PROCESS CONTROL

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ABSTRACT: This is one of a series of white papers prepared by Control Systems Principles to explain control problems and techniques that are often encountered in industry. They describe what makes a particular type of system important and how it is dealt with using feedback control. The white papers are background for the laboratory models of real systems that Control Systems Principles has designed for training in control techniques. This one is about control in the process industries as explained by our Process Trainer System. Like most of our designs the Process Trainer is manufactured and distributed by a partner company under licence. Details of the Process Trainer System can be found at: www.tecquipment.com/Control/Process-Control/CE117.aspx.

1. Why is Process Control Important?

Process control is arguably the largest area of control engineering application. It is used in the manufacturing, infrastructure and service industries, and these are grouped under the common heading: *the process industries*. Most of the things that we use or do are associated with a 'process' of some form. For example, if you print this page on to paper, then you are immediately using two process industry products: – for the paper, the papermaking industries, and for the ink, the chemical process industries. Other typical products of process industries are: metals, textiles, rubber, polymers, paint, food and drinks, pharmaceuticals and chemicals of all kinds. Of particular importance are the process industries that extract, process and distribute natural resources: such as petrochemicals, gas, minerals and electricity.

Process control began as manufacturing and supply became industrialized and there was a need for accuracy and repeatability. Before this, manufacturing and services were done to individual requirements using traditional methods. The key transition came with the move to mechanization and automation. So, for example, papermaking went from producing paper one sheet at a time and to individual demands, to a continuous process in which pulp and water entered a machine and standard finished paper flowed continuously from the process[1]. Metal production followed a similar route, as did the manufacture and treatment of chemicals, and the petrochemical industries. As cities grew, the infrastructure, the flow of information, the supply of goods and services, have become organized along process lines. And all need process control in order to function reliably

2. Standard Process Control Systems

2.1 Transducers and transmitters.

The need for accuracy and automation led to the development of measuring devices that could continuously monitor process variables. Key things that need to be measured in a process system are: (i) level (usually fluid level in vessels); (ii) pressure (liquid or gas); (iii) flow rate through a pipe or channel and, (iv) the temperature. The devices that measure these variables are usually called *transducers*, but because a process variable transducer can be a long way from the control unit or control room, the measured variable must be transmitted to where it is needed for monitoring or regulation. For this reason, we often talk of *transmitters* – e.g. a device that measures a process variable; converts the measurement into an electrical signal, and transmits it to where it is used for control.

[1] See the continuous manufacture of paper by typing 'fourdrinier paper making' in your search engine.

Level, pressure, temperature and flow transducers link naturally to the most common control systems requirements:

(i) Regulating the amount of material in a reservoir at a constant level as the demand downstream in the process varies with production rate;
(ii) Keeping the flow rate through a pipe at a constant level and loads and supplies changes;
(iii) Maintaining the pressure at which material is treated in a vessel during a process;
(iv) And controlling the temperature in a process vessel during a chemical reaction.

2.2. Process Regulation.

Regulation at a constant desired value - the 'set point' - is a hallmark of process control systems. Sometimes set points are subject to change by a higher level of control system or human operator, but usually they stay constant. Often controlled variables (like, level, pressure and temperature) interact with each other and it is necessary to regulate several related variables simultaneously. As an example, consider the process vessel system shown in Figure 1.

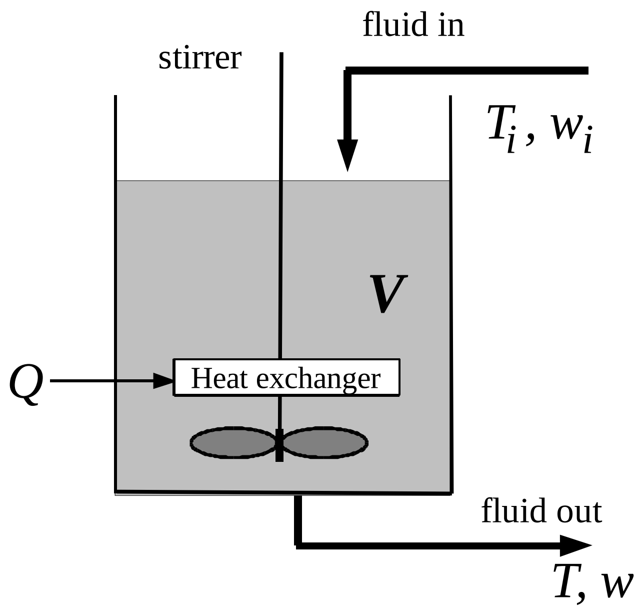

Figure 1: A basic process system

This diagram represents a typical form of industrial process and is the type of system represented in the Process Trainer. It consists of a vessel with fluid flowing in and out, plus a heat exchanger mounted inside vessel so that it can change the temperature. To ensure that every thing in the tank is well mixed, and all parts are at the same temperature, there is usually a stirring device or agitator in the tank. This is particularly important in chemical reactions and for this reason the system in Figure 1 is often referred to as a stirred-tank reactor.

The set-up shown in Figure 1 is the basis of many chemical process systems where reactions take place in a reaction vessel, or systems where fluid is either stored or stabilized to a certain temperature and flow rate. To make sure the system works in an optimal way, the total volume of fluid in the tank V and the reaction temperature T are controlled to be constant. The temperature in the vessel can be changed by a heat exchanger which supplies an input heat flow rate Q, while the fluid input to the system is at temperature T_i and mass flow rate w_i. The outflow temperature is T and mass outflow rate w.

In general, the process control aim is to regulate both the vessel temperature T and the volume of fluid V in the vessel at a desired level. The control variables are the fluid input flow rate, the outflow rate and the heat input to the heater. For this set-up most commonly encountered control tasks are:

1. Level control. Here the task is to control the volume of fluid in the vessel, usually by manipulating the inflow to the vessel, without regard to the temperature.
2. Temperature control. Here the task is only to control the temperature in the vessel, without regards to the precise volume of fluid.

For both these control tasks, a three-term controller is normally used (see our white paper: http://www.control-systems-principles.co.uk/whitepapers/three-term-control.pdf for details of this technique). And usually a suitably tuned Proportional plus Integral (P, I) controller is sufficient.

However, the situation can be more complex, because changing one of the control variables will change *both* of the system outputs. Thus if the inflow temperature is lower that the tank temperature, then an increase in w_i will tend to decrease the tank temperature. Since both outputs must be held constant, the two control systems can interact with each other. In this case an extra control mechanism is used to compensate for the interaction between the two control loops.

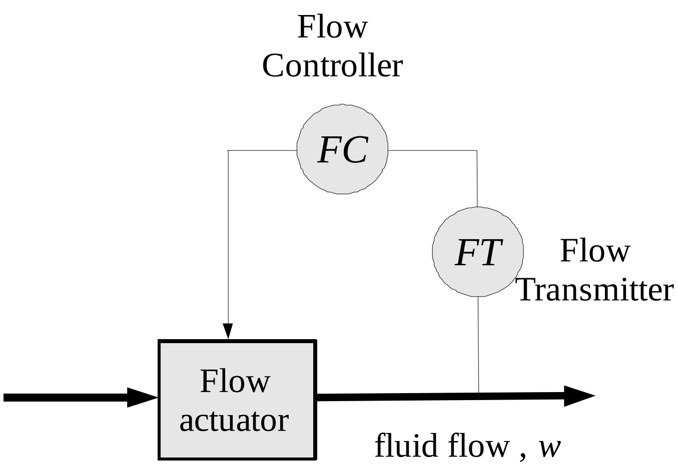

Figure 2: Flow control loop

3. Standard Process Control Loops

3.1 Flow control loop

The flow rate of material into the vessel, w_i , can vary as the supply system changes. To allow for this a flow control loop is sometimes used. These can be part of a flow actuator or a separate control system. In either case, the schematic layout is shown in Figure 2. Here the flow transmitter measures the flow, sends it to the flow controller which then changes the flow actuator. In practice the flow actuator is usually either a pump taking material from a reservoir or a motorised valve in a material feed line.

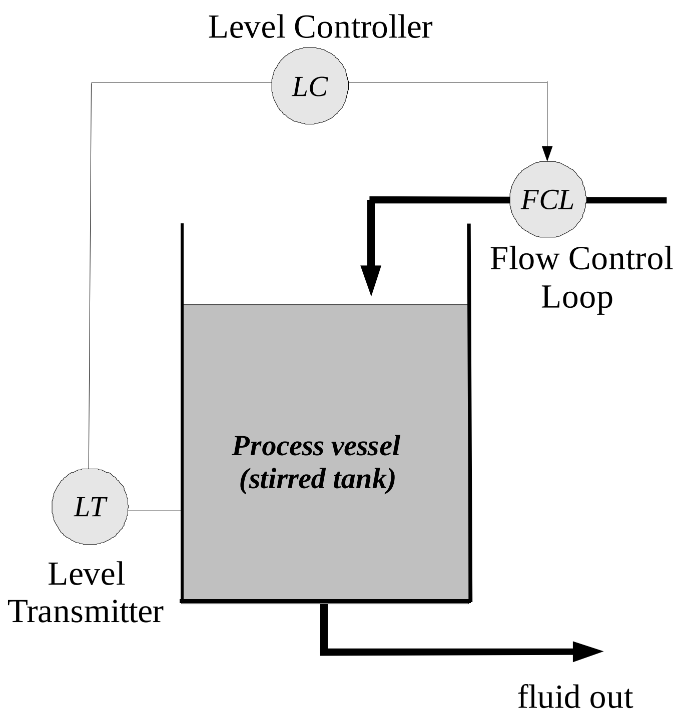

Figure 3: Level control loop

3.2. Level control loop

To control the volume of material in a tank, it is common to use either a pressure or a level transducer as the controlled variable, and to transmit this signal back to a level controller. The actuation signal from the level controller is used as the set point for the flow control loop. This is shown in Figure 3, where the level control loop consists of the Level Transmitter, the Level Controller and the Flow Control Loop.

This is an example of cascade control, where the set point to an inner loop (flow control) is derived from the output of the controller in an outer loop (level control). In this cascade system, the flow control loop is the 'slave loop' and the outer level control loop is the 'master loop'. Note that not all systems have a local control flow loop. If control is sufficiently good with just the level controller then the extra cost of a flow controller and flow transmitter is not justified. However, the inner loop control gives more flexibility in controller design. It is, in a way, the process control equivalent to the state feedback discussed in the ball and beam white paper.[2]

Local control of actuators can also help if the actuation process is significantly non-linear with dead-zone, saturation or rate limiting. These non-linearities are demonstrated in the Servo Trainer and the Engine Speed Control Systems.[3] The message in all this discussion is that a higher quality of control can be obtained with inner loop cascade control Thus, if there is no economic argument against, then do it.

3.3 Temperature Control Loop

The structure of the temperature loop for a basic process system is shown in Figure 4. A temperature transmitter sends the temperature signal to the temperature controller where it is used to regulate the heat in to the heat exchanger so that the vessel temperature is held at the set point temperature for the process. In a chemical reactor the heat exchanger may also be designed to have a cooling effect if the reaction is exothermic and therefore releases heat. Reactions should be maintained at specific temperatures to ensure a correct reaction rate and reaction products.

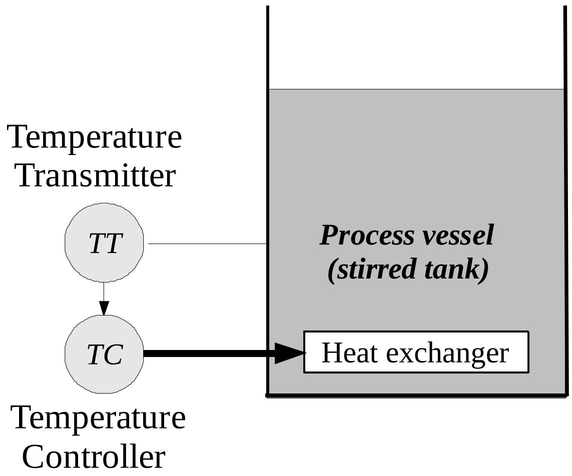

Figure 4: Temperature control loop

If there is a flow control system associated with the vessel, and there are significant variations in the temperature and the rate of in flow, then the temperature and level control systems will interact significantly. There several control schemes for compensating for this interaction. Feedforward control is the best known and simplest. We will use it as a way of introducing how to handle interaction. Feedforward was developed as a way of compensating for changes in a known disturbance to a process. So if we consider the temperature control to be the main control loop, we will show how feedforward from a flow control system can help reduce disturbances in temperature as the flow changes.

[2] See the white paper: www.control-systems-principles.co.uk/whitepapers/ball-and-beam1.pdf
[3] See the white paper: www.control-systems-principles.co.uk/whitepapers/engine-speed-control.pdf and http://www.control-systems-principles.co.uk/whitepapers/servo-control-systems1.pdf

3.3 Feed Forward Control

The main idea in feed forward control is to send information about a coming disturbance to a control loop so that it can take compensatory action in good time. In Figure 5, this situation is illustrated through the use of a feed forward loop that takes information about changes to the level control and sends it through a feed forward controller to the Temperature Controller. Thus if it is known that the feed of material or fluid is colder than the reaction vessel, then the feed forward would be designed to increase the input to the heat exchanger in proportion to increases in the inflow of feed material or fluid. This will compensate for the cooling action of the increased in flow. For this to work effectively the systems needs to be well known, but even approximate feed forward can reduce the impact of disturbances. In this case feedforward works by introducing interaction between one feedback control loop and another. Other ways of doing this exist and are explained in the Process Trainer manual.

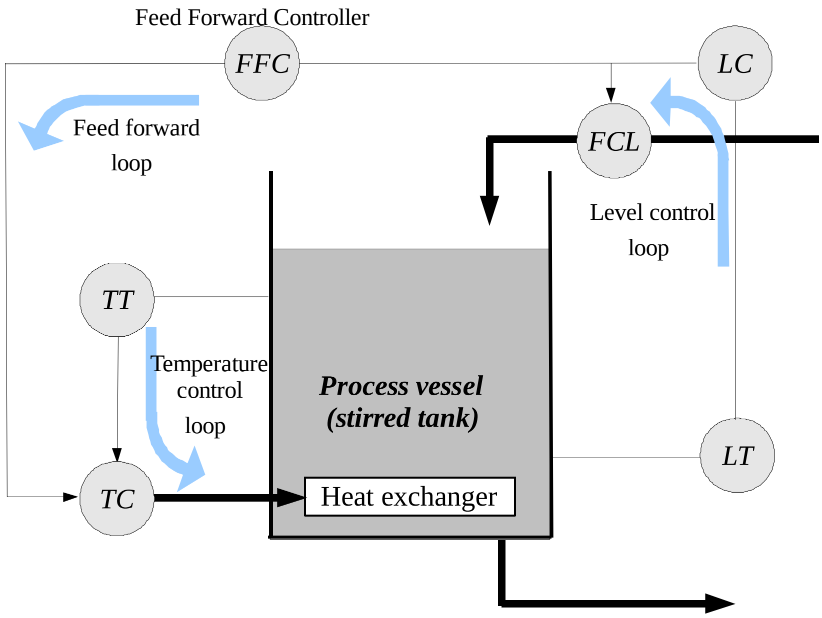

Figure 5: Combined flow and temperature control with flow feedforward loop

4. The Process Trainer

We have put these different aspects of a process control system in to a bench top system (pictured on the next page). In this system a process vessel is heated by a heat exchanger while the flows in and out of the vessel are actuated by sets of pumps and valves. In addition the vessel can be sealed at the top so that it becomes pressurised. This lets us examine pressure control and the kind of systems that use closed vessels to achieve particular process control objectives[4]. Likewise the process fluid inlet temperature can be manipulated by a special cooling system; this to adds a further dimension to the set of control problems that can be investigated and demonstrated.

[4] The pressurised head box of a paper making machine is an example of this form of system.

Figure 6. The Process Trainer

5. A Final Word

We frequently get emails from students who are keen to learn more about control and get help with their projects. However, we are sorry to say that we cannot answer general questions about the contents of our white papers, unless we have a contract with your organisation.

6. Bibliography

History of Control and Control Industries: At Control Systems Principles we recommend the historical books of Stuart Bennett. They are:

Bennett, S. *A history of control engineering*, 1800-1930, Peter Peregrinus Ltd, 1979
Bennett, S. *A history of control engineering*, 1930- 1955, Peter, Peregrinus Ltd, 1993

New books on process control are regularly published , but we still prefer the following book, authored by world authorities in the field:

Seborg, DE, Mellichamp, DA, Edgar, TF and Doyle FJ, *Process dynamics and control*, Prentice Hall, 2003

Technology moves fast, and with the advent of mass computerization and automation, process control has become integrated within plant -wide automation, system integration and business process design. This means that process control systems are now part of the bigger task of optimizing and regulating entire enterprises. This area evolves quickly and is specific to particular enterprises and process automation companies. Up-to-date material on this area is rarely found in textbooks or taught courses. The best thing is to get practical laboratory experience and then relate it to the literature and presentations of the companies that are driving innovation in process automation.