MTS FSE MODULAR TRAINING

Closed Loop Control

July 8, 2015 Rev D

be certain.

What is Open Loop Control?

- Control where there is no feedback to make corrections to the process to ensure correct operation of the system.

- A lawn sprinkler system using a timer is an example of open loop control.
  - The timer is set to turn on the sprinkler every day.
  - If it is raining out the sprinkler does not need to run however the timer does not know it is raining.
  - The sprinkler will run and the lawn will flood

Closed Loop - Definition

- Definition of Closed Loop Control *
  - An automatic control system in which an operation, process, or mechanism is regulated by feedback

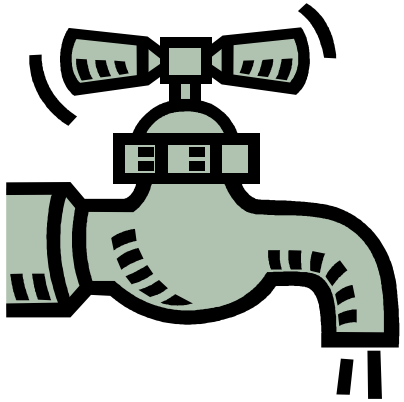
- A key element of a closed loop system is feedback
  - A method of monitoring the output of the process such as temperature, speed, force or any other characteristic which can be measured
  - Another way to think of this is to monitor the effect of the process
    - Did the temperature go up? Down?

- Another key element is the ability to regulate the process using the feedback

* Merriam-Webster

Control Example

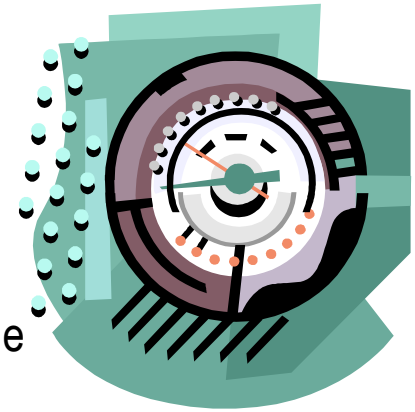
- Open Loop – Fill a Bucket from a Water Faucet
  - Cover the eyes and ears of a person and ask them to fill a bucket of water from a faucet
  - After a couple of attempts they will be able to get close by filling for the same amount of time
  - Replace the bucket they are using with a bucket that is already half full without them knowing it
  - Now running the faucet the same amount of time will overfill the bucket



- Closed Loop – Fill a bucket from a Water Faucet
  - Uncover the eyes and ears of the person filling the bucket
  - Now there are two feedback mechanisms
    - Visual, Sound
  - When the bucket is full the person will shut off the faucet. This is regulating the process of filling the bucket using feedback

Control Example

- Open Loop – Operate the furnace by a programmed amount of time hourly
  - Set the programmer to run the furnace for 10 minutes every half hour
  - When the temperature outside is warm this will produce too much heat
  - When the temperature outside is cold this may not be enough heat
  - Leave a window open and this will not be enough heat



- Closed Loop – Thermostat
  - Automatically starts and stops the furnace or Air conditioning, as the room reaches the desired temperature.
  - The room temperature is the feedback
  - When the room cools or heats, the thermostat again restarts or stops the unit.

Control Example

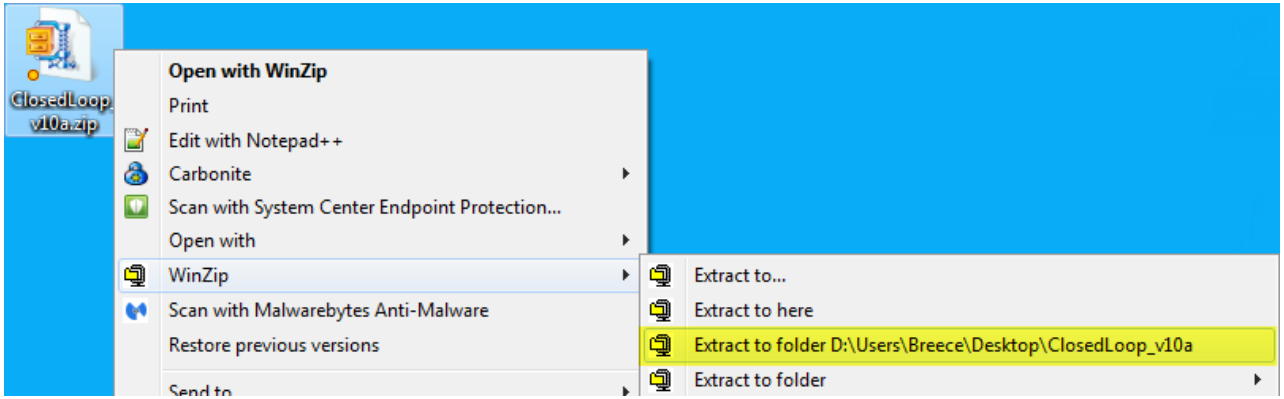
- Open Loop – Automobile
  - Press the accelerator pedal down 10 mm and hold that position while driving on a flat road. Do not change the position.
  - The car will reach a steady speed
  - When you go up a hill the car will slow down. When you come down the hill the car will speed up

- Closed Loop – Automobile cruise control
  - Engage the cruise control at 100 km/h
  - When you go up a hill the throttle is automatically increased to maintain a constant speed
  - When you go down a hill the throttle is automatically reduced to maintain a constant speed
  - The cruise control system monitors the speed (feedback) and automatically regulates the throttle to maintain a constant speed

Closed Loop Control Simulator

- Simulator:
  - Download the file “ClosedLoop_v10a.zip” from the link below to your local hard drive. This is a compressed file in Zip format.
  - If you have WinZip installed right click on file and select
    - WinZip > Extract to folder X:\ ….
  - Use windows explorer and run file “ClosedLoop_v10a.exe”
  - See next page if you do not have WinZip

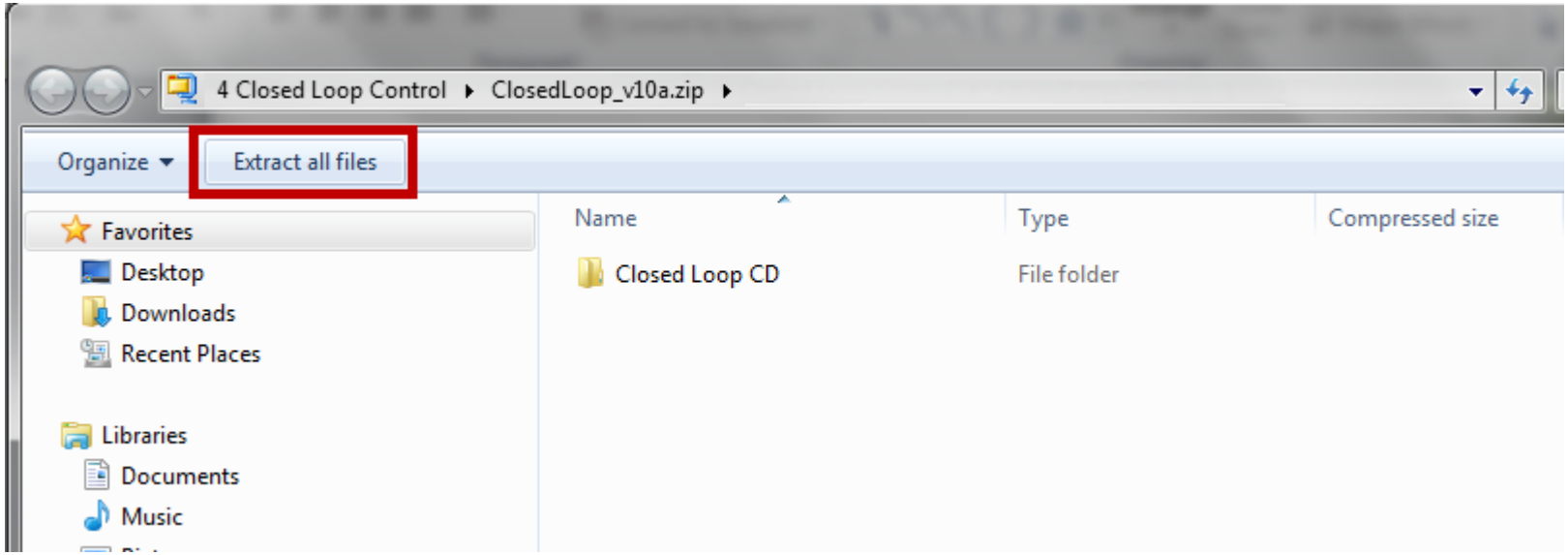
  - Link to Closed Loop Control Simulator



Closed Loop Control Simulator

» Simulator:

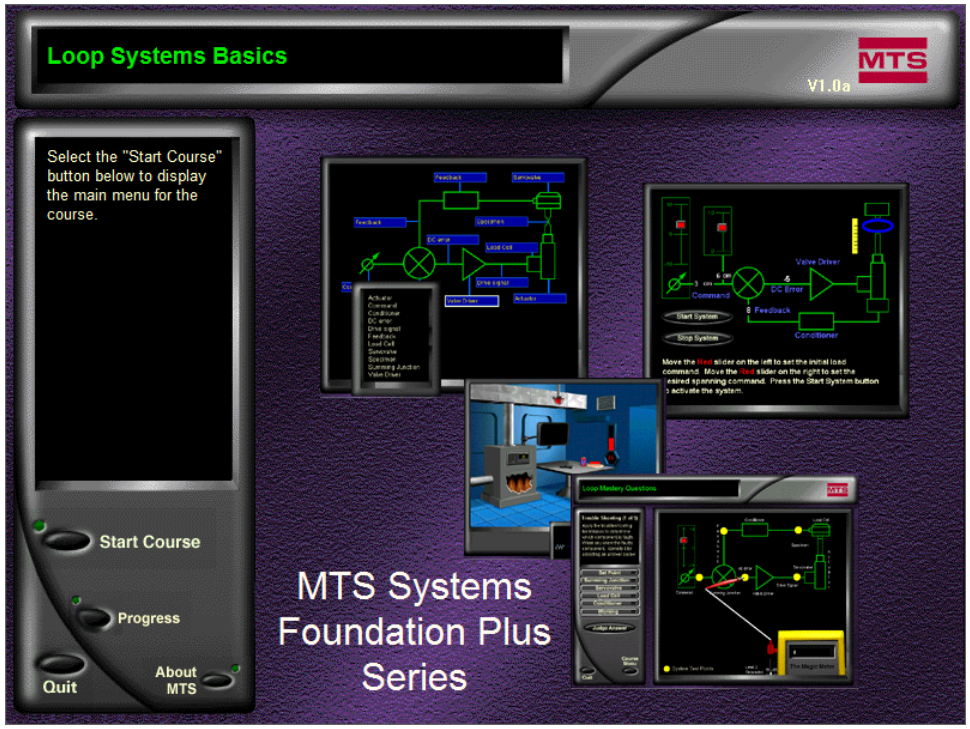
- If you do not have WinZip installed
- Double click on file to open in windows explorer
- Select “Extract All Files” from Menu bar
- Choose a destination folder
- Use windows explorer and run file “ClosedLoop_v10a.exe”



Closed Loop Control Example

» Simulator:

- Complete the Closed Loop Control tutorial
- Do not continue until closed loop tutorial is complete

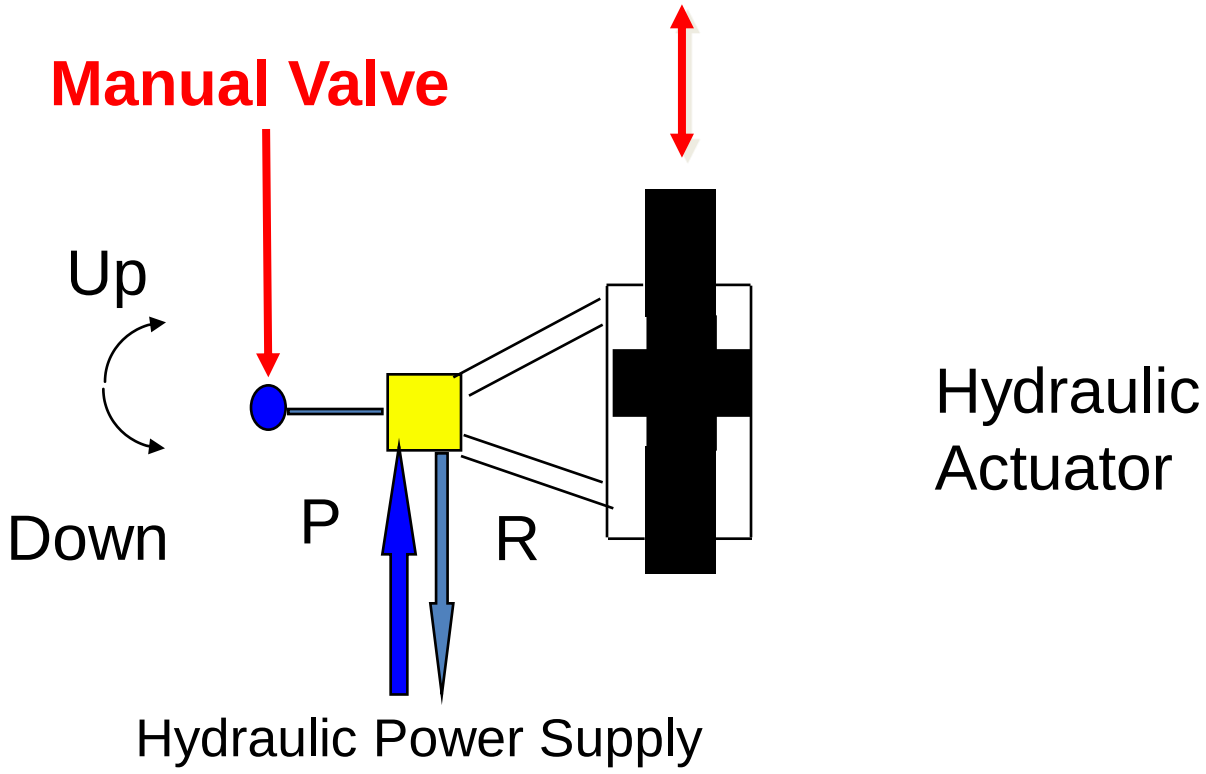


Hydraulic Open Loop Example

- A Dump truck is an example of a open loop hydraulic circuit
  - A hydraulic pump is connected to the engine
  - A manual valve controls the flow of oil
  - Moving the valve one direction ports high pressure oil to the cylinder in a way which raises the dump truck bed
  - Moving the valve in the other direction ports oil so the dump truck bed lowers
  - There is no feedback or automatic control system to stop the bed at a desired position. It will raise or lower until it reaches the end of travel of the cylinder

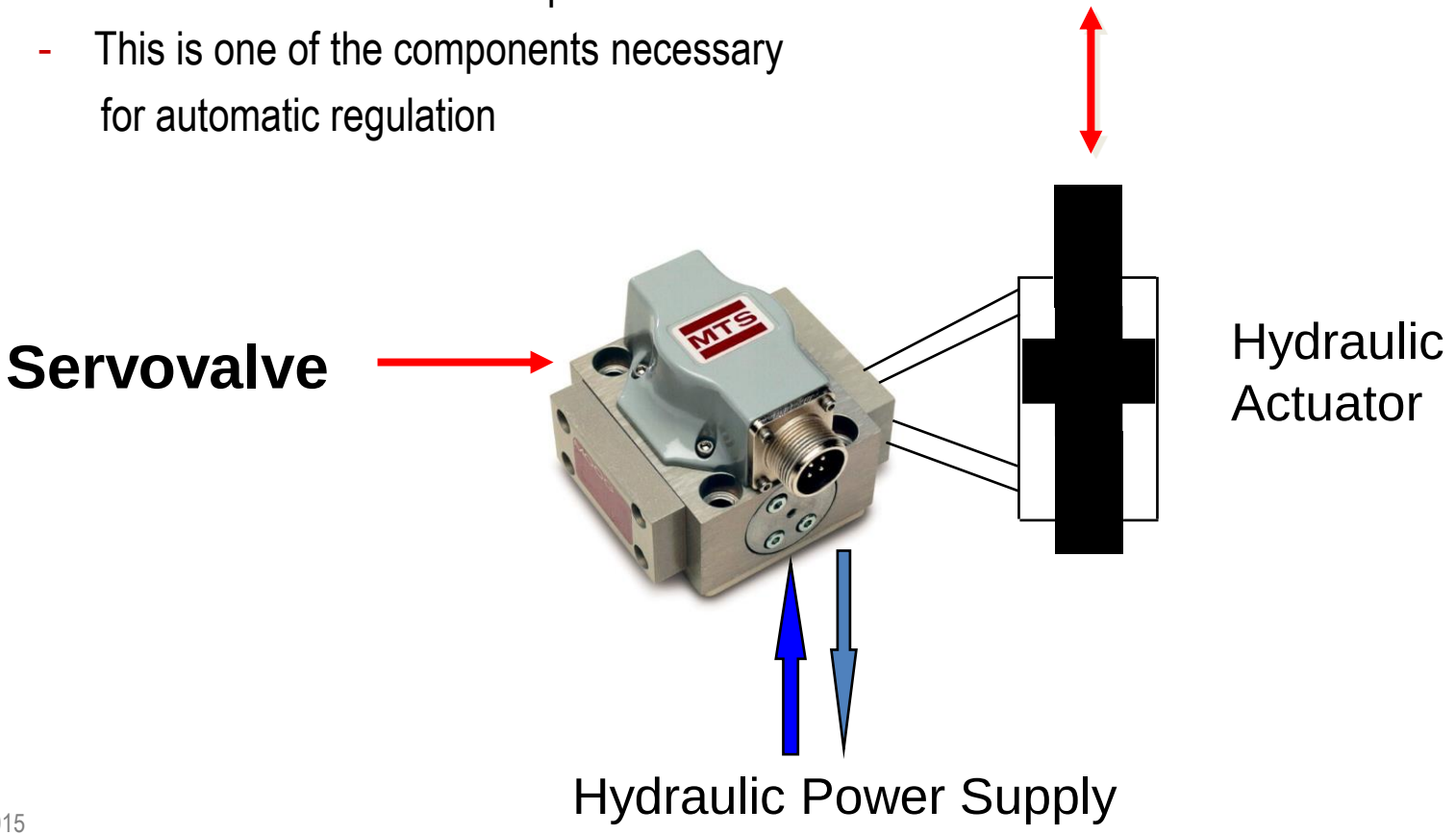
Open Loop System

- Example of open loop hydraulic system
- The valve handle controls oil flow into the hydraulic actuator



Closed Loop System

» In a closed loop system the “Manual Valve” is replaced by an electrically operated valve to control the flow of oil into the hydraulic cylinder
  - MTS uses a Servovalve to perform this function
  - This is one of the components necessary for automatic regulation



Closed Loop System Components

Hydraulic Power Unit
- Provide Hydraulic Power

Controller
- Closed Loop Control
- Transducer / Feedback Conditioner

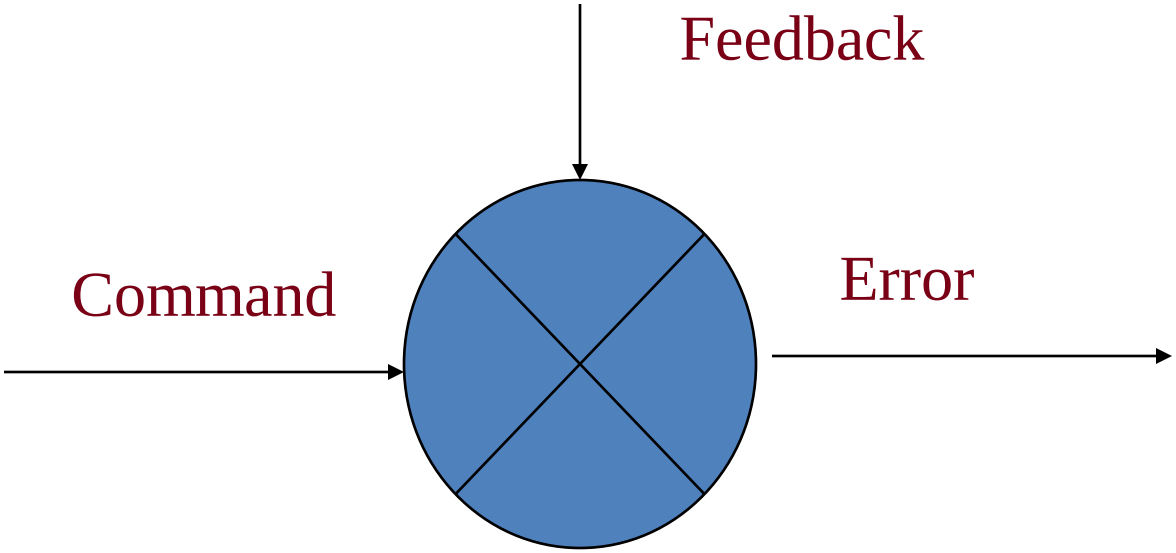
Load Frame
- Position Transducer
- Force Transducer
- Servovalve
- Hydraulic Service Manifold

Hydraulic System Closed Loop Control

- Lets put this all into a basic hydraulic closed loop system.
- In our Hydraulic system we have the following components:
  - Controller – Device regulating the system
    - Equivalent to digital thermostat in Lab example
  - Actuator – Device being controlled by closed loop
    - Equivalent to flame in Lab example
  - LVDT – Feedback – Used to measure the position of the hydraulic actuator
    - Equivalent to temperature gage in Lab example
  - Servo Valve – Used to move actuator to new position
    - Equivalent to gas valve in Lab example

Summing Junction

» What make this different from the open loop system is feedback and the addition of the summing junction.

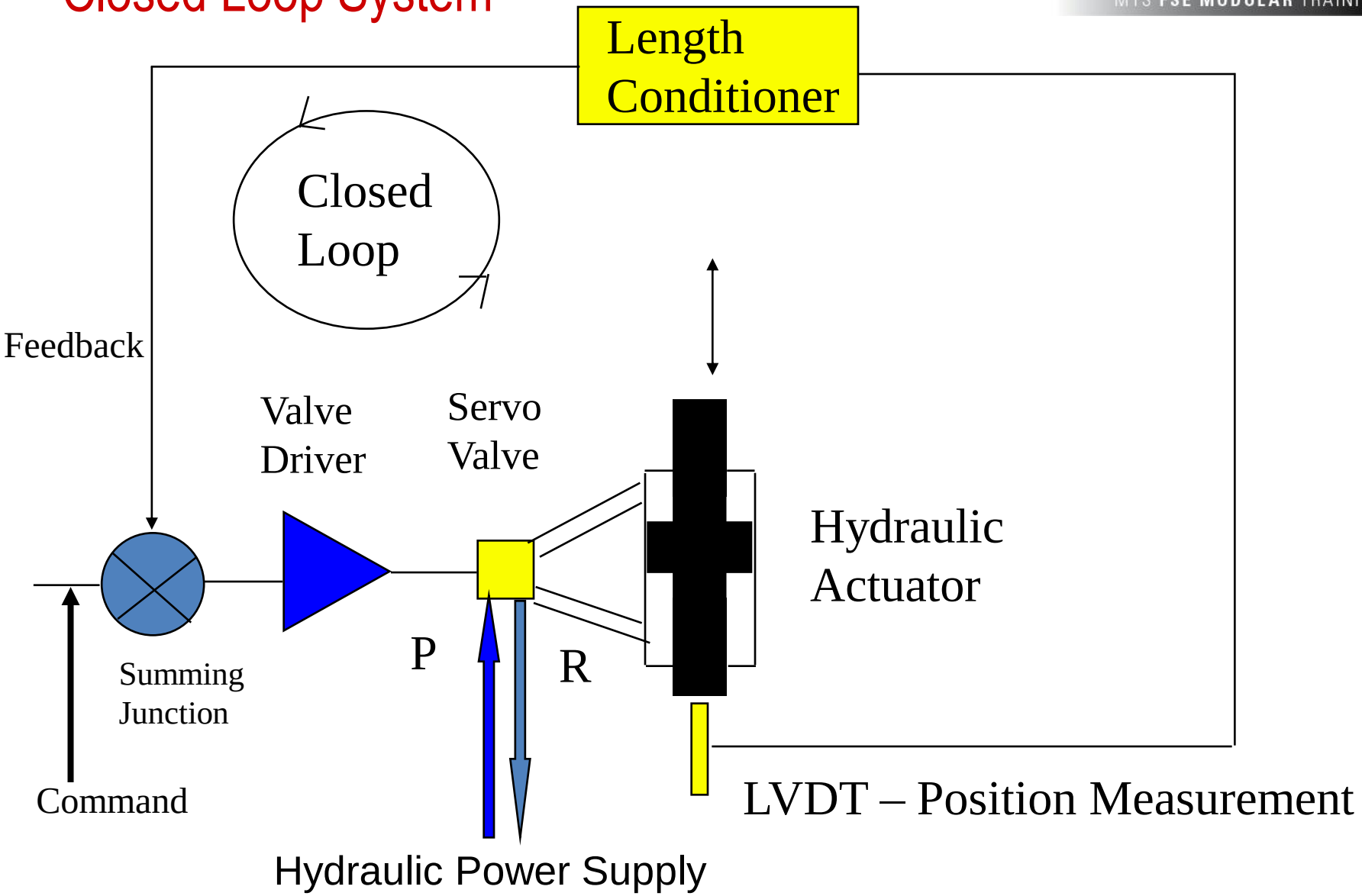


Command - Feedback = Error

Summing Junction

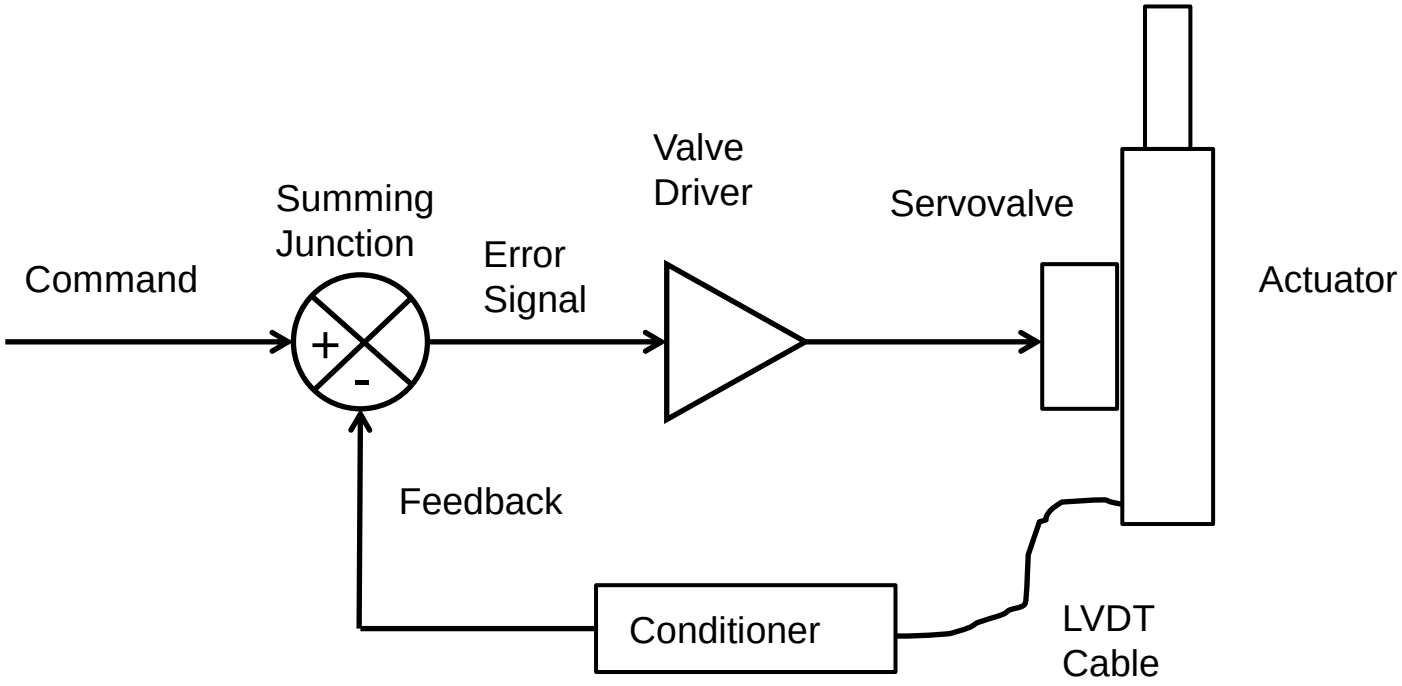
- The function of the summing junction is to compare two inputs, Command and Feedback, and output the difference. The difference is continuously computed even when hydraulic power is not energized
  - Command is what we are asking the system to do
  - Feedback is what it is actually doing
  - Error is the output of the summing junction
    - The term Error does not mean something is wrong. This is a control loop term which simply means the difference of the command and feedback
- In digital controllers, like FlexTest products, the summing junction is a software routine.
- The complete closed loop system is illustrated on the following pages

Closed Loop System



Closed Loop Diagram

» The symbols shown below for summing junction and valve driver are commonly used in closed loop control diagrams



Valve Driver

- In the previous slide there is a block between the error output of the summing junction and the servovalve
  - This is the valve driver
  - This converts the error signal being output of the summing junction into an electrical signal that be sent to the servovalve
  - In the case of MTS controllers this converts the error to a current signal
    - +50mA = rated servovalve flow one direction and -50mA = rated servovalve flow in the opposite direction

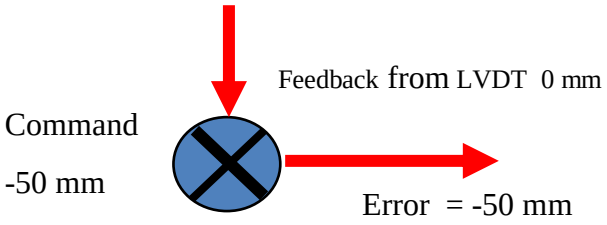
Closed Loop Feedback

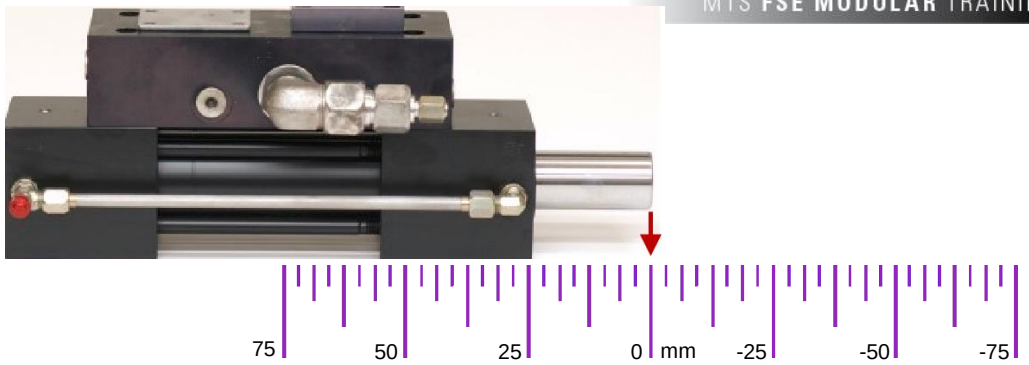
- Common MTS control methods
- Displacement Control (stroke control is another term for this)
  - Actuator moves to commanded position regardless of force required
  - Will move until actuator reaches commanded position or maximum actuator force
  - Closed loop control continuously computes error and regulates the system using the feedback even after reaching the commanded position.
  - If the position changes for some reason the error will regulate the system and return the actuator to the commanded position
- Force Control (load control is another term for this)
  - Actuator moves to commanded force regardless of amount of travel required
  - Will move until actuator reaches commanded force or maximum actuator travel
  - Closed loop control continuously computes error and regulates the system using the feedback even after reaching the commanded force.
  - If the force changes for some reason the error will regulate the system and return the actuator to the commanded force

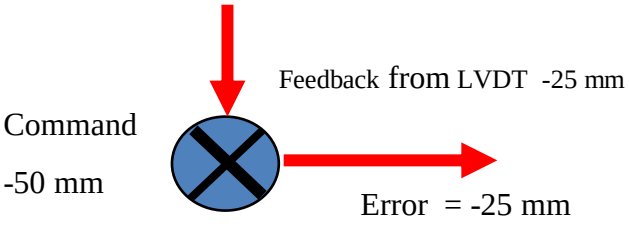
Error Signal

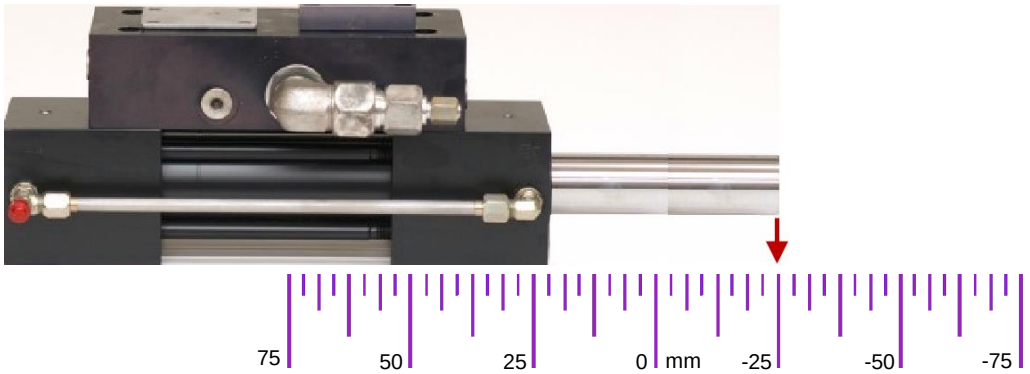
- When the command and feedback do not agree the error value increases. This signal then tells the servovalve to open. This will port oil to one side of the actuator causing it to retract or extend.
- As the two signals approach each other, the magnitude of the error value gets smaller.
- When the error value is equal to zero, the servovalve closes and the system holds the position if in displacement control or load if in force control.
- In the example on the following page the actuator is at 0 mm and is commanded to negative 50 mm. Note the error signal value.
  - The top image is at the instant the command changes
  - The middle image the actuator is in the process of moving
  - The bottom image the actuator has reached the command and is stopped moving
- The actuator only moves when the error signal is not zero

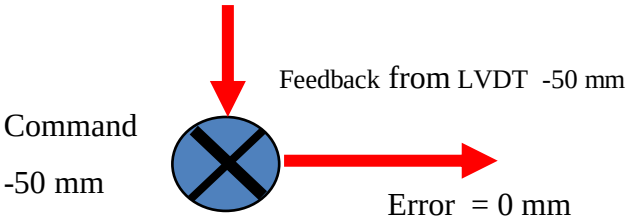
Displacement Control

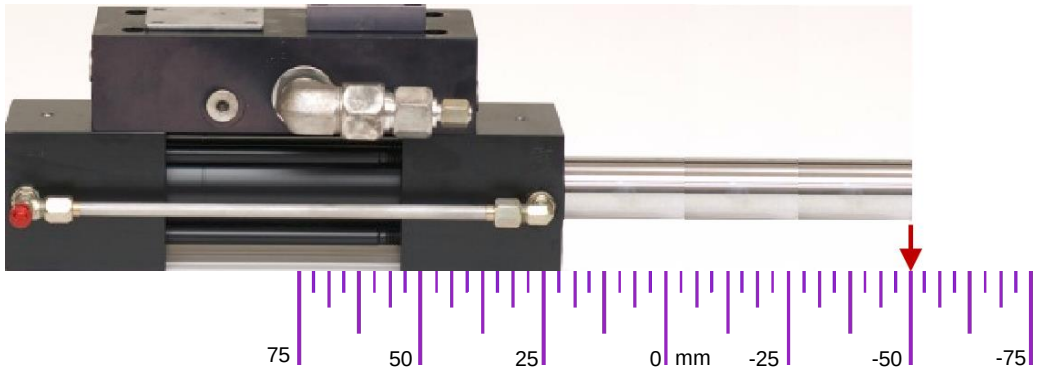












Polarity

- The polarity of the command and feedback indicate direction of actuator movement
- These are not standardized and are customer or application dependent

- Typical Load frame configuration
  - Positive command and Feedback
    - Actuator is retracting
    - Force is tension
  - Negative command and Feedback
    - Actuator is extending
    - Force is compression

Full Scale Values

- Load Frame example of Full scale and polarity

  + 25 kN = 25 kN Tension on the load cell
  - 25 kN = 25 kN Compression on the load cell
  + 50 mm = 50 mm retraction from center position with no offset
  - 50 mm = 50 mm extension from center position with no offset

- The polarity of the error determines which direction the actuator moves
  - Command minus feedback equals error
    - Be sure to include polarity when manually computing to ensure you have the correct error signal polarity

Control Mode

- The operator can select which one of the available feedback channels will be used to control the servo loop.
  - Displacement control = LVDT feedback
  - Force Control = Load Cell feedback
- This is performed by switching which transducer is used at the summing junction for feedback
  - This is know as changing the control mode
- Both channels are available for data acquisition and limit detection.

Control

- Many factors impact the control loop performance
- Items such as tuning, valve sizing, and other characteristics which define performance will be discussed in upcoming modules

Troubleshooting Closed Loop Systems

» Understanding the basic concept of a closed loop system will allow you to troubleshoot a system which does not function correctly

- Always remember the basic rule
- Command minus Feedback equals Error

- Measure magnitude of Command Signal
- Measure magnitude of Feedback Signal
- Compute the Error signal
- Determine if actuator is carrying out the correct action as indicated by the Error signal

Troubleshooting Closed Loop Systems

- Sometimes it is beneficial to create an open loop condition when having control issues.
  - The easiest way to accomplish this is to put the system in load control with no specimen and to ensure the actuator cannot contact the load cell.
  - Examples of this are in the troubleshooting section of the closed loop control tutorial.

- If in load control with zero load feedback the error signal will equal command
  - This can be used to troubleshoot the system
  - Allows valve current to be created
  - If in stroke control with hydraulics on the actuator will always follow the command resulting in zero error. This prevents analysis of error and valve drive circuits.