Solutions for Tutorial 1
Feedback Concepts

1.1. **Drawing symbols**: Determine all letters that would be used to designate each of the following instruments on process and instrumentation (P&I) drawings.

The approach for assigning symbol letters is explained in Appendix A in Marlin, 2000. Much more detail is provided in ISA 5.1-1984.

For example, for a level controller, the designation would be LC.

i)	Liquid level alarm high,	**LAH**	**Set value for the alarm is NOT shown on the drawing**
ii)	Pressure indicator,	**PI**	**Not used for control**
iii)	Temperature indicator in a packed bed,	**TI**	**"in a packed bed" is not relevant; the symbol is independent of the process application**
iv)	Volume flow rate of butane in a pipe,	**FI**	**Flow == F**
v)	Mass flow rate of hydrogen,	**FI**	**The units of the flow are not indicated in the symbol.**
vi)	Weight of a solid in a vessel,		
vii)	Speed of rotation of a shaft, and	**SI**	
viii)	Mole % of propane in a gas stream	**AI**	**"Analyzer" is A**

You might wonder, "Where are the details?" A detailed instrument specification sheet is completed for every sensor. This indicates the stream conditions, physical principle, range of operation and other information. You will be able to purchase the instrument and design installation based on the information in the data sheet.

Conclusion: We must use a standard set of symbols so that all engineers and plant operators understand the design.

1.2. **Common examples of automation:** Discuss whether each of the common systems below uses automatic ***feedback*** to achieve its desired performance.

Note: The question asks if automatic feedback is applied. "Automatic" implies the use of a computing device, such as a digital computer. Feedback could be applied by a person, which is generally not as reliable. We're smart but we get tired.

a. Boiling water on a burner in a home stove.

The burner is set to a constant gas flow or electrical power, and no automatic adjustment is applied to achieve a desired rate of boiling.

Note that the temperature is constant when the water is boiling, regardless of the heating applied. This is NOT due to control, but is a result of the process principles.

b. Maintaining a temperature in an oven in a home stove.

The typical home oven has a temperature controller. The automatic approach is not complex; it applies and on/off feedback algorithm. If the temperature is below a set point, the furnace is turned on; if the temperature is above a set point, the furnace is turned off. Usually, a "dead band" is applied to prevent the heater from switching on and off too frequently.

c. An alarm clock used to wake you for class.

No automatic mechanism is applied to the alarm clock. If the power fails, the clock cannot recognize this and correct. Also, if you do not awake, the clock stops sounding the alarm after a specified time.

So, the success of the alarm depends on our participation, which we regret every morning.

Conclusion: We apply automatic feedback control when we desire reliable application of a consistent policy.

1.3. **A Chemical Engineering Example:** A chemical reactor with recycle is depicted in textbook Figure 1.8 and repeated below.

a. Can the following variable be controlled by feedback? Hint: determine which valves have a causal effect on each sensor.
b. Select the best valve to control each, if more than one valve can effect the sensor.
c. Select a sensor principle for each of the sensors. (**Hint**: Check the WEB site!)

i.	T4, reactor feed temperature	iii.	F3, reactor effluent flow
ii.	T1, feed temperature	iv.	L1, reactor liquid level

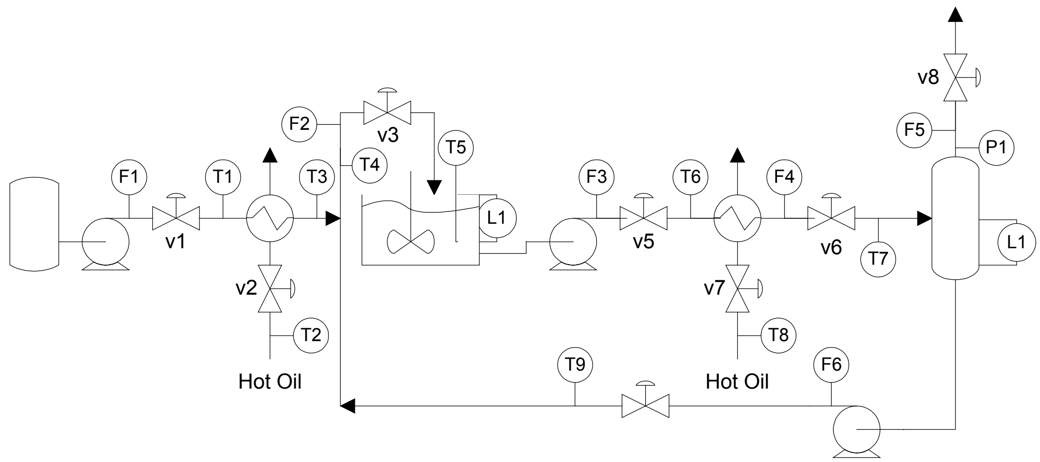


Figure 1.1

T4, reactor temperature

v1	**Yes, strong**	**This will influence the flow rate through the feed exchanger and the ratio of fresh to recycle, which can be at different temperatures.**
v2	**Yes, strong**	**This will affect the flow of heating oil to the feed heat exchanger.**
v3	**Yes, weak**	**This will affect the flow rate of both fresh and recycle feeds, without changing the ratio.**
v4	**Yes, temporary**	**This will change the recycle flow temporarily. Note that the supply of recycle material is limited that the average over time can be no more (or less) than what remains liquid in the flash drum.**
v5	**no**	**This affects the flow out of the reactor.**
v6	**no**	**See v5 above**
v7	**Yes, weak**	**This will affect the heat to the reactor effluent, which influences the flow rate and temperature of the recycle.**
v8	**Yes, weak**	**This will affect the pressure in the flash drum and thus, the fraction of reactor effluent that is vapor. The liquid recycles to the reactor.**

The best choice should provide a fast and strong effect on T4 and leave valves for other important controllers. Let's select v2.

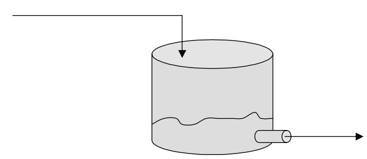
Because this is a reactor, we could select an RTD sensor for good accuracy, but we need more information.

1.4 When we consider history, we encounter a puzzle. Automatic control has been applied for a long time. Certainly, scientists and engineers needed automatic control since the time of the steam engine to prevent explosions and maintain the driver speed at a desired valve. (Actually, before then, but let's use the revolution of the steam engine as our marker in history.) However, digital computers were not available for these purposes until after World War II. In fact, digital control did not begin until the 1960's.

So, how was automatic control implemented physically before digital computation?

As usual, we have been preceded by many clever people who were able to overcome limitations to achieve their goals. Before digital computers, we employed a concept of "analog computation". In analog computation, we build a physical device that behaves in the same way as the calculation we intend to implement. To be feasible, we typically limit ourselves to relatively simple calculations. Even so, considerable ingenuity is required.

Let's look an example of a simple process control application. We have a tank containing liquid that supplies a downstream process. The flow rate to the downstream process depends on the production rate, which changes in an unpredictable manner. It is our task to maintain the liquid level in the tank at a desired value (let's say at 50% of the tank height) by manipulating the flow into the tank. Why? If the level were not controlled,



- It could overflow and cause loss of valuable material, or perhaps, a hazard
- It could decrease to zero. Then, not liquid would be available to the process and we would have to stop production.

First, we decide to use the feedback principle. This requires a measurement of the level and adjustment of a causal variable. We will select a very simple automatic control strategy, but one that is very widely used, as we will see later. We chose to manipulate the flow in proportion to the amount that the level deviates from its desired value. The feedback approach is given in the following equation.

$$F_{in} = F_0 + K_c(L - L_{desired})$$

with

F_0 = the base case flow

$L_{desired}$ = the desired level

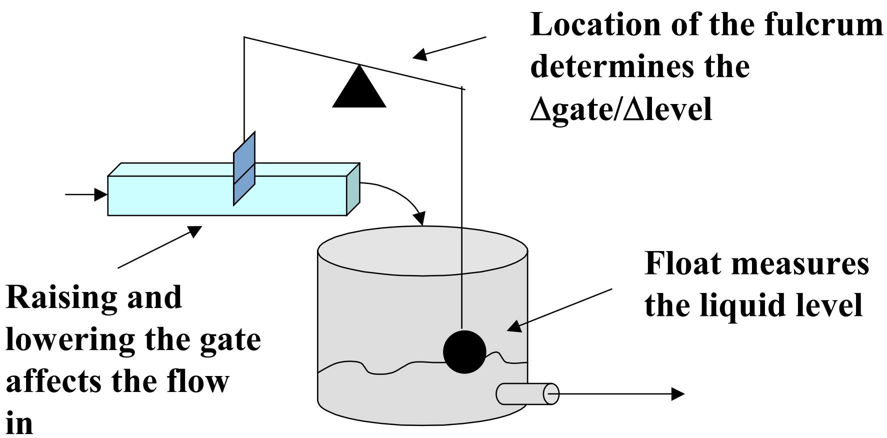
L = the measured (actual) level

K_c = an adjustable constant, which we will later call the controller gain

We want this implemented without human interference, i.e., we seek *automatic* control. This calculation would be easy via digital computation. How would you have achieved this in 1895?

Let's look at one way. We implement the calculation using a mechanical analog computation. The mechanism is shown in the sketch below.

Lets look at each element of the automatic control device.



- <u>Sensor</u>: The level is measured by a float, whose position indicates the level.
- <u>Final Element</u>: The flow in is influenced by a "gate", whose position determines the flow rate. As the gate position is elevated, the opening for flow increases, as does the flow.
- <u>Controller</u>: The controller is a lever that can rotate about a fulcrum. As the float increases (decreases), the connecting rod forces the level to decrease (increase) the gates' position.

This device exactly implements our strategy and the control equation! It is simple, inexpensive, and reliable (does not require electricity). However, it is not very flexible. If we want to change the proportionality constant (K_c), we have to change the location of the fulcrum.

Current process control technology takes advantage of digital computation to achieve tremendous increases in process safety, product quality and profitability. However, let's not forget the ingenious pioneers who established automatic control by solving practical problems with the tools and technology available at the time!

