . This  $R(s)$  may vary in time, of course. The output of the system must be measured with a sensor. Typical measurement devices include variable resistors, speedometers, flow meters and thermocouples. In Figure 1, the measurement takes place at a pick-off point – a gross oversimplification!

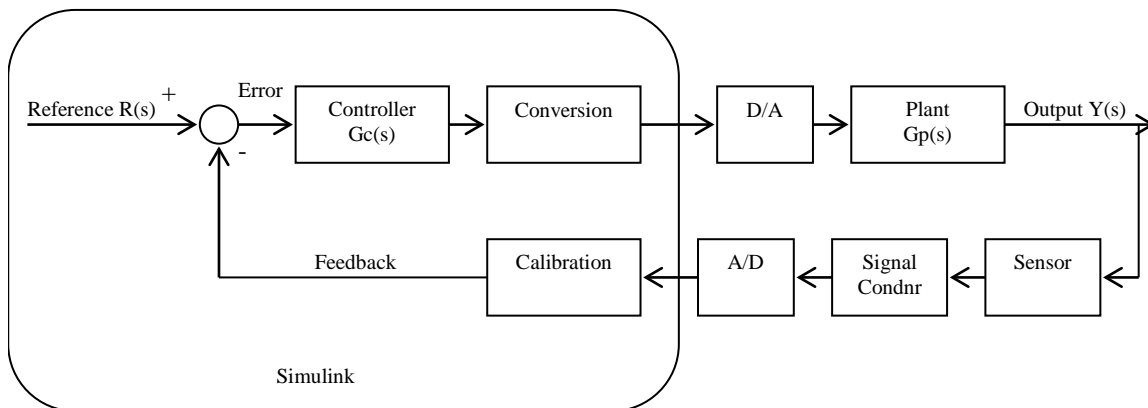
A controllable system must also have an actuator of some sort. This is the means by which the engineer can manipulate the output  $Y(s)$  of the system. For example, in a conventional oven, the actuator may be the valve that opens a gas burner which changes the temperature inside. In modern control systems, these actuators typically receive electronic instructions. A small voltage or current, for example, can drive a servo motor which opens the valve that lets more gas into the burners of the oven. Actuators, however, can also receive mechanical instructions. Either way, the instructions are known as the control inputs. We concentrate on electronically actuated devices and electronic control inputs in this laboratory.

In a closed loop system, the difference between the output  $Y(s)$ , as measured by the sensor, and the desired reference,  $R(s)$ , as determined by the engineer, serves as the basis for the control inputs. The error signal is not directly used as the control input, in most cases. It is first scaled by some transfer function. This transfer function is the controller. By scaling the error signal with a properly designed controller, the system output  $Y(s)$  can be made to match the reference  $R(s)$  in many cases. The field of controls engineering is mainly concerned with designing these controllers.

### *Unity Feedback Closed Loop Systems – Physical Implementation*

Several issues must be considered when physically implementing a closed loop system. We will specifically consider the system used in the Parker Motion and Control Laboratory; however, the same issues apply to any control system that uses electronic feedback, control and actuation.

In Figure 2, we see a block diagram of an actual control system. The additions to Figure 1 to get Figure 2 are necessary to account for the conversion of real world physical signals into digital signals that the computer can use. The left half of the block diagram in the big box takes place entirely within the computer. The D/A and A/D blocks stand for Digital to Analog Conversion and Analog to Digital Conversion. This is the interface between the computer's digital signals and the real world's analog signals. For a more detailed explanation of D/A and A/D, see Horowitz and Hill, pp. 612.



**Figure 2:** Physical Unity Feedback System

A sensor typically does not send its electronic signals in the units of the phenomena it is measuring. For example, a thermocouple does not transmit electronic signals in Celsius. Rather, it sends an electronic voltage signal that is proportional to the temperature. The same applies to a tachometer. It does not

transmit speed information in RPM; instead, it generates a frequency proportional to the speed at which it spins. In order to use the sensor's electronic information in Simulink, we must convert it into voltage signals that range from  $-5$  to  $+5$  Volts, which can be read. This is the job of the signal conditioner box (Coinversion) that follows the sensor in Figure 2. In the Parker Lab, this is the MW2000, the blue and white box with many BNC terminals that has the hard to reach power switch. The conditioned signal can then be converted to a digital signal via the A/D.

Assume that the A/D has digitally converted the conditioned analog signal and Simulink can now use it. However, the sensor information now exists in terms of voltage. Before we can use the sensor information and compare it to our desired reference  $R(s)$ , we must convert it into the appropriate units. In the Parker lab, all sensors are linear in the variable they are measuring with respect to voltage. Therefore, there is a single scaling parameter that will convert the voltage information into the appropriate units. Finding this scaling parameter is called calibration. The gain block in the feedback loop in Figure 2 is a conversion parameter that has been determined by calibration.

In the feed forward loop, after the controller  $G_c(s)$  we note another gain block that converts from the physical units of the control input into a suitable voltage signal for the actuator. The selection of this scaling parameter is heuristic and will not be discussed here. This gain is typically included with the controller using block diagram algebra, but is not in this laboratory exercise. Finally, the actuating signal generated by the controller  $G_c(s)$  is translated into a real world signal by the D/A converter and is sent to the actuator.

### ***Proportional, PI and PID Control***

Read Ogata 5<sup>th</sup> ed. for an overview of the above three types of controllers. The control input from a proportional only controller is simply the error signal multiplied by some gain. This is a most simple controller and has limited value when used alone. However, it is important to understand the effect of proportional control, as it is used in conjunction with integral and derivative control (PI and PID).

PI control is the sum of the error signal multiplied by a gain plus the error signal multiplied by a gain integrated over time. The PI controller transfer function looks like:

$$H_{c(PI)}(s) = K_p + \frac{K_I}{s} \quad (2)$$

Its effects will be discussed in the lab exercises.

The PID controller's transfer function appears in (3).

$$H_{c(PID)}(s) = K_p + \frac{K_I}{s} + K_d s \quad (3)$$

It is identical to the PI control transfer function except for the addition of a proportional derivative. Again, its effects will be investigated in the lab exercises.