Introductory 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 $(R(s))$ can represent the ***desired speed*** or ***position*** of the cylinder, and the ***output*** $(Y(s))$ can represent the ***actual speed*** or ***position*** of the cylinder.

Linear proportional valves are probably better suited for controlling the ***velocity*** of a hydraulic cylinder because of ***dead-band*** associated with the valve spool position. However, in the example that follows, a linear proportional valve is used to control the position of a hydraulic cylinder.

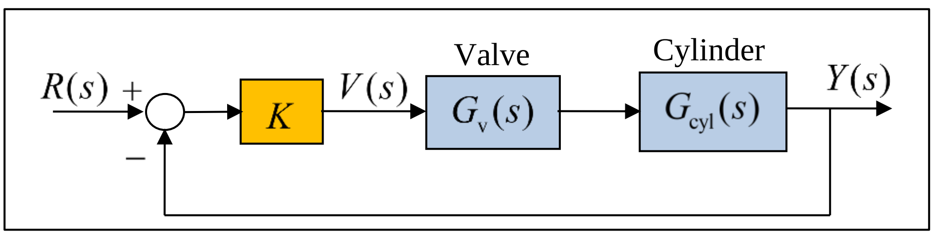

Fig. 1. Block Diagram of a Closed-Loop Hydraulic Actuation System

To understand the response of the closed-loop system, 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, for example, can have an input voltage limit of ± 10 volts.

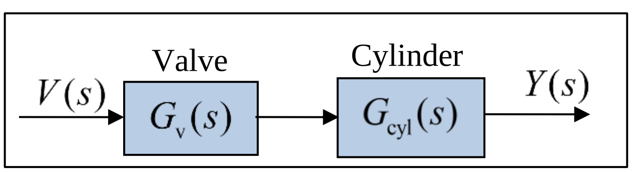

Fig. 2. Block Diagram of an Open-Loop Hydraulic Actuation System

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 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, the transfer functions derived from the 5-volt data will be used. This should be a good representation of the system at larger voltages. In this case, the loop transfer function is

$$GH(s) = \frac{116303}{s(s+27.864)(s^2+127.83s+10417)} \quad (1)$$

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

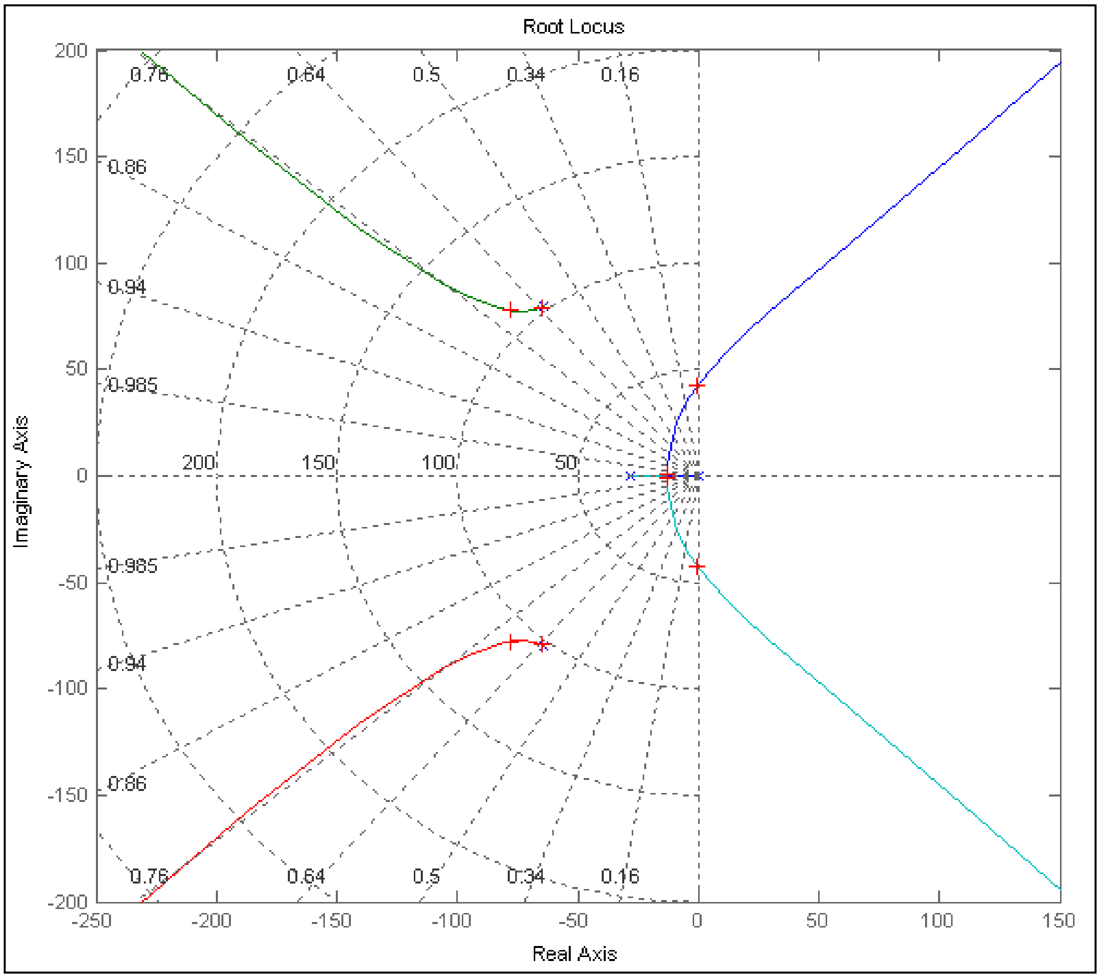

Fig. 3. Root Locus Diagram for Hydraulic Actuation System of Eq. (1)

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 a ***linear*** model. However, the model also includes the ***non-linear*** effects of ***saturation*** and ***dead-band***. The ***command*** to the ***valve*** and the ***valve spool position*** are both forced to be in the range of ± 10 volts (saturation), and for small commands it is assumed to have no response (dead-band).

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.

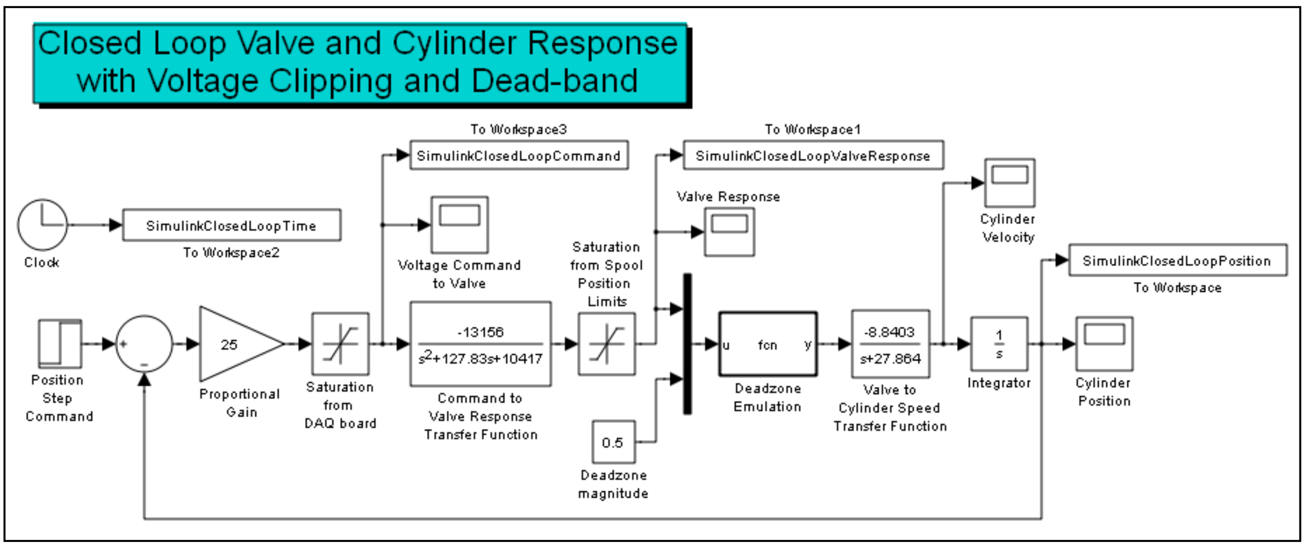

Fig. 4. Simulink Model of Closed Loop Hydraulic Actuation System

Fig. 5 shows the ***model*** and ***test 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.

The "closed-loop" system behaves like an "open-loop" system for about the first 1.8 seconds of the response. 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.

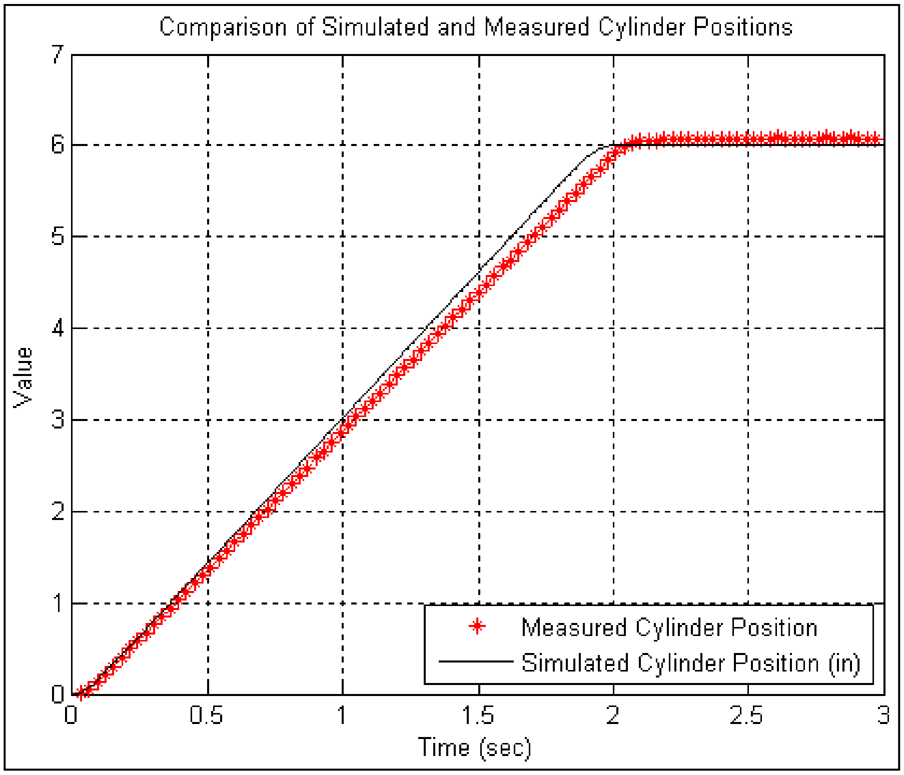

Fig. 5. Closed Loop Cylinder Step Response (6-inch step)

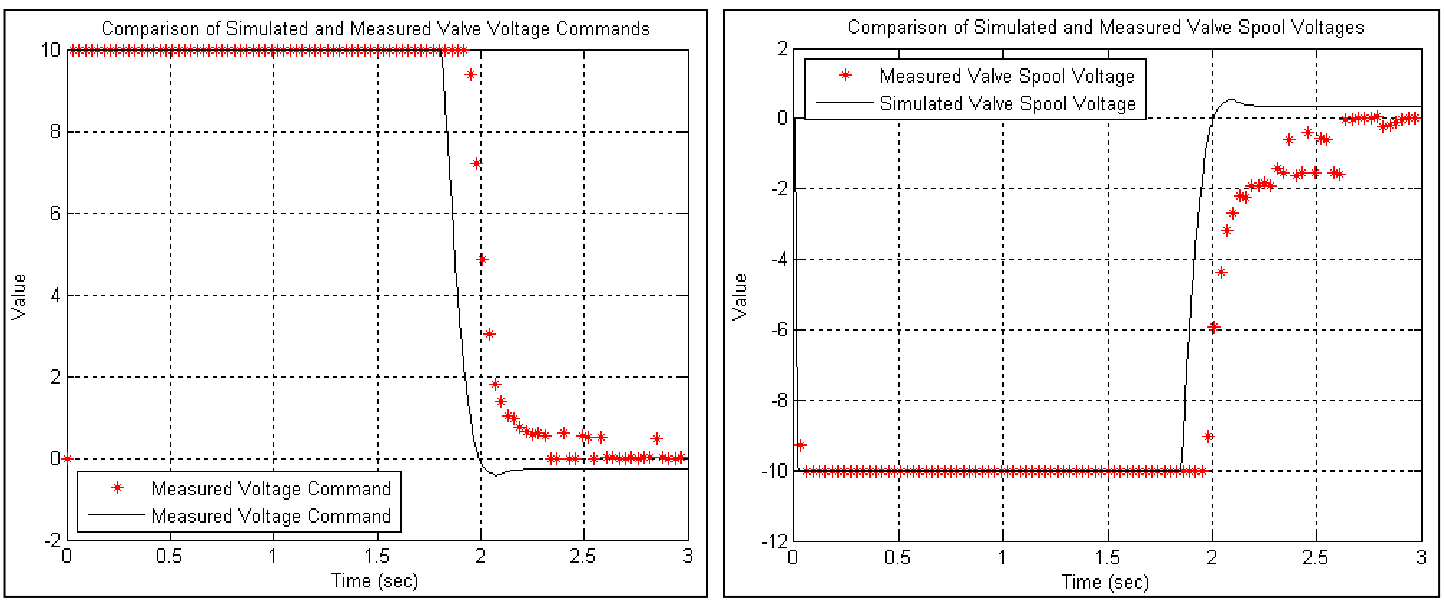

Fig. 6. Closed-loop Valve Command and Spool Responses