

ME 4710 Motion and Control

Closed Loop Hydraulic Positioning System

Introduction

- **Fig. 1** shows the block diagram of a basic closed-loop, hydraulic actuation system. The system consists of a linear proportional control valve, a hydraulic cylinder, and a proportional controller.
- The transfer functions $G_v(s)$ and $G_{cyl}(s)$ represent the **valve** and **cylinder** dynamics, respectively. The input to the system ($R(s)$) may represent the **desired speed** or **position** of the cylinder, and the output ($Y(s)$) may represent the **actual speed** or **position** of the cylinder.
- Due to the **dead-band** experienced with many linear proportional valves, they are probably better suited for **velocity control** than position control. However, we will consider the use of this system to control the position of the hydraulic cylinder.

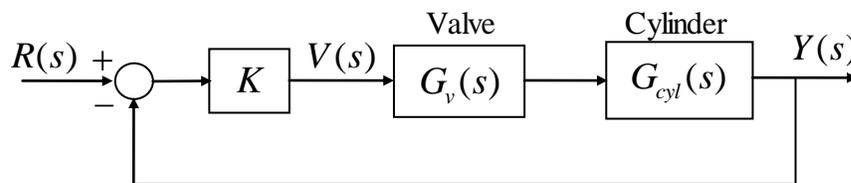


Figure 1. Block Diagram of a Closed-Loop Hydraulic Actuation System

- To understand the response of the closed-loop system, we start by analyzing the open loop system shown in Fig. 2. Unfortunately, measurements of this system show the transfer functions $G_v(s)$ and $G_{cyl}(s)$ both depend on the magnitude of the input voltage $V(s)$. In short, the system is **non-linear**.
- Analysis of this system is further complicated by **voltage limits** on the valve. The valves used in the laboratory, for example, have an input voltage limit of ± 10 volts.

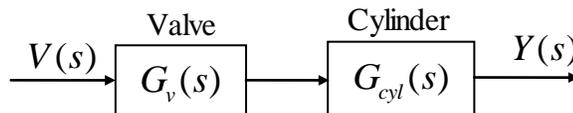


Figure 2. Block Diagram of an Open-Loop Hydraulic Actuation System

- It should be noted that, even though the transfer functions $G_v(s)$ and $G_{cyl}(s)$ do change as the input voltage $V(s)$ changes, the **form** of the transfer functions **does not change**.

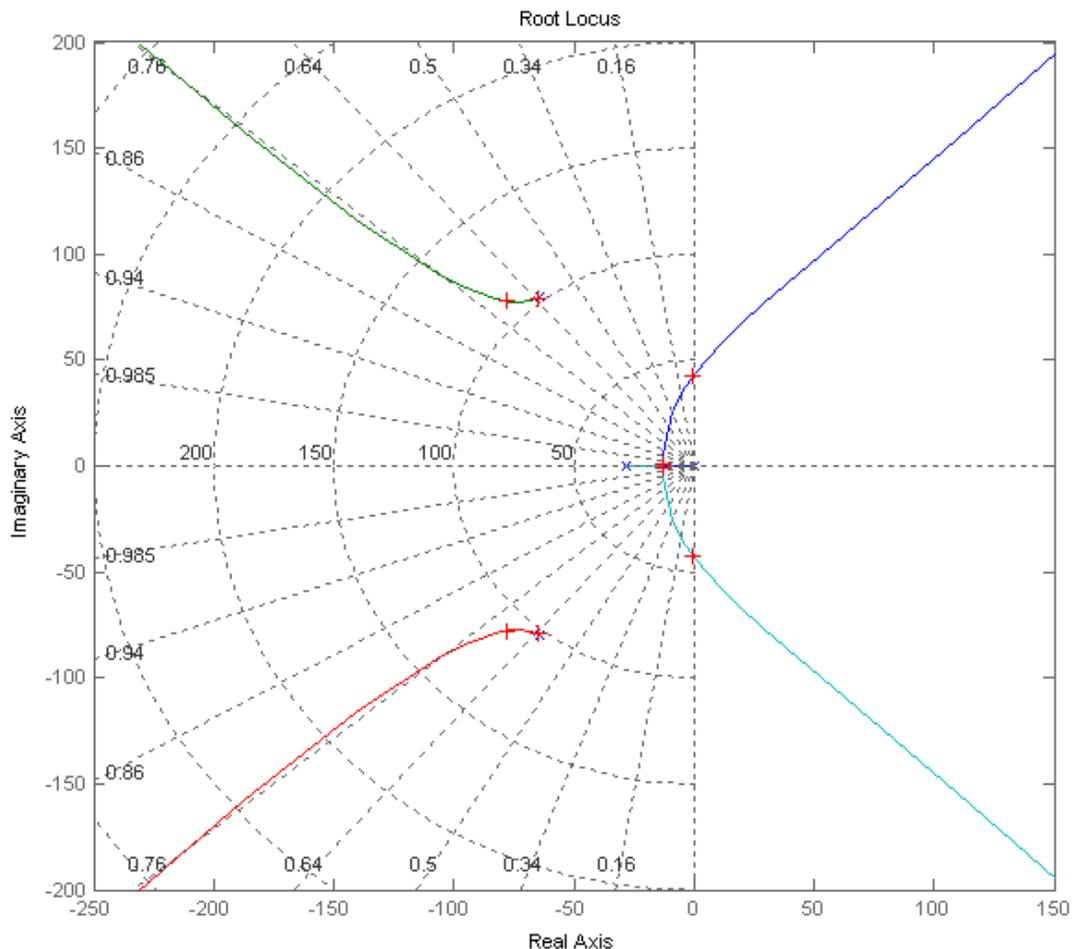
- In fact, for some range of voltages, the *transfer functions are similar*. For example, transfer functions calculated for a 5 volt command (as part of the Data Acquisition Laboratory) tend to provide reasonable predictions of the cylinder position response for a 7 volt command.

Root Locus Analysis of Closed Loop System

- To get an initial estimate of what proportional gain K could be used for the closed loop system, we will use the transfer functions derived from the 5 volt data. This should be a good representation of the system at larger voltages. In this case then, the loop transfer function is

$$GH(s) = \frac{116303}{s(s + 27.864)(s^2 + 127.83s + 10417)}$$

- The *RL diagram* shown in Fig. 3 indicates that the system will be *stable* for $0 < K < 190$ and the two slowest poles will be *critically damped* for $K \approx 15$.



Simulation of the Closed Loop System

- **Fig. 4** shows a Simulink model of the closed loop hydraulic actuation system. As in the root locus analysis, the valve and cylinder transfer functions were derived from the 5 volt data.
- The model assumes these transfer functions apply for all voltages, and in this sense, it is *linear*.
- However, the model also includes the *non-linear* effects of *saturation* and *dead-band*. The command to the valve and the valve position are both forced to be in the range of ± 10 volts, and for small commands it is assumed to have no response.
- The code sends the calculated data for *valve command*, *valve response*, *cylinder speed*, and *cylinder position* to the MATLAB workspace for later plotting and analysis.

Closed Loop Valve and Cylinder Response with Voltage Clipping and Dead-band

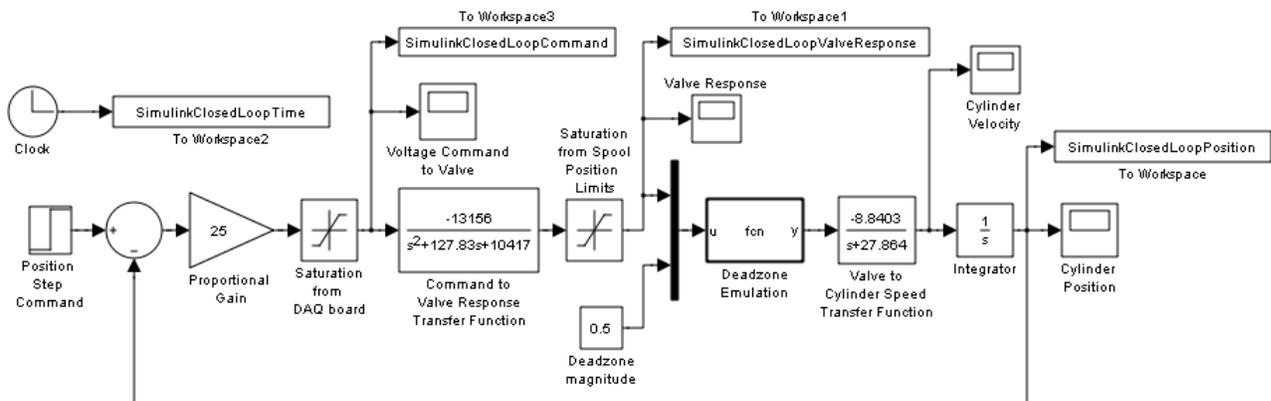


Figure 4. Simulink Model of Closed Loop Hydraulic Actuation System

- **Fig. 5** shows the results using a proportional gain of $K = 25$, saturation limits of ± 10 volts, and a dead-band of ± 0.5 volts. Note the *valve command* is *saturated* for about the first 1.8 seconds of the run forcing the cylinder to run at maximum speed until it is close to the final value. At that point the valve command quickly decreases to its minimum value.
- Note that when the command gets within the *dead-band*, the cylinder velocity goes to zero. As a result, the final position of the cylinder may exhibit a steady-state error.
- Note the “closed loop” system behaves like an “open loop” system for about the first 1.8 seconds. After that time, as the command reduces to its lowest value, the system

behaves as a closed loop system. Because the transfer functions will vary with command magnitude, the actual system will not have this exact response.

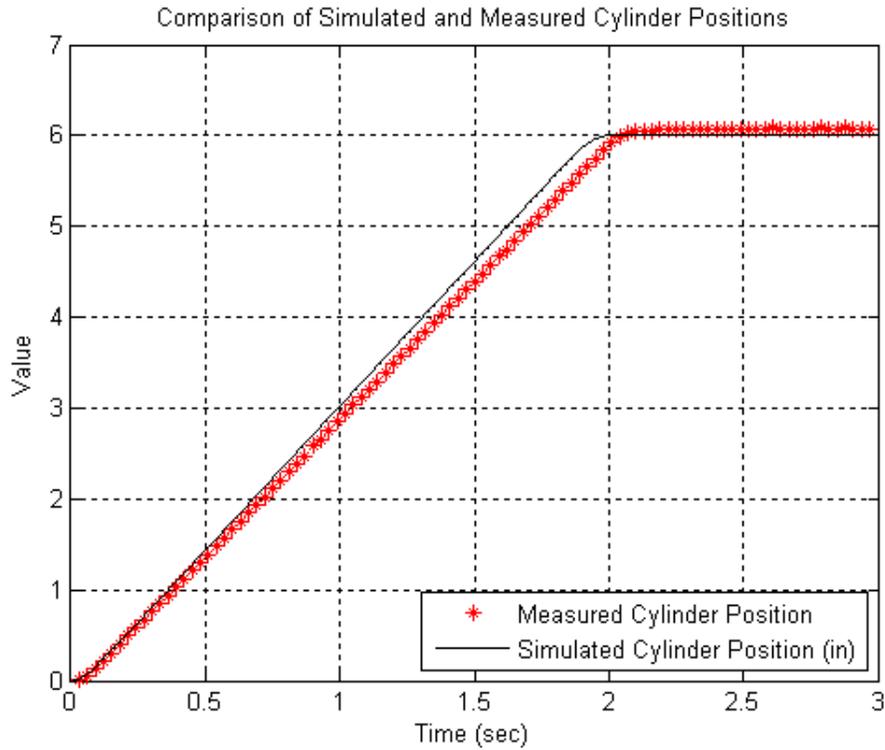


Figure 5. Closed Loop Cylinder Step Response (6 inch step)

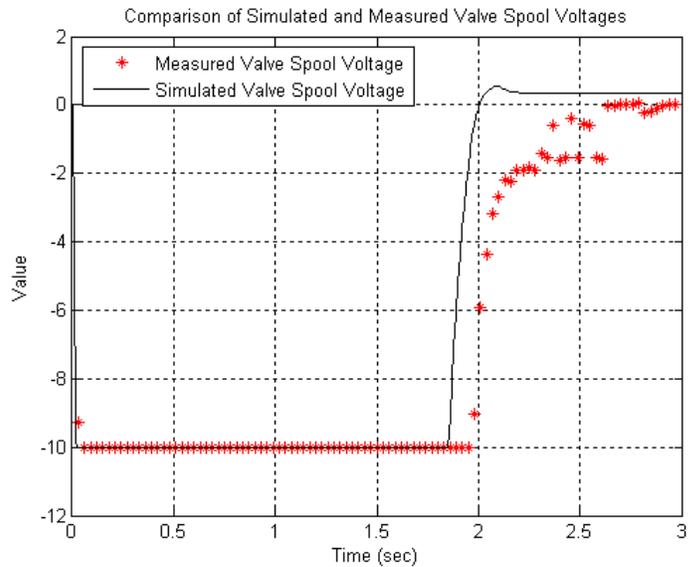
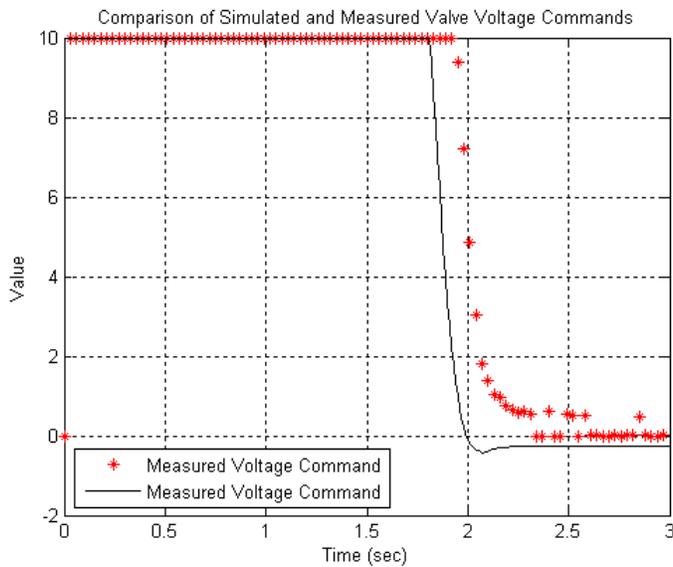


Figure 6. Closed Loop Valve Command and Spool Responses