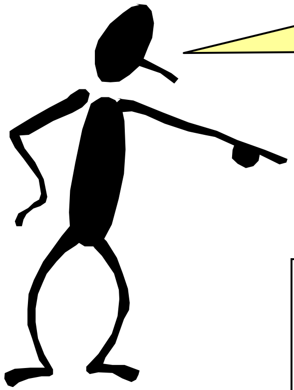
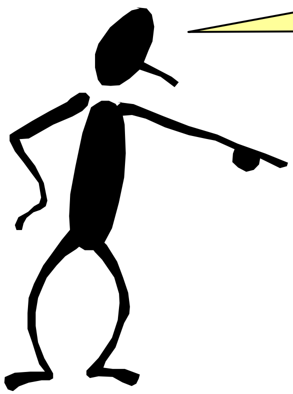
CHAPTER 22: VARIABLE STRUCTURE CONTROL



When I complete this chapter, I want to be able to do the following.

- **Understand why many applications of process control require variable structure**
- **Implement a design using more than one valve in a “control loop”**
- **Implement a design using more than one controlled variable in a “control loop”**

CHAPTER 22: VARIABLE STRUCTURE CONTROL



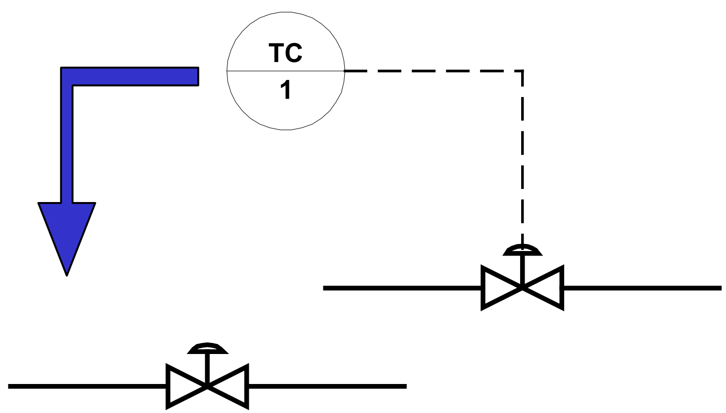
Outline of the lesson.

- **Reasons for variable structure**
- **Split range control**
- **Signal select control**
- **Applications for constraint control**
- **Workshop**

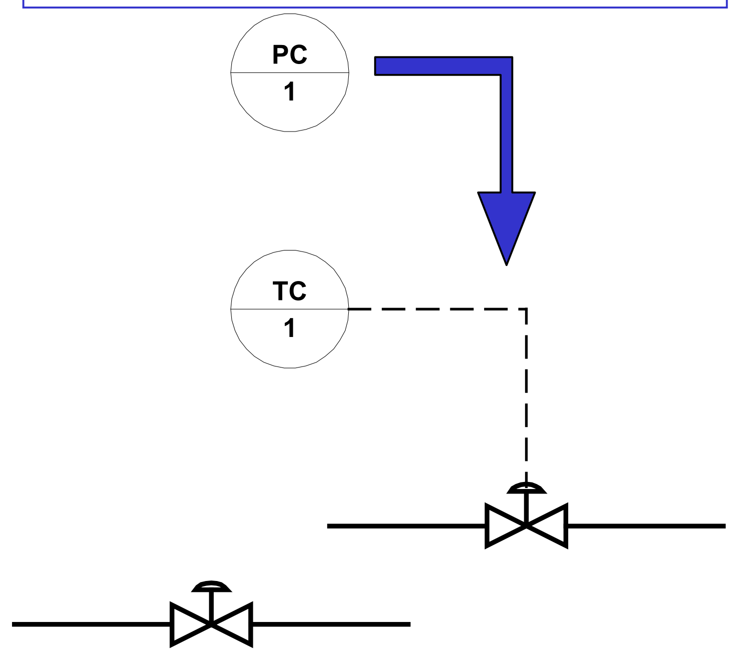
CHAPTER 22: VARIABLE STRUCTURE CONTROL

Sometimes, the control objectives cannot be achieved with a strict pairing of one sensor/controller/valve. We need the flexibility to change the pairing automatically, as part of the control system.

We might need to adjust a different valve



We might need to control a different measured variable



CHAPTER 22: VARIABLE STRUCTURE CONTROL

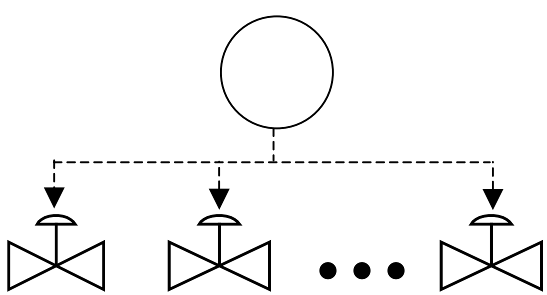
Sometimes, the control objectives cannot be achieved with a strict pairing of one sensor/controller/valve. We need the flexibility to change the pairing automatically, as part of the control system.

In this chapter, we will learn methods that are easily applied

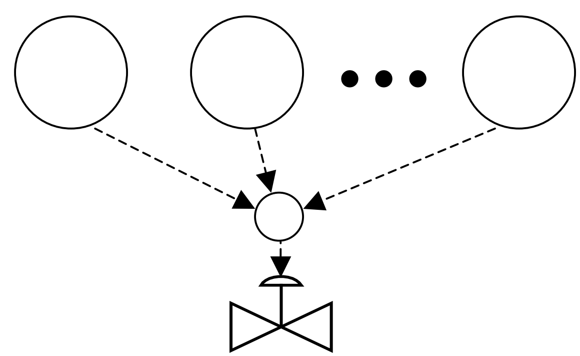
- **Retain the PID (or IMC) single-loop controller**
- **Use the same tuning approaches**

This advantage is gained by accepting the following limitations

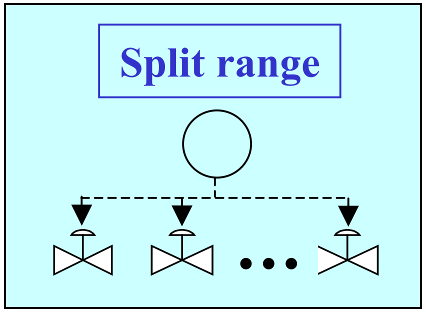
One controller - many valves



Many controllers - one valve

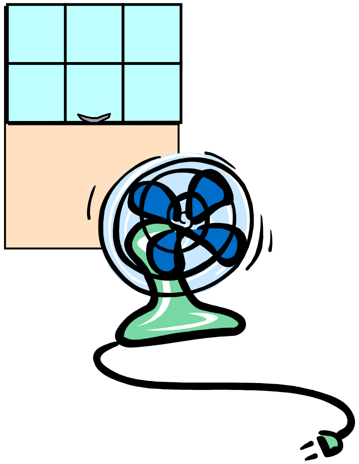


CHAPTER 22: VARIABLE STRUCTURE CONTROL

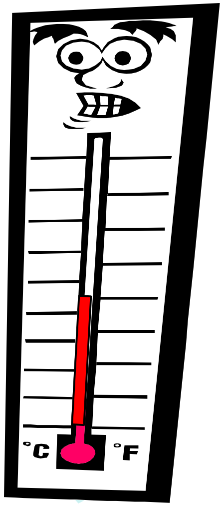


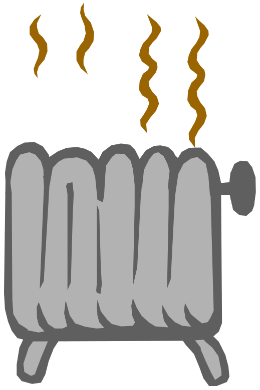
We often manipulate several variables to achieve our objectives.

For example, to achieve a comfortable temperature in a room.



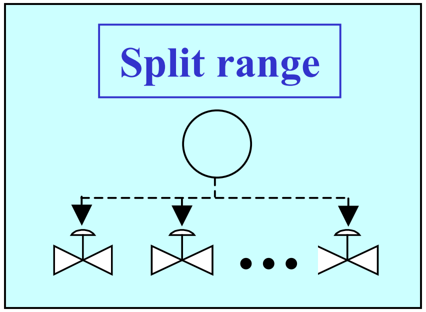
cooling



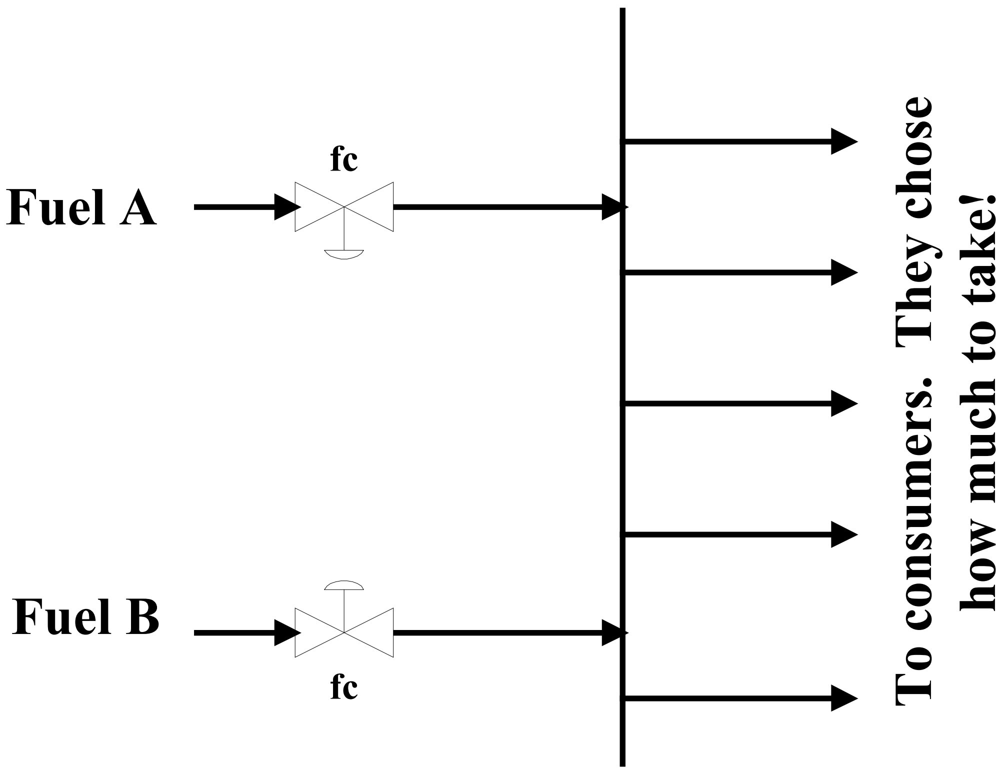


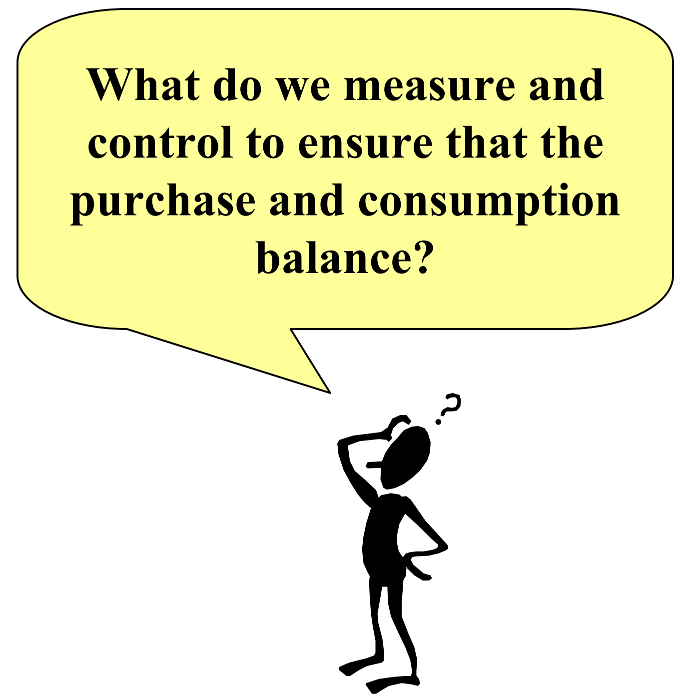
heating

CHAPTER 22: VARIABLE STRUCTURE CONTROL

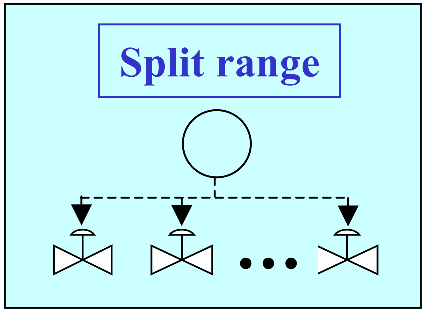


Split range enables one controller to adjust more that one final element. We will introduce this through a process example, purchase and distribution of fuel gases.

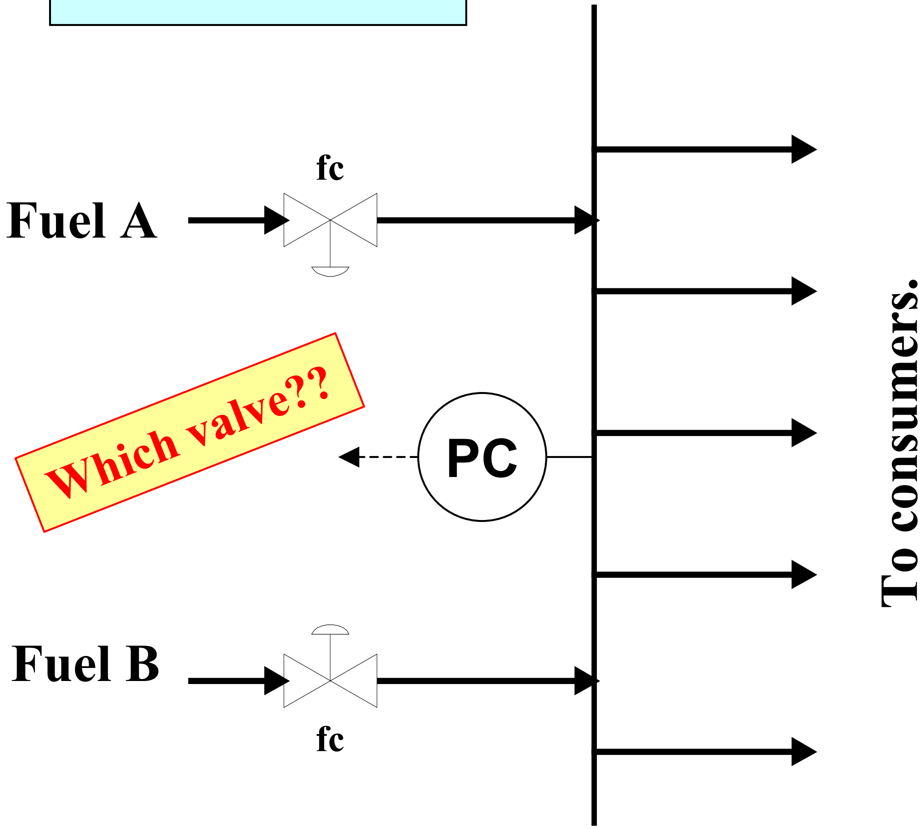




CHAPTER 22: VARIABLE STRUCTURE CONTROL



We chose to control **pressure**.



Measured variable

Pressure which is constant when flows in and out are the same.

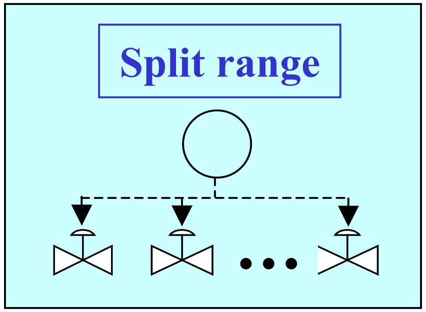
Manipulated variable

Either valve has causal relationship and fast dynamics

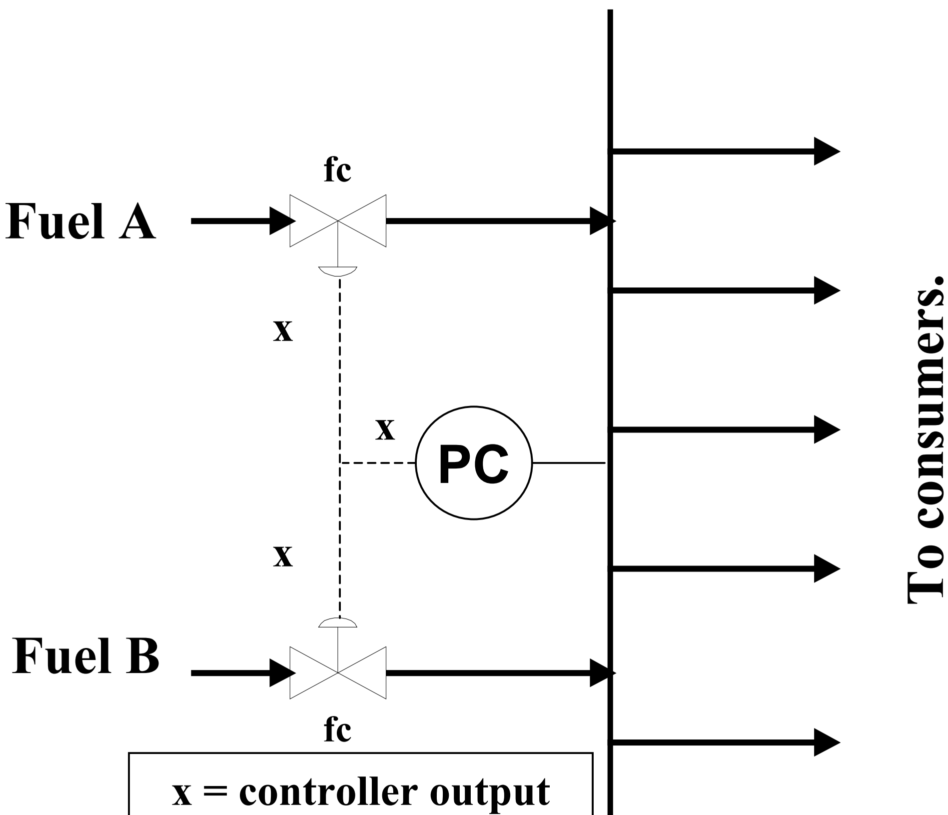
Disturbances

Changes in consumption rate

CHAPTER 22: VARIABLE STRUCTURE CONTROL



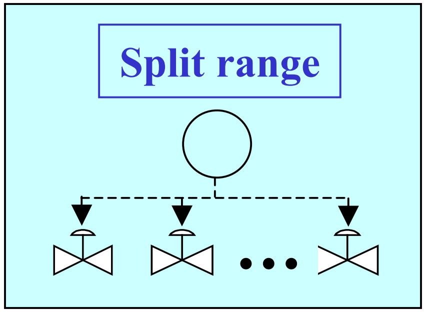
We chose to adjust **both** valves!



Manipulating two valves gives more flexibility, but how does it work?

First, if we adjust two valves, on what basis can we decide which valve to open first?

CHAPTER 22: VARIABLE STRUCTURE CONTROL



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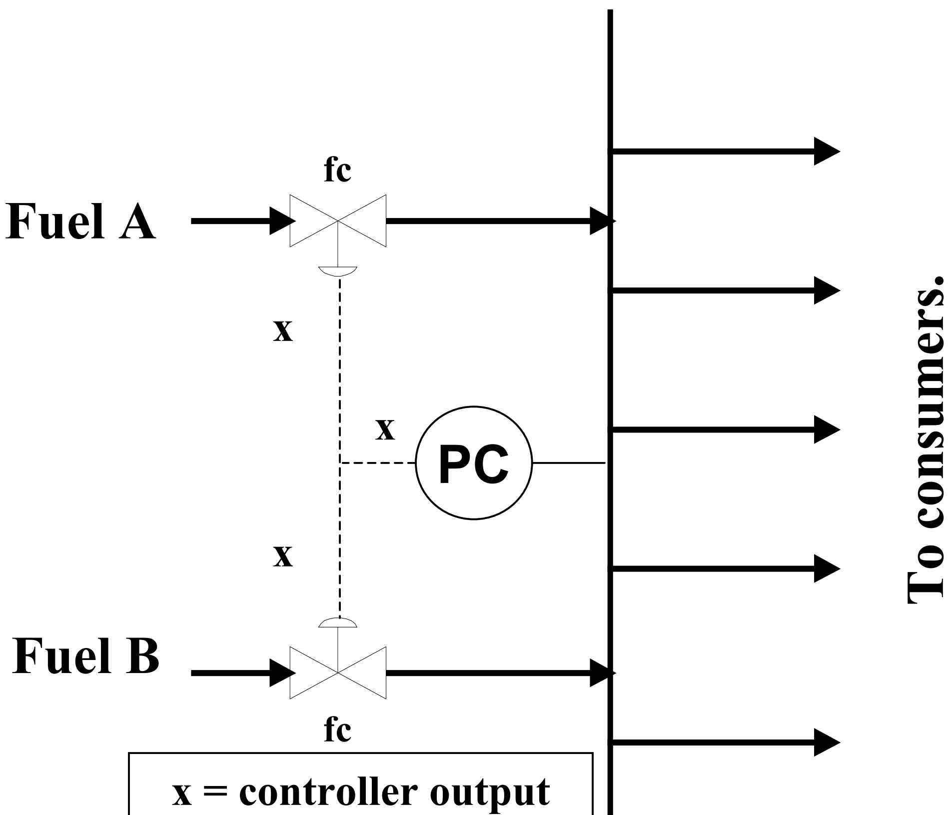

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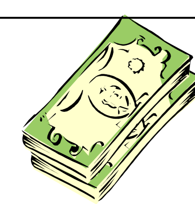
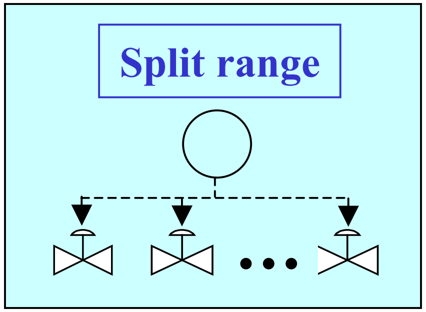
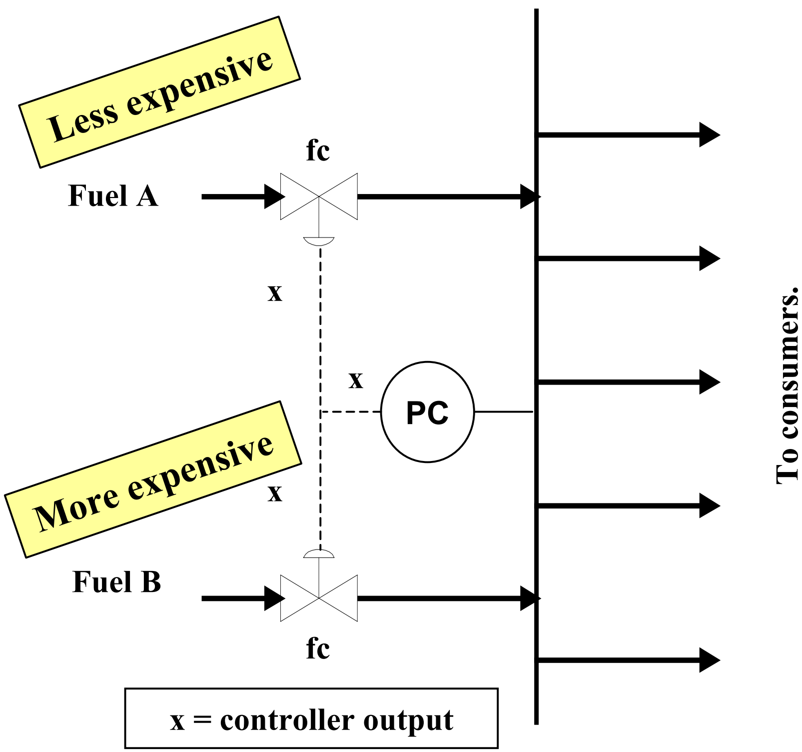
Hint:



CHAPTER 22: VARIABLE STRUCTURE CONTROL

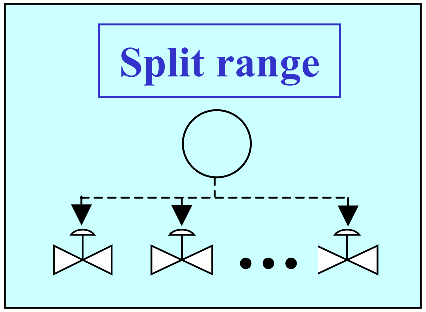


We will have a **ranking** for use of valves. This priority ranking will **not** **change**.



We have determined that fuel A is less expensive than fuel B.

CHAPTER 22: VARIABLE STRUCTURE CONTROL



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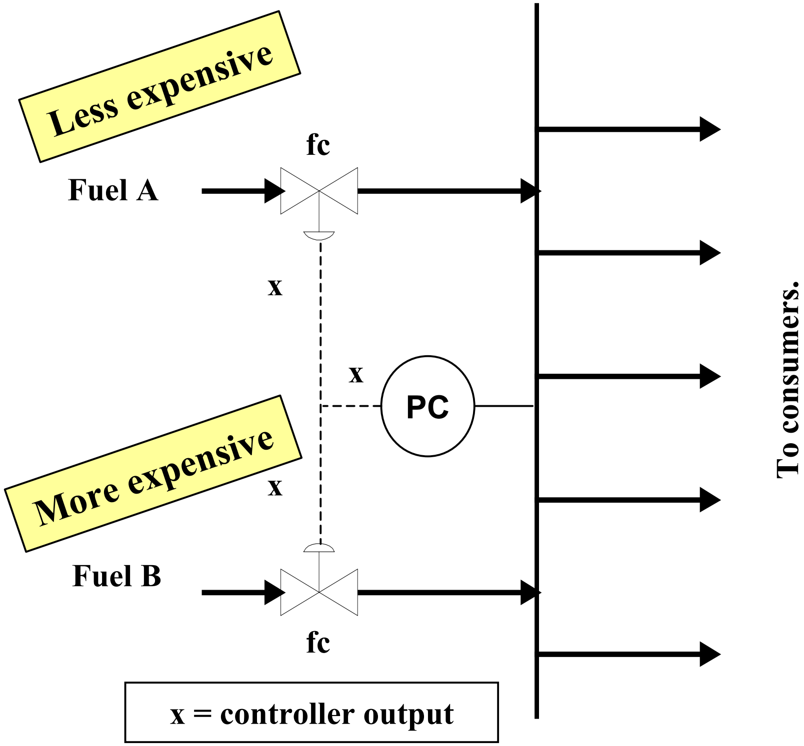
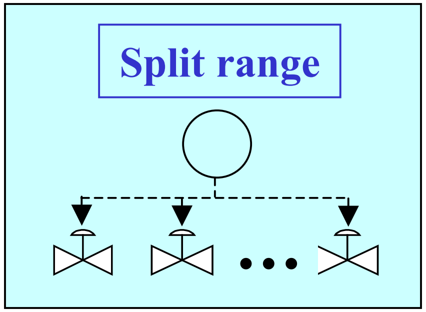


We have determined that fuel A is less expensive than fuel B.

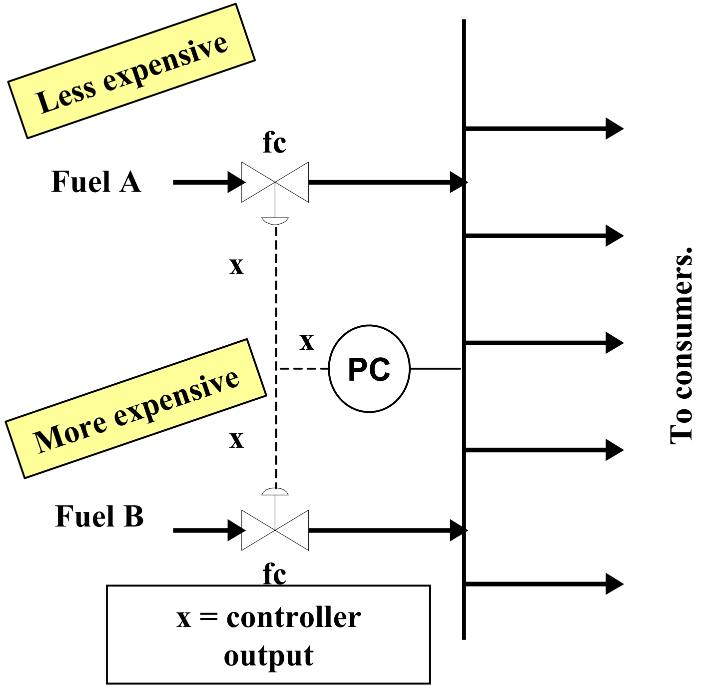
Our strategy is to use only fuel A unless we must use B (when fuel valve A is completely open).

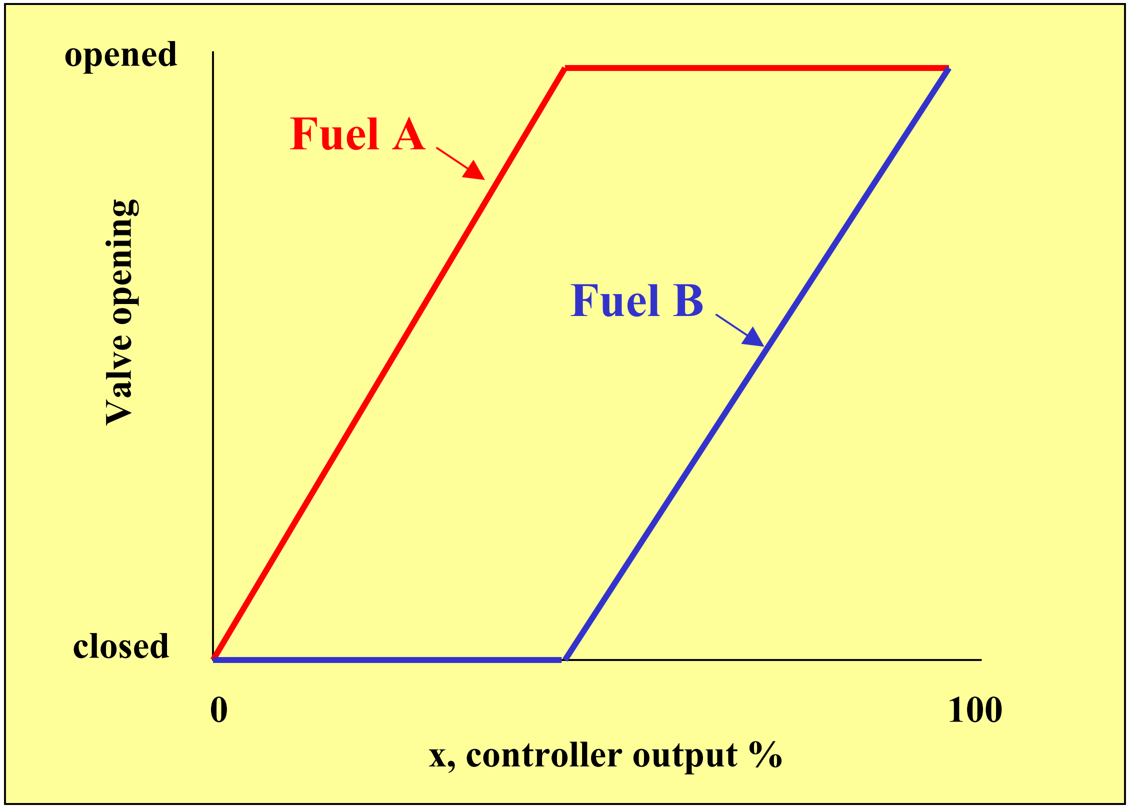
How?

CHAPTER 22: VARIABLE STRUCTURE CONTROL

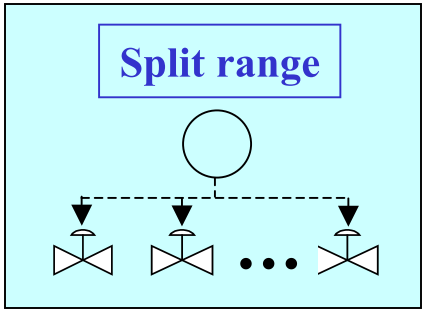


Split range: The valves are calibrated to respond as shown in the figure



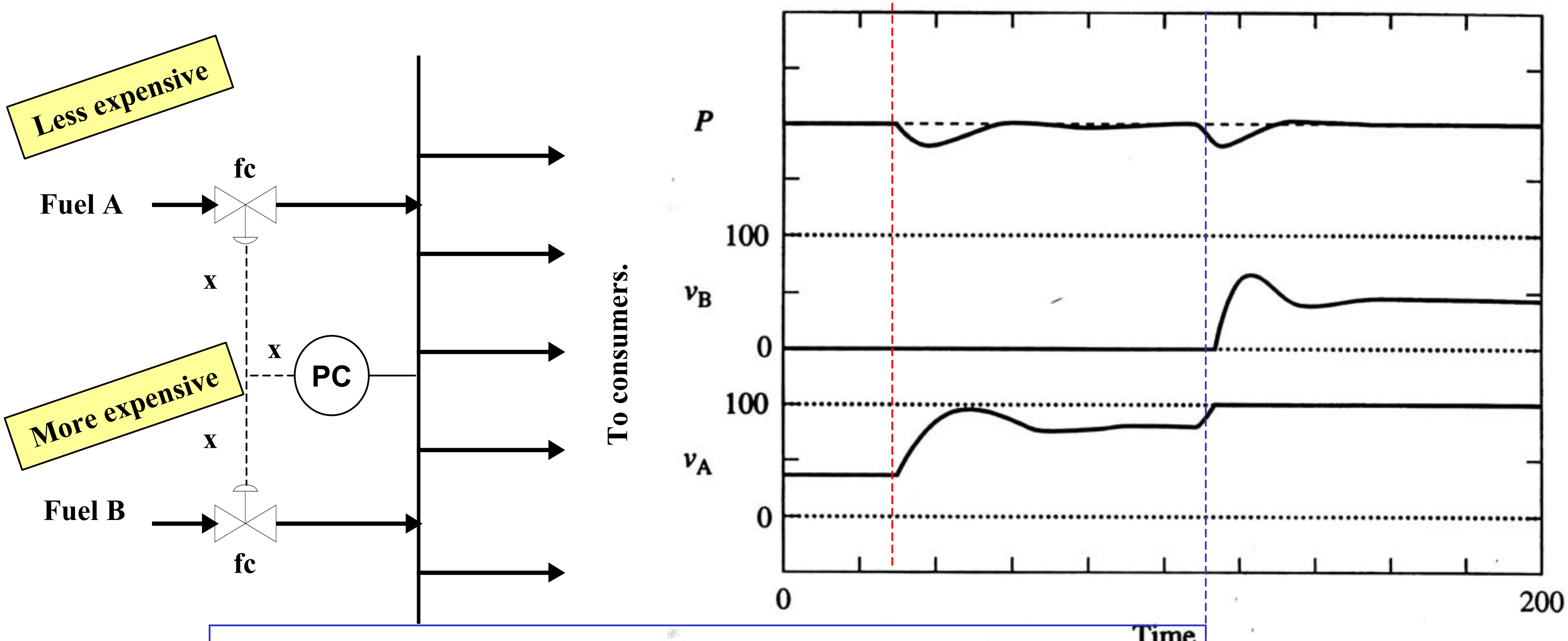


CHAPTER 22: VARIABLE STRUCTURE CONTROL



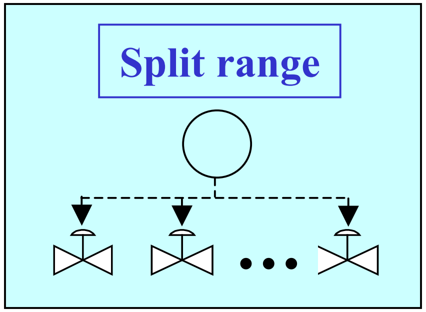
Dynamic response of the split range control system to two step increases in fuel consumption.

First increase in consumption, PC increases its output, which affects only v_A

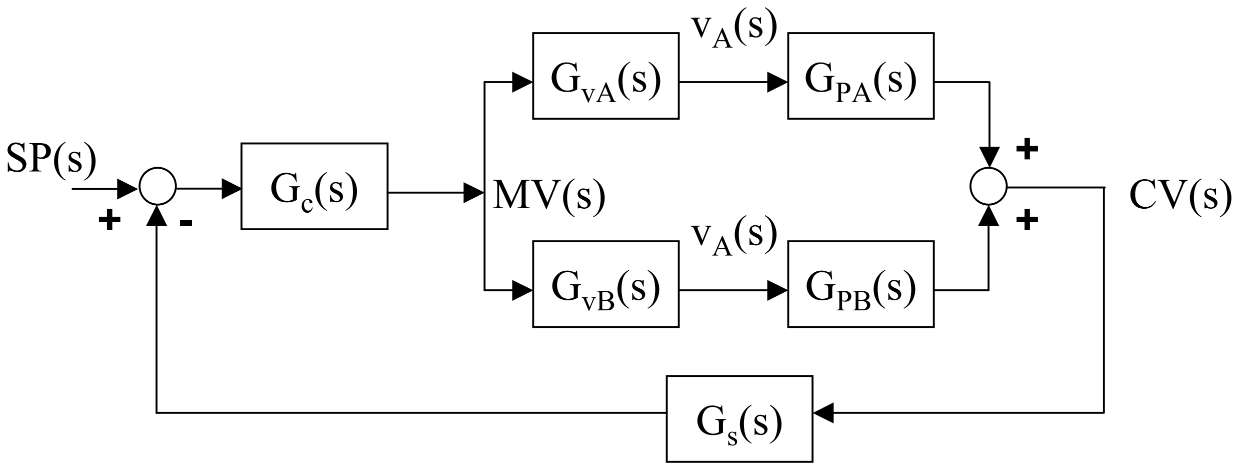


Second increase in consumption, PC increases its output, which increases v_A to its maximum, then begins to open v_B.

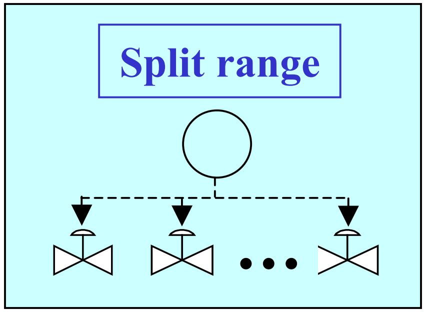
CHAPTER 22: VARIABLE STRUCTURE CONTROL



Split range: **The closed-loop system (characteristic equation) changes when the valve being adjusted changes. This affects stability and performance.**



CHAPTER 22: VARIABLE STRUCTURE CONTROL



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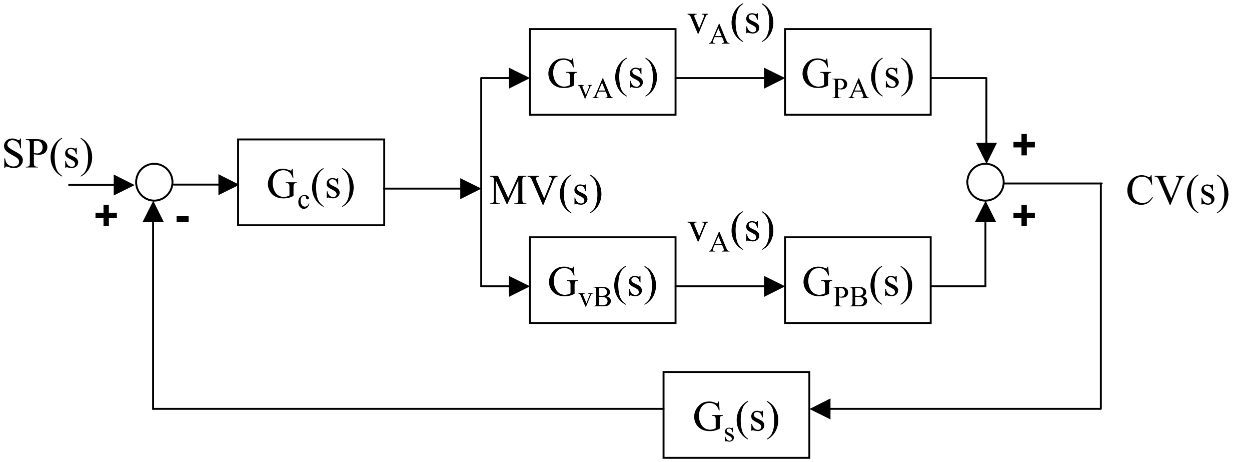
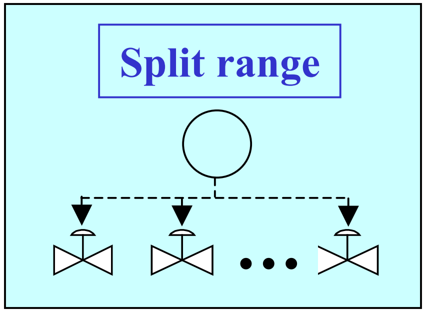


Value of MV	Characteristic equation
0 - 50%	$1+G_{PA}(s)G_{vA}(s)G_C(s)G_S(s)$
50 - 100%	$1+G_{PB}(s)G_{vB}(s)G_C(s)G_S(s)$

CHAPTER 22: VARIABLE STRUCTURE CONTROL



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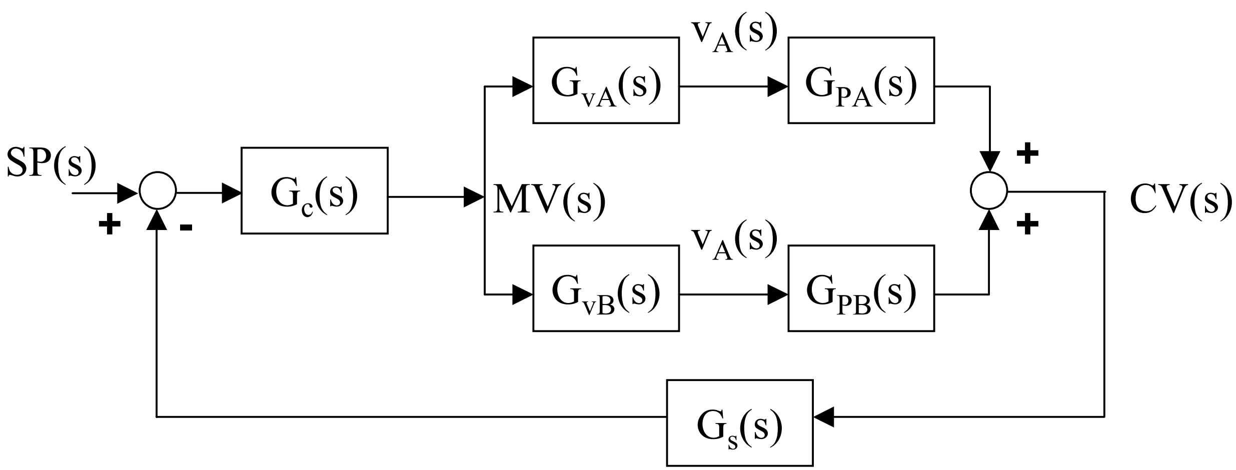

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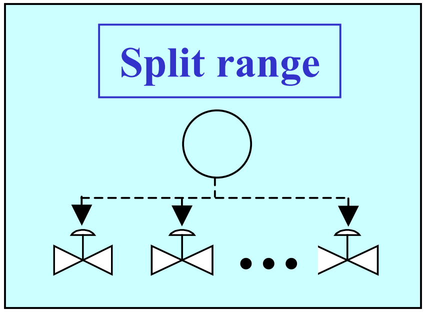
May have to adjust tuning when the adjusted valve changes.

CHAPTER 22: VARIABLE STRUCTURE CONTROL

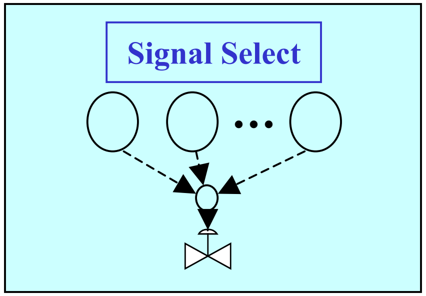


Split range is used widely in practice to provide flexibility, retain simple technology and employ simple calculations.

SPLIT RANGE DESIGN CRITERIA

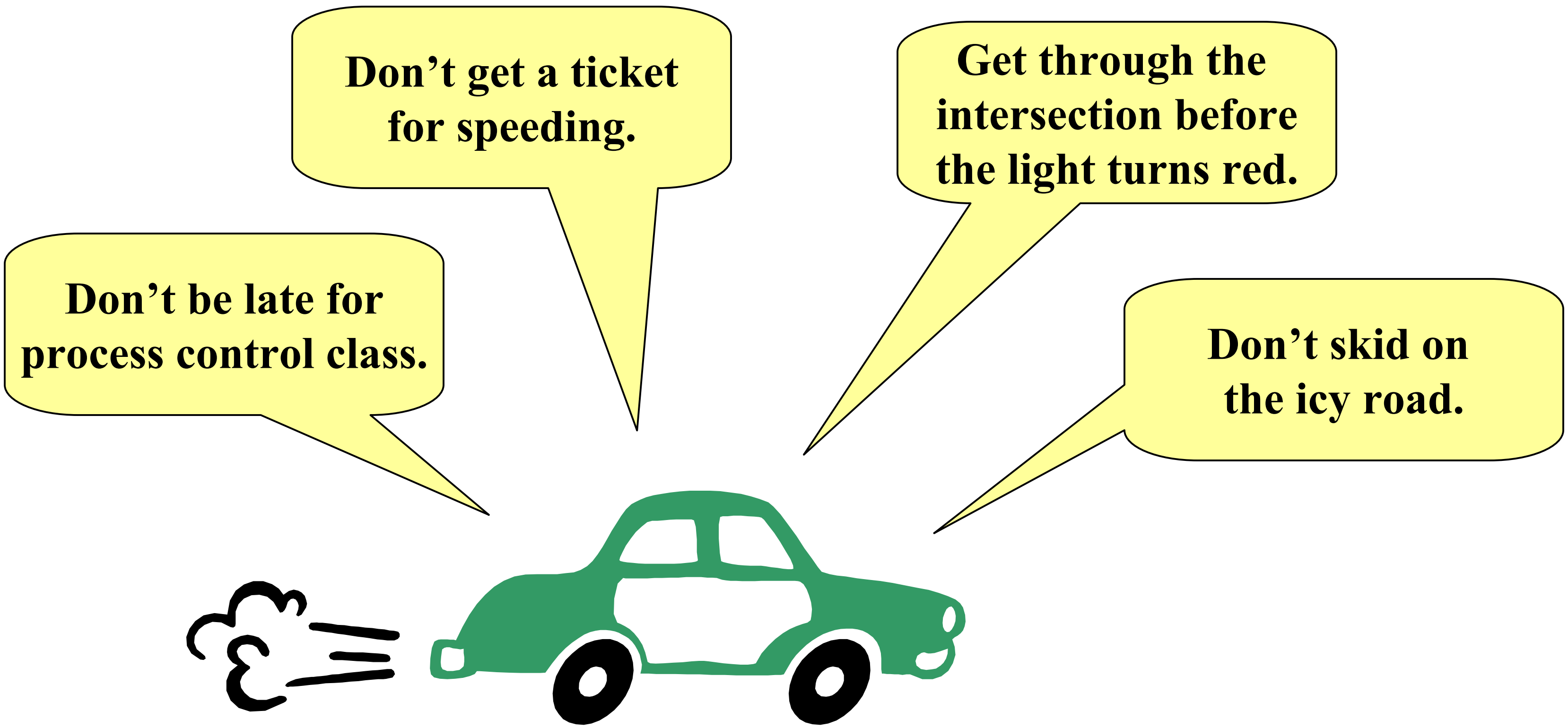
1. There is one controller and **more** than one final element.
2. There is a **causal** relationship between each final element and the controlled variable.
3. The proper order for adjusting the final element adheres to a **fixed priority ranking**.

CHAPTER 22: VARIABLE STRUCTURE CONTROL

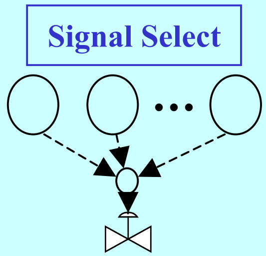


We often try to achieve many objectives when manipulating one final element.

For example, when we are driving and adjusting our speed.

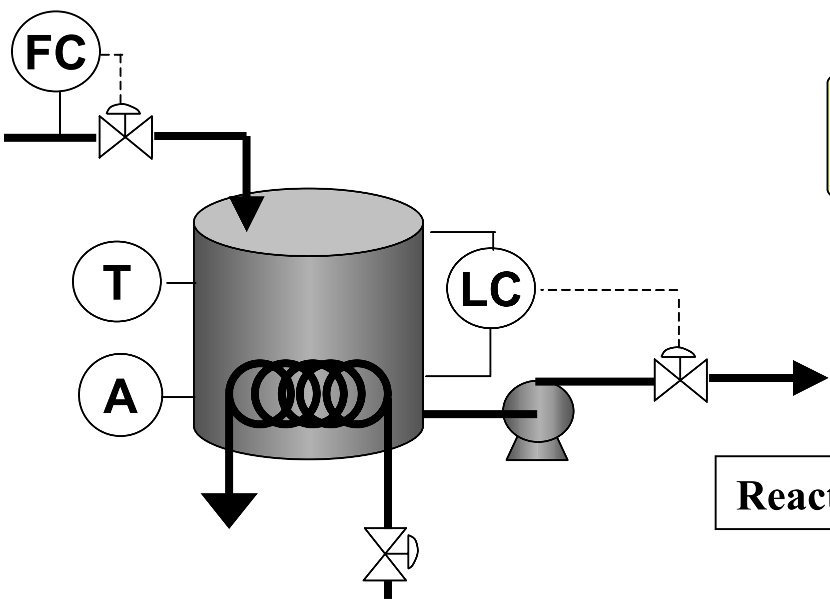


CHAPTER 22: VARIABLE STRUCTURE CONTROL



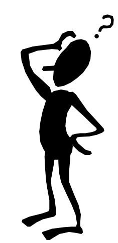
Now, we will address the other method, **split range**. Again, we consider a process example.

The process involves a CSTR with an exothermic reaction and a cooling coil. Generally, we wish to control the composition of the reactant in the effluent. However, we must keep the temperature below a maximum limit to prevent damaging the glass lining of the reactor.

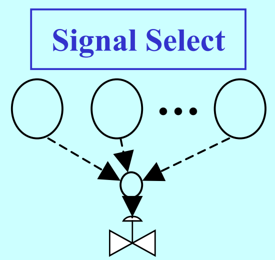


I am not sure what to do, so let's start with a controller for the composition.

Reaction: A → B



CHAPTER 22: VARIABLE STRUCTURE CONTROL



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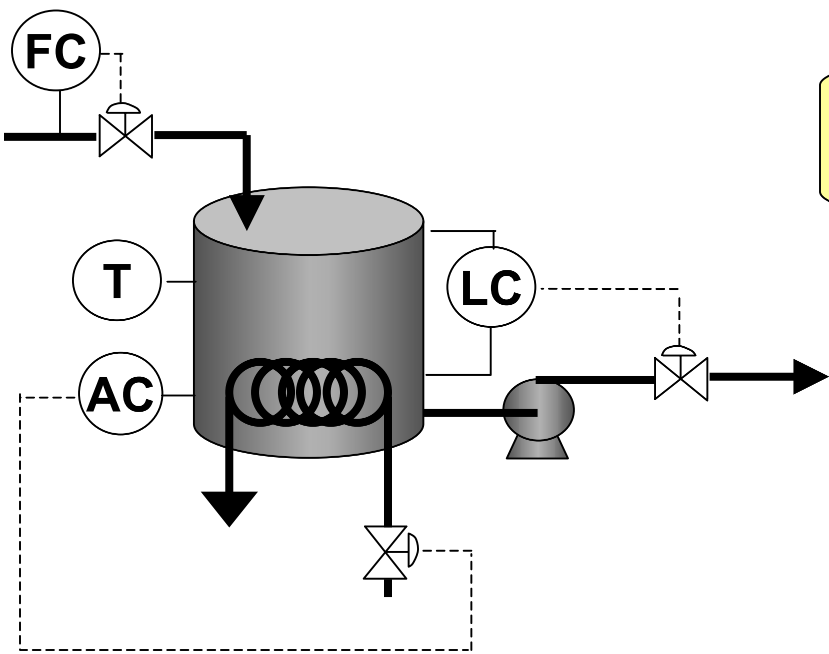
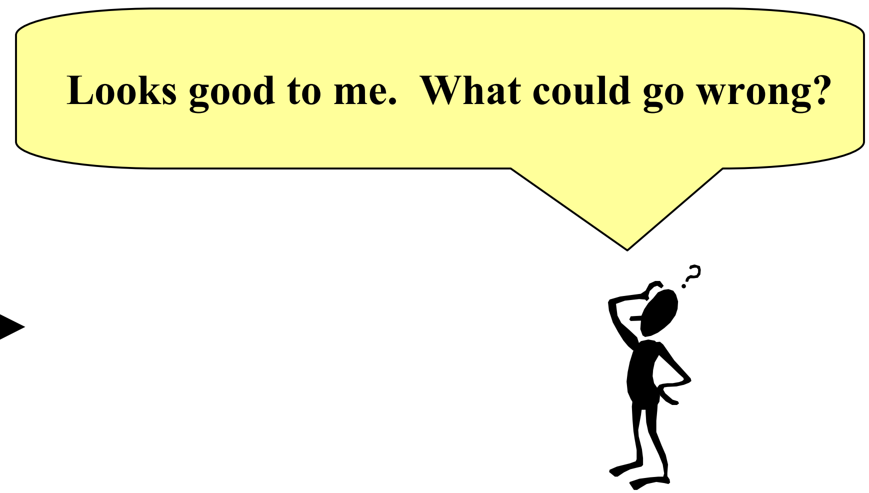
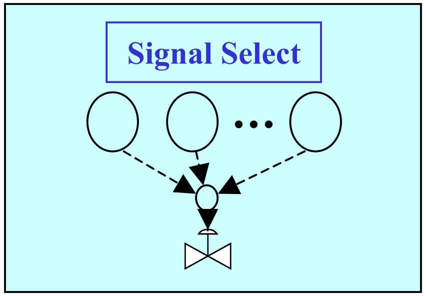




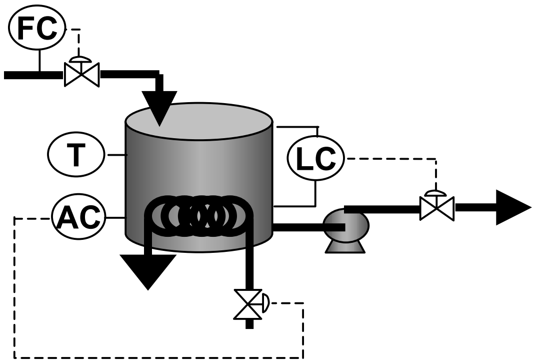
Reaction: A $\rightarrow$ B

CHAPTER 22: VARIABLE STRUCTURE CONTROL



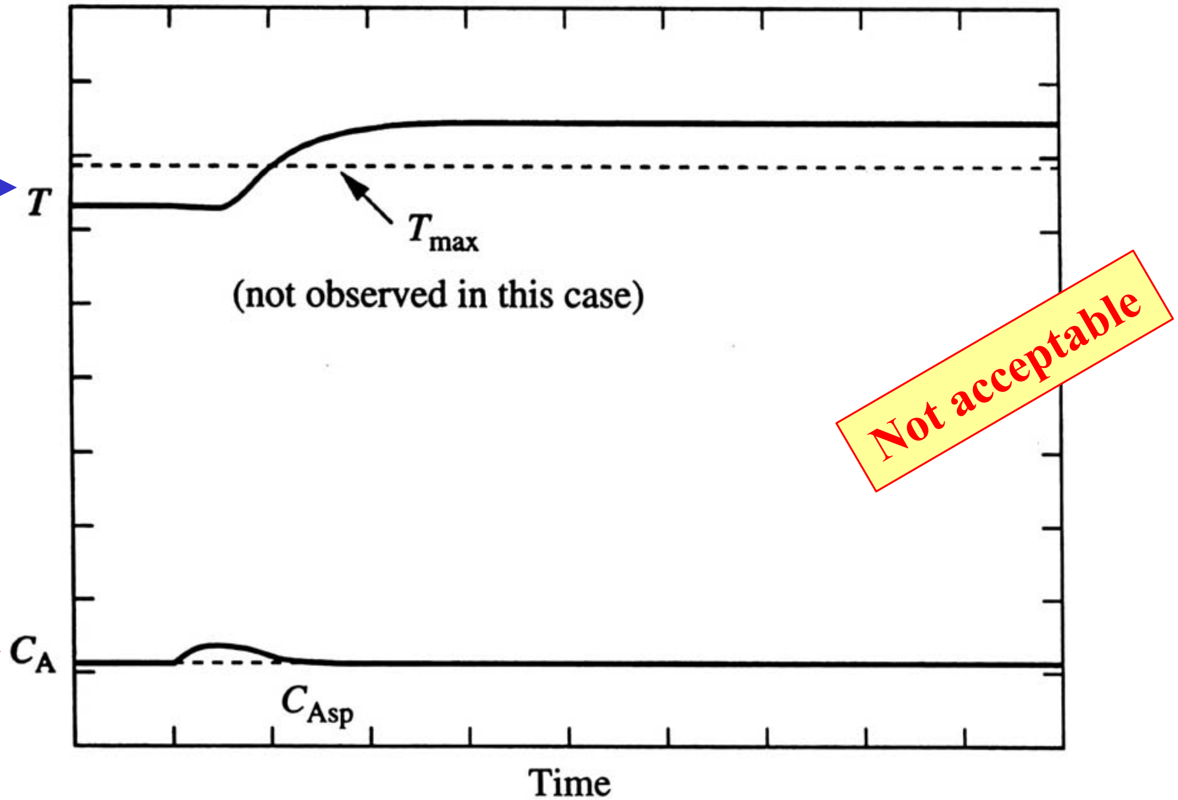
Disturbance is feed inhibitor increase.

Reaction: A → B

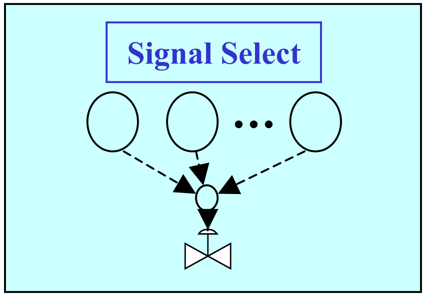


Unfortunately, the design does not consider T, which exceeded its maximum. The equipment was damaged!

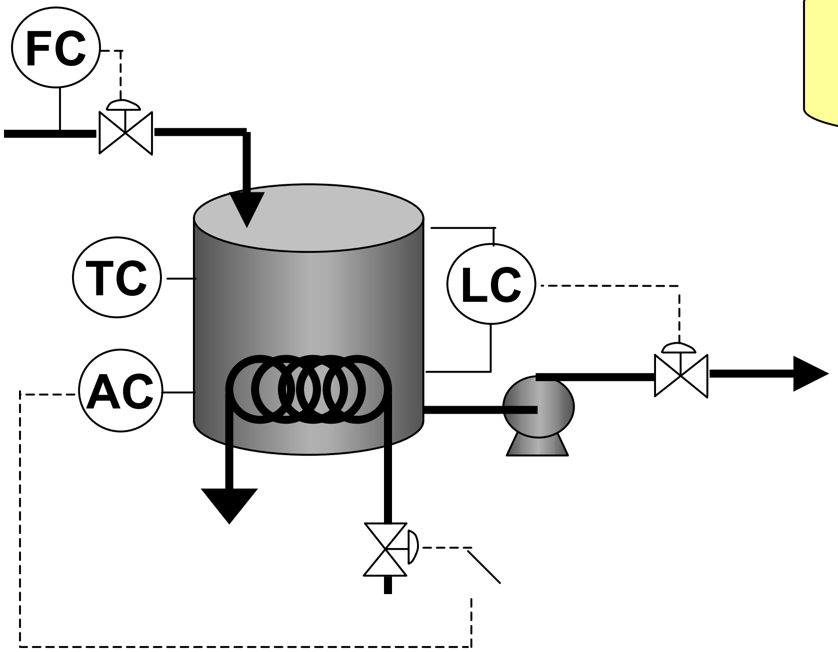
The controller did a good job of keeping C_A near its set point.



CHAPTER 22: VARIABLE STRUCTURE CONTROL

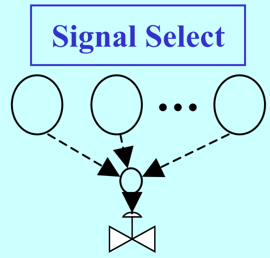


The process involves a CSTR with an exothermic reaction and a cooling coil. Generally, we wish to control the composition of the reactant in the effluent. However, we must keep the temperature below a maximum limit to prevent damaging the glass lining of the reactor.



Well, back to the drawing board!
What can we do to improve the design?

CHAPTER 22: VARIABLE STRUCTURE CONTROL



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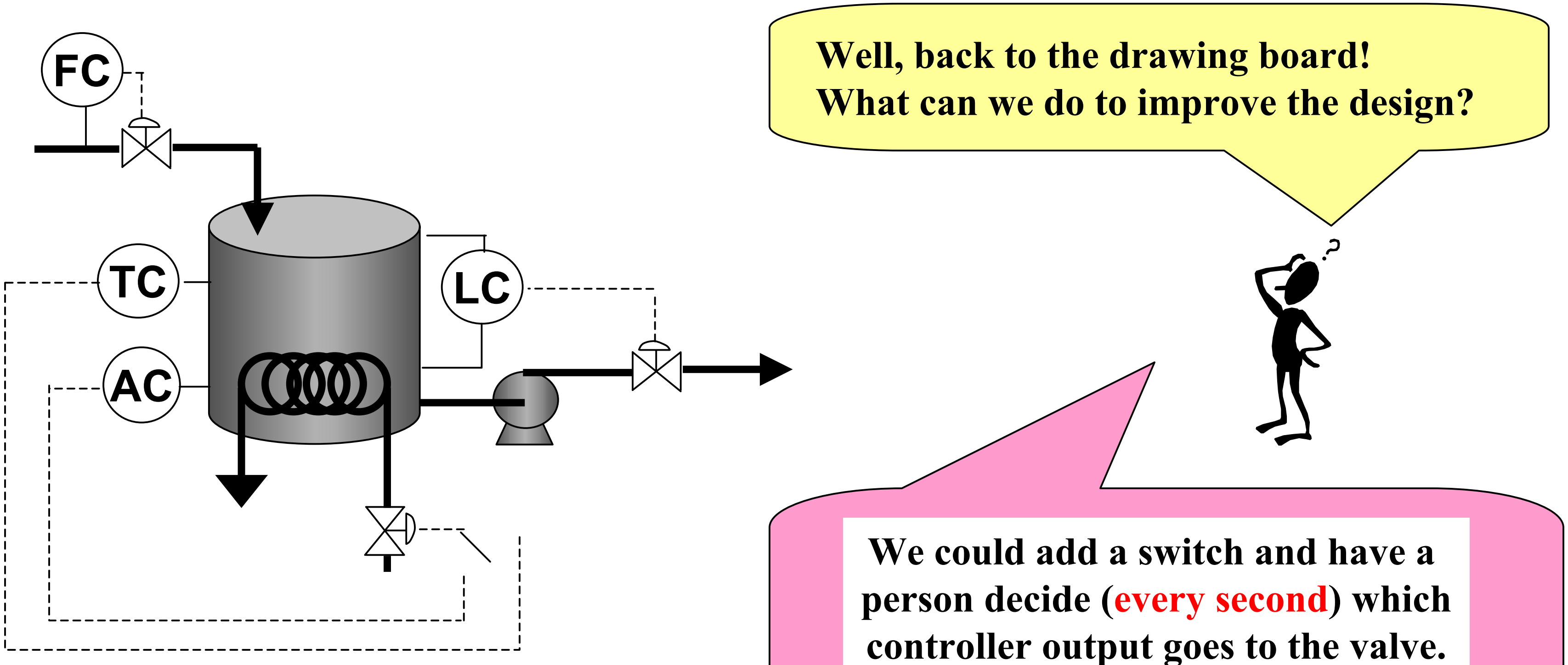
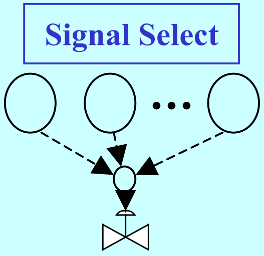


We could add a switch and have a person decide (every second) which controller output goes to the valve.

CHAPTER 22: VARIABLE STRUCTURE CONTROL



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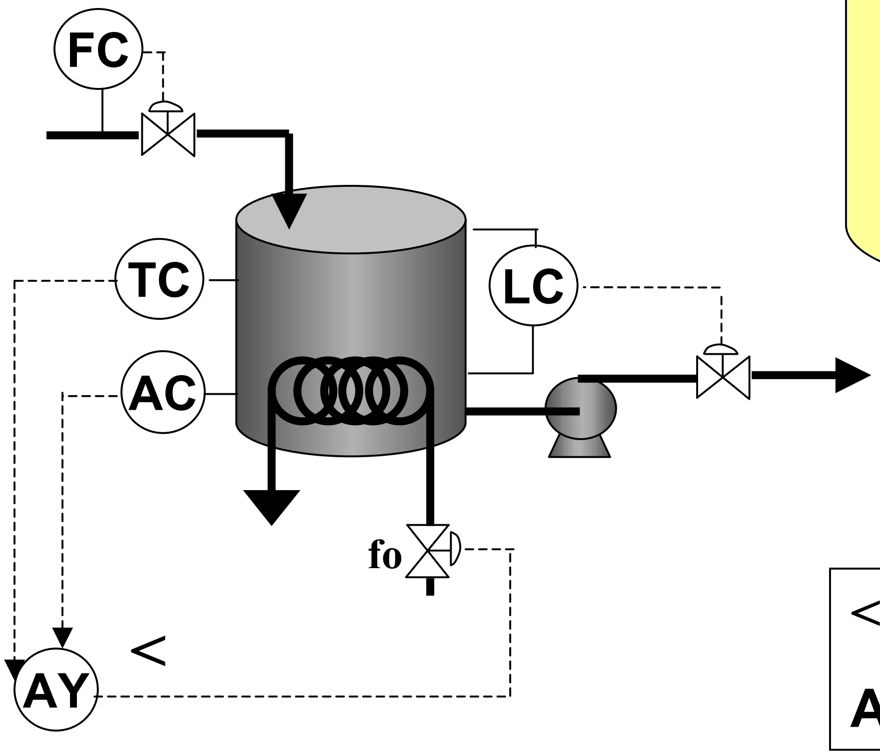


Now, the correct controller is selected automatically.

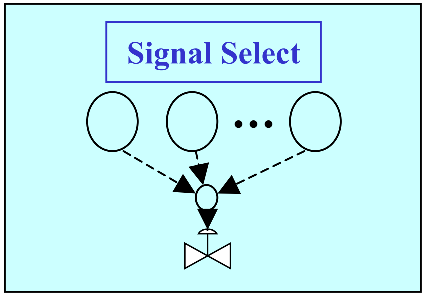
Why was a low signal select used?

Hint: What is the safest % valve opening?

< = low signal select

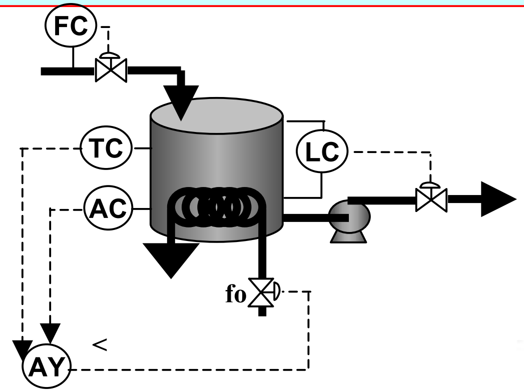
AY = calculation element

CHAPTER 22: VARIABLE STRUCTURE CONTROL



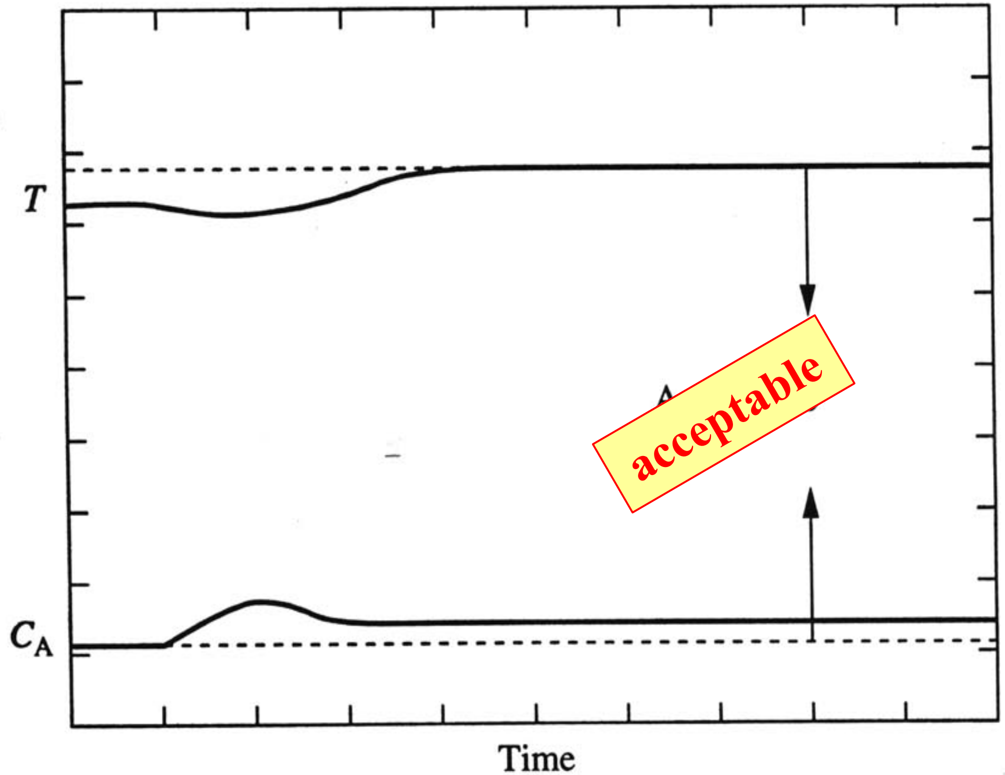
Disturbance is feed inhibitor increase.

Reaction: A → B

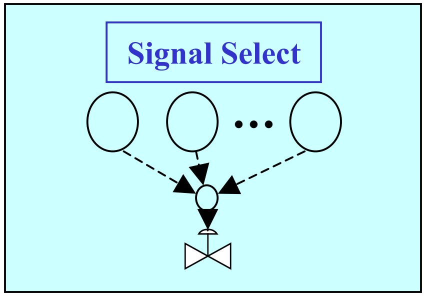


The design controls T, as it approaches its maximum. The equipment was not damaged!

The controller cannot keep C_A at its set point!



CHAPTER 22: VARIABLE STRUCTURE CONTROL



Signal select is used widely in practice to provide flexibility, retain simple technology and employ simple calculations.

SIGNAL SELECT DESIGN CRITERIA

1. **There is one manipulated variable and more than one final element.**

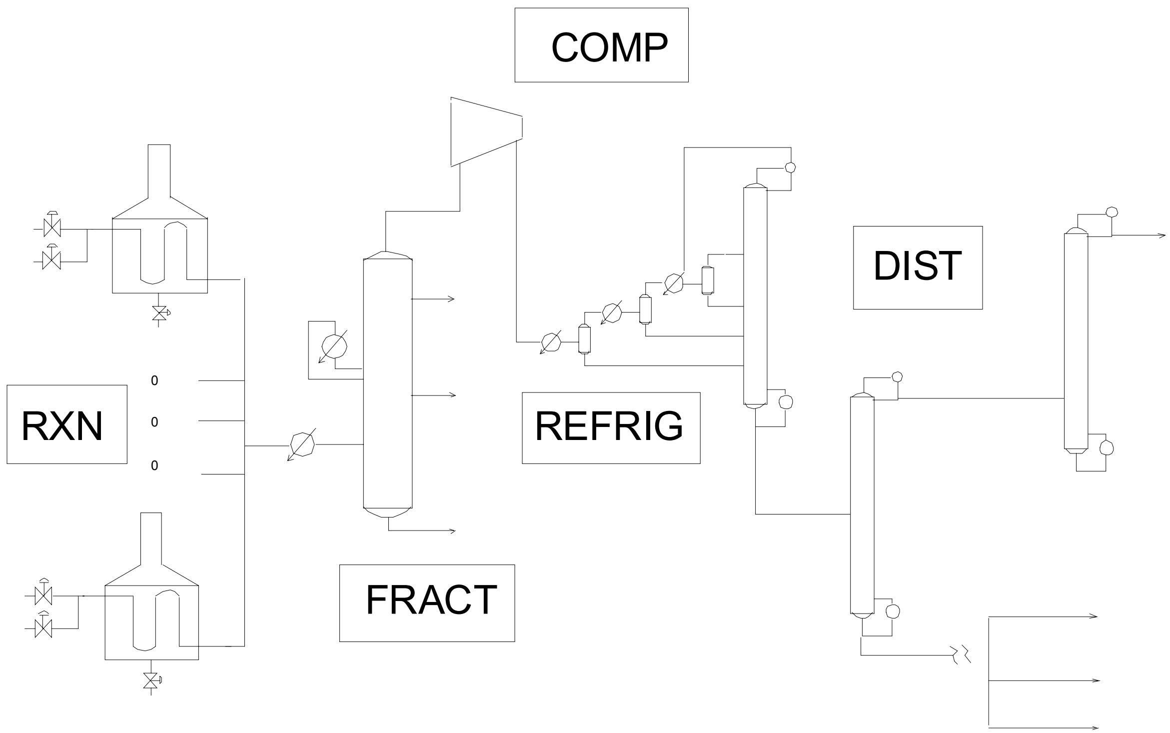
2. **There is a causal relationship between the manipulated variable and each controlled variable.**

3. **There is a feasible operating point that satisfies the control objectives.**

CHAPTER 22: VARIABLE STRUCTURE CONTROL

CONSTRAINT CONTROL

Signal select and split range are often used for achieving constraint control. Often, good plant operation occurs when some of the manipulated and/or controlled variables are near their limiting values (constraints).

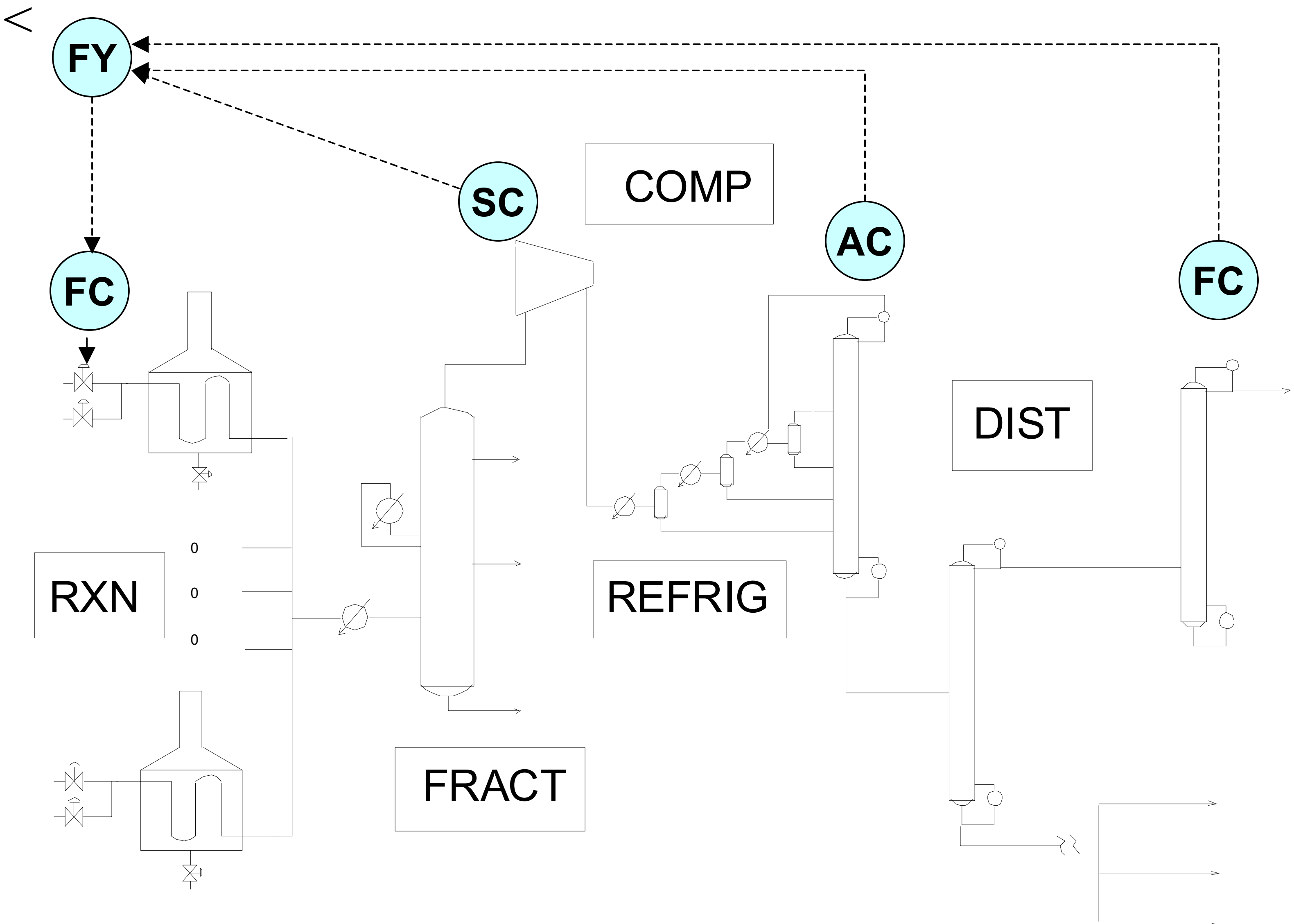


For example, let's consider the ethylene plant. We would like to maximize the feed rate (production), but many possible constraints exist.

How do we do this?

CHAPTER 22: VARIABLE STRUCTURE CONTROL

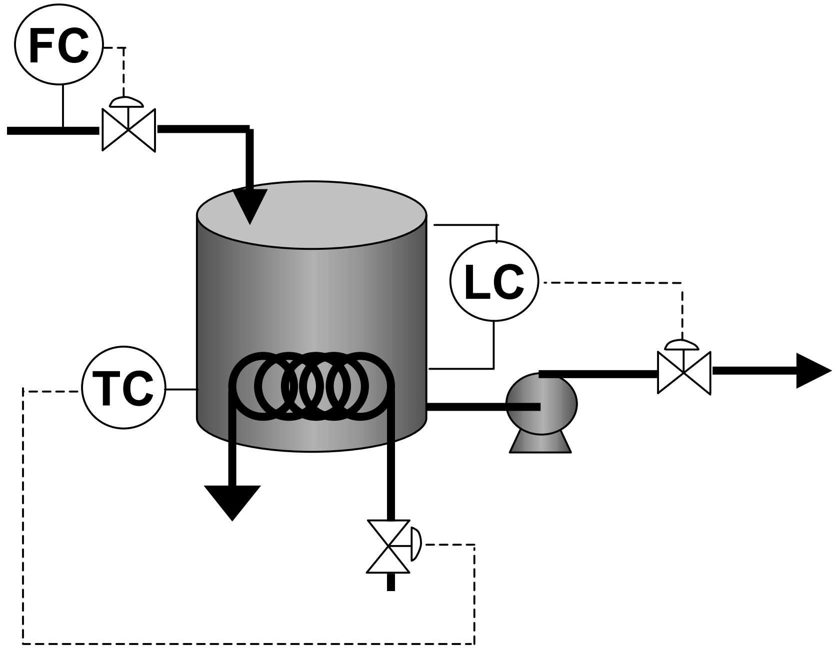
CONSTRAINT CONTROL



CHAPTER 22: VARIABLE STRUCTURE CONTROL

CONSTRAINT CONTROL

Other methods are sometimes used for achieving constraint control. Often, good plant operation occurs when some of the manipulated and/or controlled variables are near their limiting values (constraints).



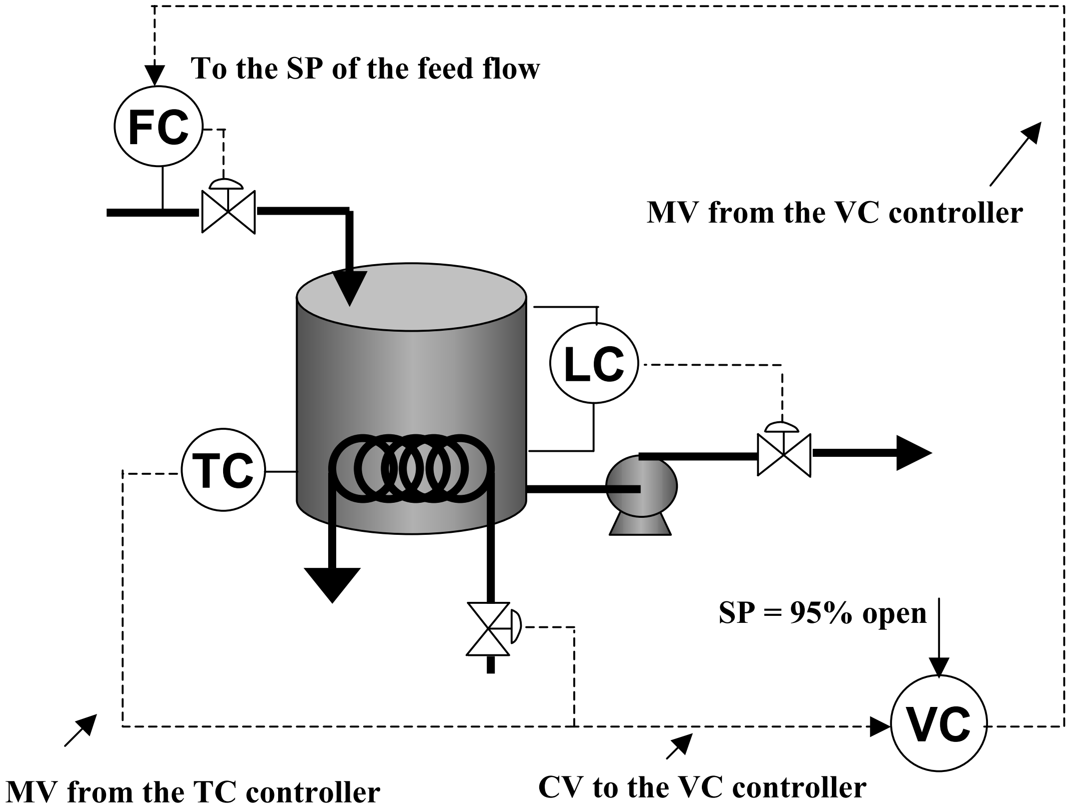
For example, let's consider the CSTR. We would like to maximize the feed rate (production), but we must always control the temperature.

How do we do this?

CHAPTER 22: VARIABLE STRUCTURE CONTROL

CONSTRAINT CONTROL

We would like to maximize the feed rate (production), but we must always control the temperature.



VC = "valve position" controller using feedback principle and PI algorithm

This design achieves the maximum feed flow rate consistent with being able to control the temperature.

CHAPTER 22: VARIABLE STRUCTURE CONTROL

Potential issues with variable structure control designs

1. **The integral mode for controller not "selected" will windup.**

   Every algorithm must have anti-reset-windup protection. This must also provide smooth transitions between selected variables.

2. **The control system for a valve position controller can become unstable if a different controller is placed in manual (off) status.**

   The control design should have an "interlock" that places other controllers (that would become unstable) in manual when the operator places a controller in manual.

   For example, in the previous example if TC is placed in manual, VC must be placed in manual at the same time.

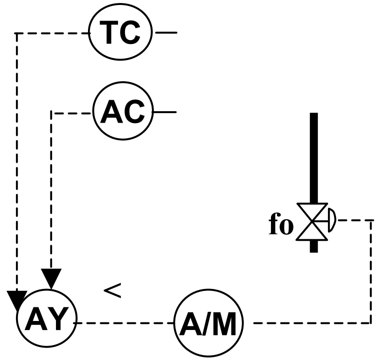
CHAPTER 22: VARIABLE STRUCTURE CONTROL

Potential issues with variable structure control designs

3. **Noise can reduce the effectiveness of signal selects.**

   The effects of noise can be reduced by (1) removing a derivative mode, (2) filtering the signal, and (3) reducing the controller gain as the controller deviates from its set point on the "safe side".

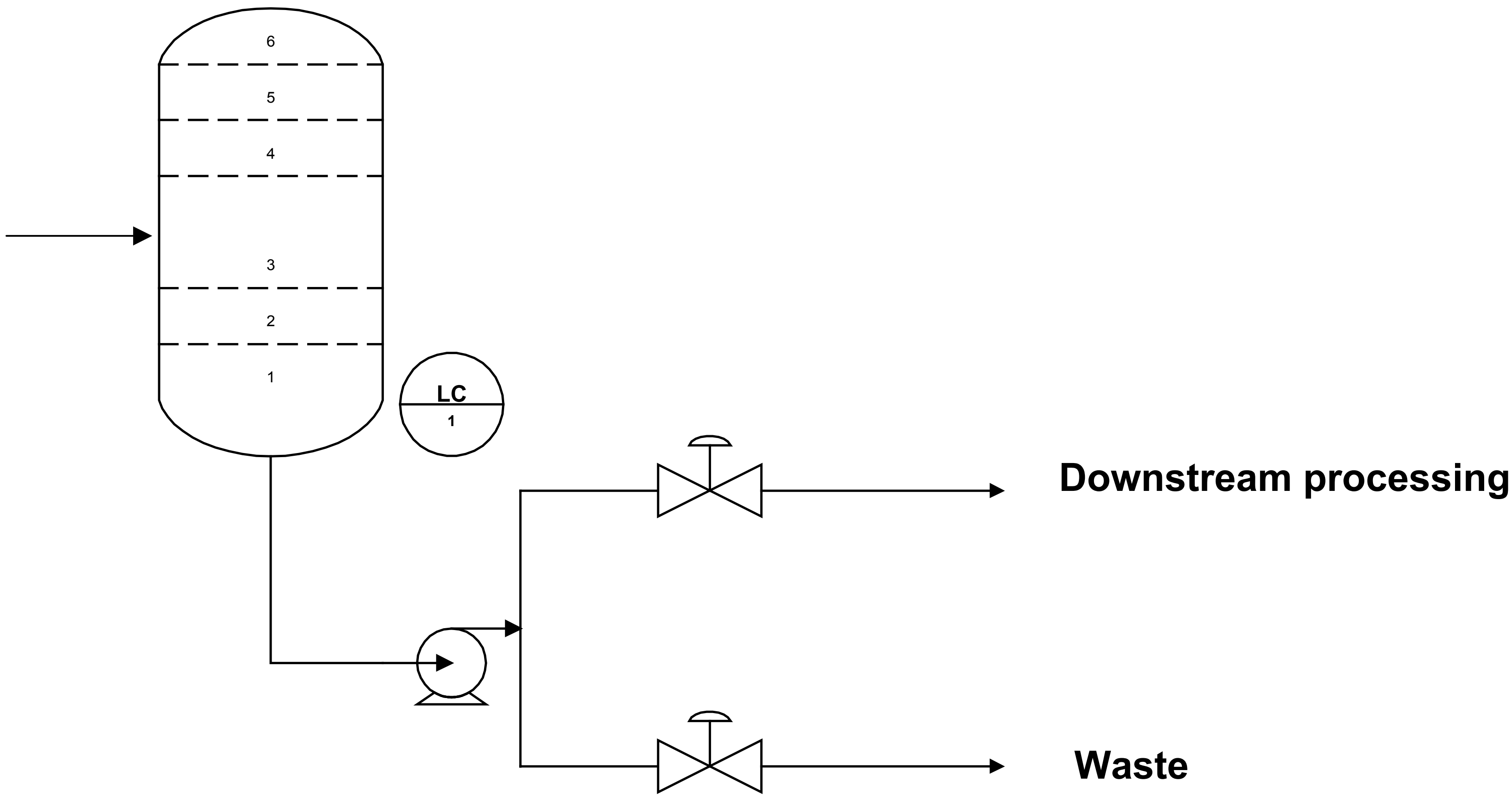
4. **For signal select, the operator does not immediately know how to adjust the valve manually.**



An "auto-manual station" should be placed after the signal select.

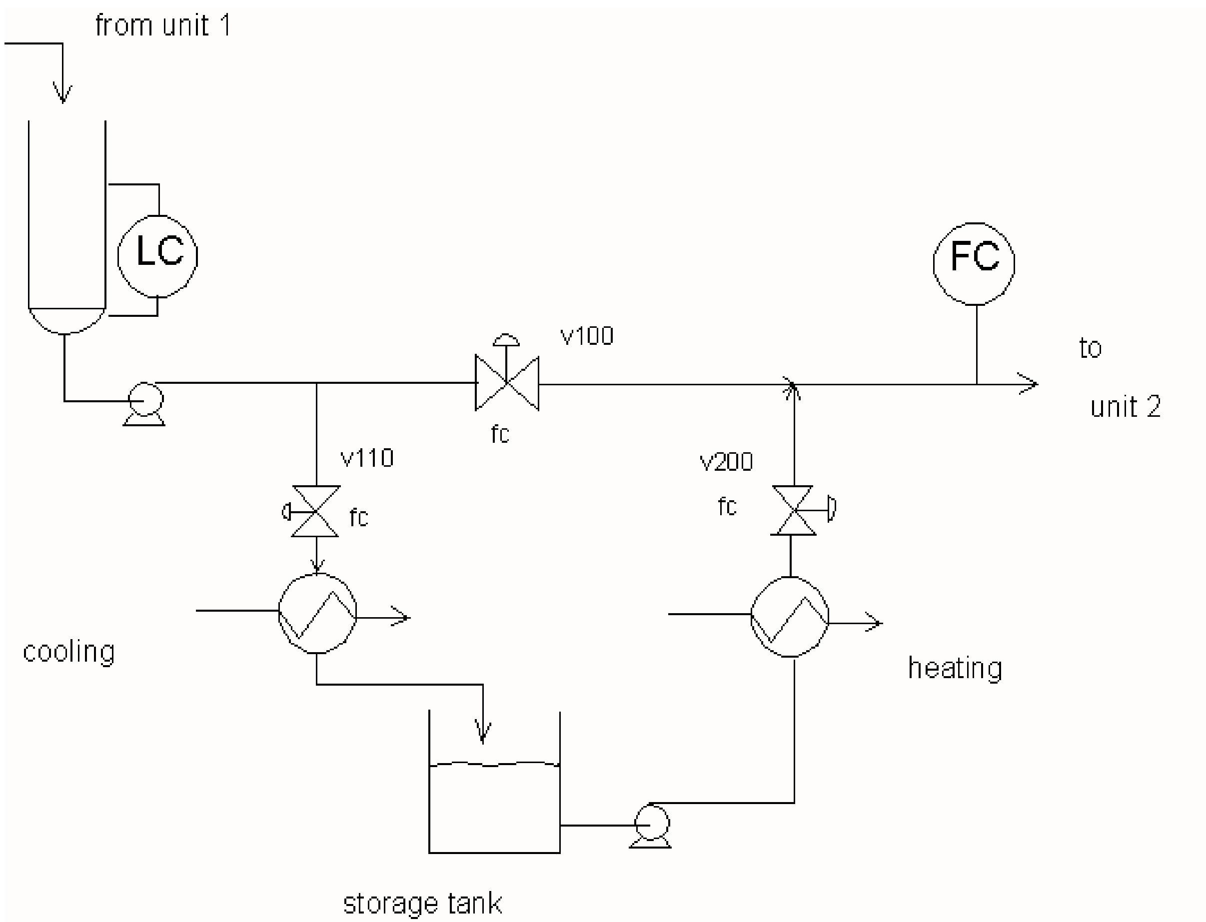
CHAPTER 22: VARIABLE STRUCTURE WORKSHOP 1

Design controls to maintain the level within limits and to minimize the flow to waste.



CHAPTER 22: VARIABLE STRUCTURE WORKSHOP 2

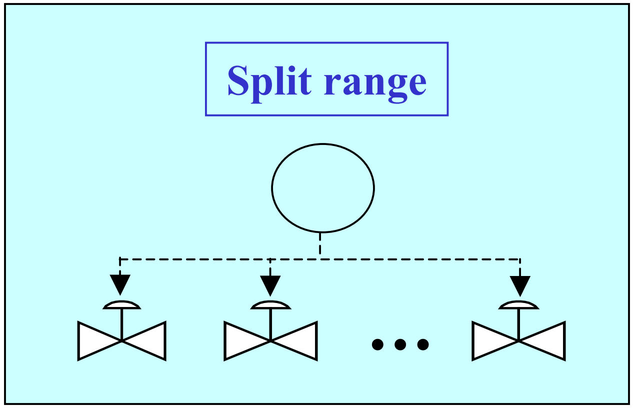
Design controls to control the level and the feed to unit 2 while minimizing the heating and cooling associated with the storage tank.

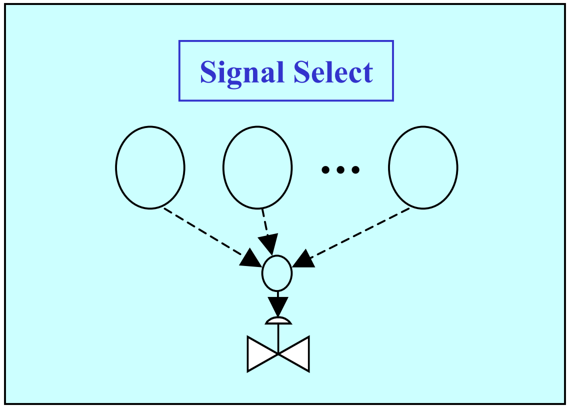


CHAPTER 22: VARIABLE STRUCTURE WORKSHOP 3

Describe examples in everyday life when you

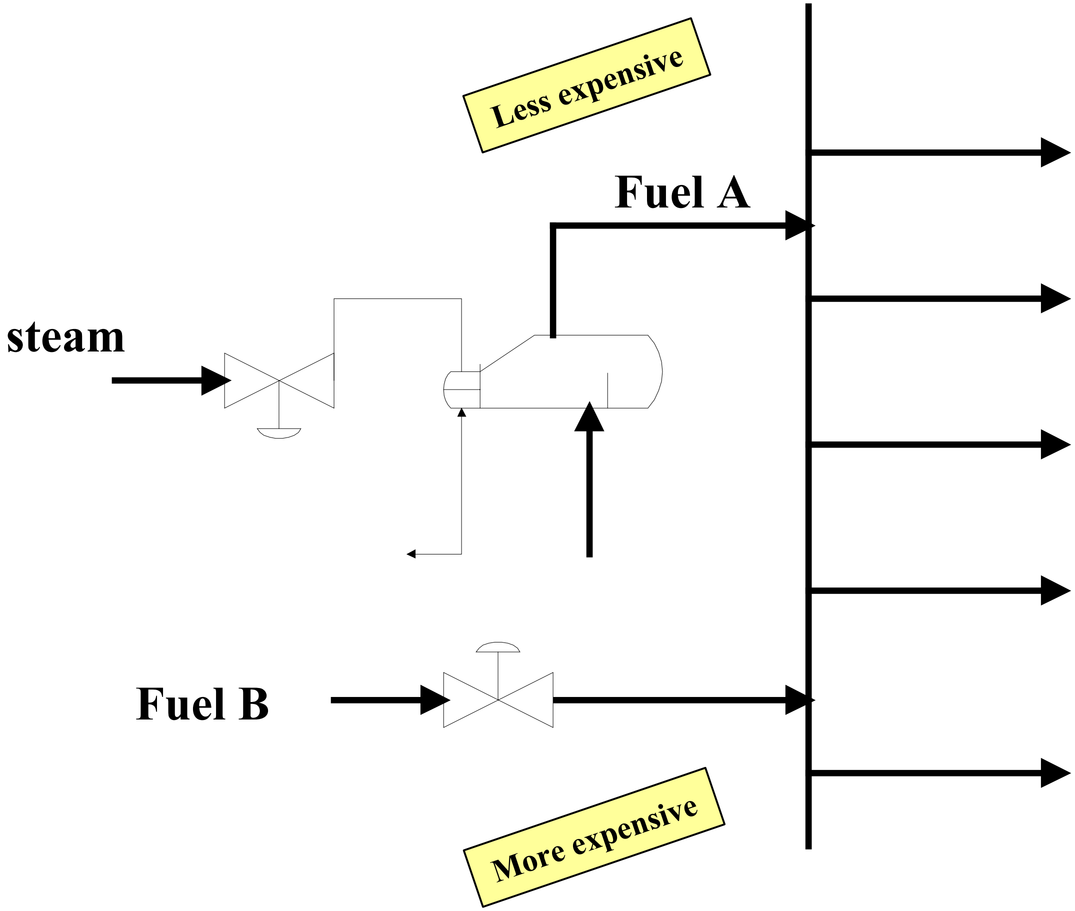
- Employ signal selects
- Employ split range





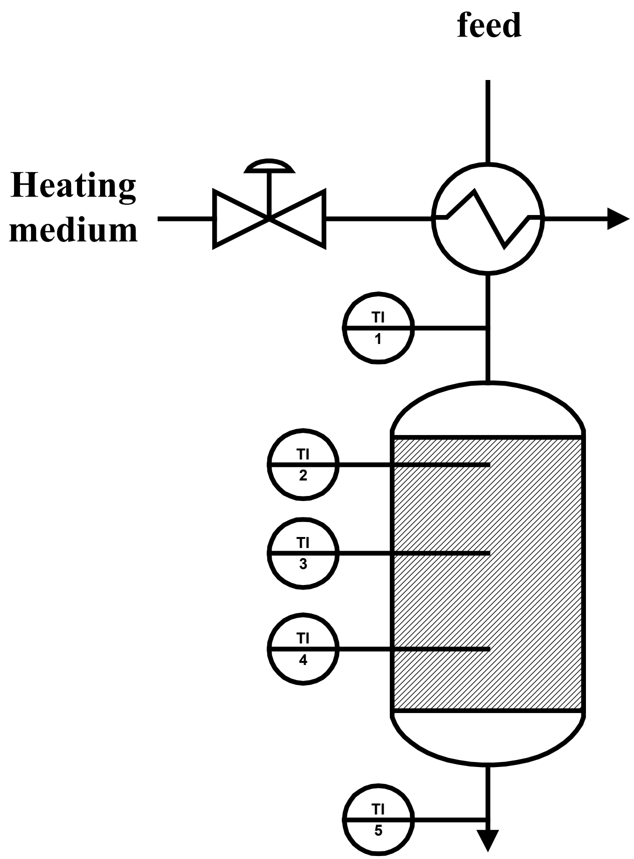
CHAPTER 22: VARIABLE STRUCTURE WORKSHOP 4

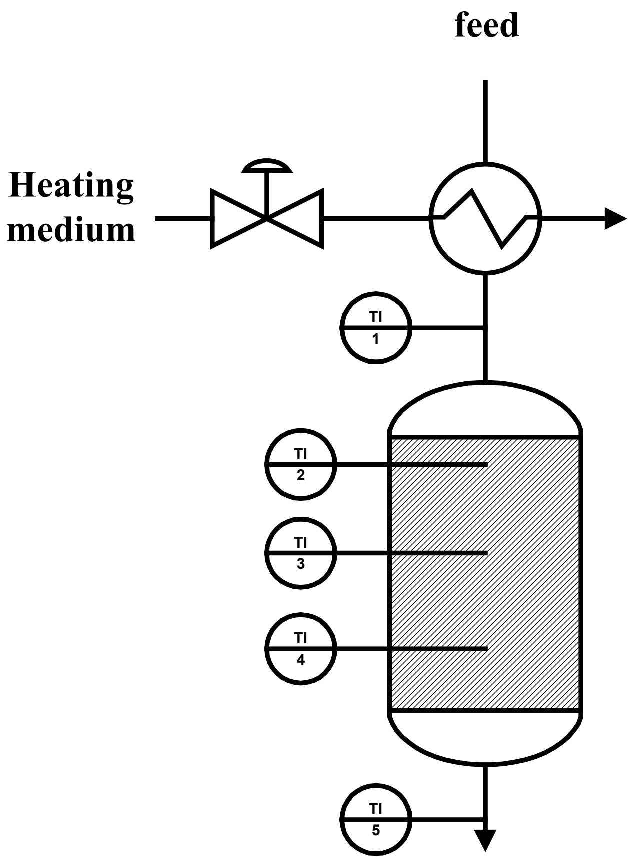
Design controls for the situation in which the least expensive manipulated variable has a substantially slower response, as in the figure where fuel A is evaporated.



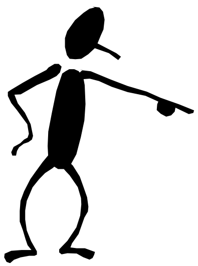
CHAPTER 22: VARIABLE STRUCTURE WORKSHOP 5

Design two control approaches for the packed bed reactor. The feed is preheated. The goal is to maximize the conversion in the reactor, but no temperature should exceed its maximum limit.



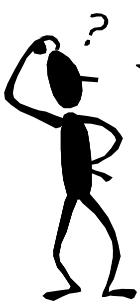


CHAPTER 22: VARIABLE STRUCTURE CONTROL



When I complete this chapter, I want to be able to do the following.

- **Understand why many applications of process control require variable structure**
- **Implement a design using more than one valve in a "control loop"**
- **Implement a design using more than one controlled variable in a "control loop"**



Lot's of improvement, but we need some more study!

- **Read the textbook**
- **Review the notes, especially learning goals and workshop**
- **Try out the self-study suggestions**
- **Naturally, we'll have an assignment!**

CHAPTER 22: Learning Resources

- **SITE PC-EDUCATION WEB**
  - Interactive Learning Module (Chapter 22)

- **The Textbook, naturally, for many more examples.**

CHAPTER 22: Suggestions for self-study

1. **Evaluate additional examples of variable structure control given in Shinskey, F.G., *Controlling Multivariable Processes*, ISA, Research Triangle Park, NC, 1981.**

2. **Program the controllers and additional logic for the CSTR signal select control example in the lecture and textbook.**

3. **Design a modified split range control implementation in which different signals with different values are sent to the two valves for the fuel gas pressure control example in the lecture and textbook.**