Industrial Steam System Process Control Schemes

This paper was developed to provide a basic understanding of the different process control schemes used in a typical steam system. This is however a fundamental overview and the reader should be aware that more in-depth knowledge is required to get the ultimate process control result.

The process control schemes that will be discussed are:

I. Feedback
II. Feedforward
III. Back-pressure
IV. Ratio
V. Cascade
VI. Differential

Some control systems will have one or more of the above schemes to achieve process control. The applications of the various control schemes are detailed in the typical application examples defined in this fact sheet.

The above control schemes can be applied to the following generic applications:

I. Temperature
II. Flow
III. Level
IV. Pressure

In any control scheme that is applied, there are three elements that must be defined by the user for the control process.

I. Process Variable (Sensing device)

   a.) Flow transmitter
   b.) Level transmitter
c.) Pressure transmitter
d.) Differential transmitter
e.) Temperature transmitter

II. Controller
   a.) Self contained
   b.) Proportional and Integral (PI)
   c.) Proportional, Integral, Derivative (PID)

III. Output control signal (Final controlling mechanism)
   a.) Control valve
   b.) Actuator
   c.) Or another device

This review focuses on control valves, which are used the majority of the time as the final element. The control valve has several classifications.

I. Regulating design valve
   a.) Self contained
   b.) External pilot operated

II. Pneumatic actuated valve
   a.) Globe design
   b.) Caged trim
   c.) Ball

In any process control selection, it is important to understand the advantages and disadvantages of each selection.

The regulating control valve (regulator) is a device that has a 20 to 1 turndown and limited selections of flow trim characteristics.
The globe style control valve has 30 to 1 turndown and is a device that can provide a limited number of selections of flow trim characteristics. Flow trim characteristics can be linear, non-linear, or modified equal percentage. Flow trim selection can enhance control of steam flow at varying load demands.

The cage trim control valve is the most flexible and probably is the most commonly used for precise steam process control. This valve provides the largest selection of different flow trim characteristics and the highest turn down capabilities (40 to 1).

The ball valve has a number of different flow characteristics that can be provided. The flow profile can be changed by the design of the ball (standard, V ball, etc.) The ball valve turndown can be as high as 25 to 1.

**Symbol Definitions**

- PT = Pressure transmitter
- FT = Flow transmitter
- TT = Temperature transmitter
- CT = Controller
- R = Ratio
- CS = Cascade

**Feedback Control**

One of the simplest process control schemes used in steam applications is the feedback control scheme (shown below). The advantage of this control scheme is that it is the simplest. It’s disadvantage are that it is dependent on a single transmitter sensing a change in flow, pressure, or level to provide the response back to the controller or valve. This control scheme does not take into consideration any of the other variables in the process.
Feedback Control (Back pressure application)

Feedback control for a steam system backpressure control scheme utilizes another parameter to provide the controller with information on process changes. Backpressure control is used to maintain inlet steam pressure above a predetermined setpoint. Pressure transmitters are located on the inlet and outlet piping which will notify the control that changes are occurring. Consequently, backpressure control is used in conjunction with feedback control. The most common application for a steam system is the elimination of instant high demand for steam from a process that will effect the boiler operation.

Feed Forward Control

Feed forward control uses a secondary input from another variable to assist or provide the controller with the knowledge that various changes are occurring in the process. Flow measurement in pressure reducing applications adds instant identification that a change is occurring. This allows the controller to make corrective actions before a significant temperature or steam pressure change has occurred. Consequently, feed forward control is used in conjunction with feedback control. The feedback loop is used to maintain setpoint control and feed forward is used to compensate for any errors and unmeasured disturbances. One of the most common applications is a pressure transmitter that is used on a shell and tube heat exchanger to sense and feed forward a change in steam pressure. The steam pressure change on the shell side is 
first indication that the temperature (process variable) will change in a very short period of time.

**Ratio Control**

Ratio control is a duplex form of feedback control that has two sets of variables, for which the controller calculates a setpoint from the two variables for the control scheme. The object of a ratio control scheme is to keep the ratio of two variables at different values depending on the final objective of the control system.

As diagram below indicates, on a pressure control system, the control output to the different valves is ratio depending on the percentage of travel (0-100%) and the pressure transmitter. This type of control scheme is applied when two or more control valves are used in a pressure reducing application.

**Cascade Control**

Cascade control is widely used within steam process industries. The conventional cascade scheme has two distinct functions with two control loops. Cascade control is used to improve the response of the single feedback strategy. A heat exchanger varying process flow will have different steam requirements depending on the flow. Cascade control understands the requirements and adjusts the output to...
the control valve according to process flow. The main objective is to achieve the desire output temperature of the process, which is the lead process variable. The idea is similar to that of the feed forward control scheme.

**Differential Control**

Differential control is used typically on rotating cylinder dryers because differential pressure is required across the siphoning joint to assist in evacuating the condensate. The use of rotating cylinders is the only process where gravity drainage of condensate is not possible. Therefore, using differential control identifies the parameters of inlet and outlet process pressures and maintains a lower outlet steam pressure, thus achieving the differential. Differential control is also used on other limited heat transfer applications.

**Control Actions**

The controller’s output to the final control element (valve or actuator) is accomplish by different methods

I. On/off
   a.) Simplest
   b.) Least accurate
   c.) PI (proportional and integral)
   d.) Medium cost factor
   e.) Medium accuracy
II. PID (proportional, integral and derivative)
   a.) Highest cost
   b.) Highest accuracy

On/Off Control

Control schemes using a feedback control parameter can use on/off control. On/off control is the simplest control scheme with the highest degree of inaccuracy. The controller has setpoint with high and low control action points, similar to a home air conditioning or heating system. The thermostat has a desired setpoint and the system is actually operated between two temperature points (on/off). A desired outlet temperature is 180°F and the on/off control would activate the steam valve to heat the product to 185°F. At 185°F, the steam valve would be deactivated and this would allow the process to cool down to 175°F (lower setpoint). The steam would be activated and deactivated between the high and low process setpoints.

PI Control

PI control will use proportional (proportional to the difference between a setpoint and a process variable) and integral (a totalizing function) algorithm, which provides a continuous control process output to meet the desired setpoint. This is similar to a light dimmer switch versus an on/off light switch. The dimmer mechanism provides a light variable from off to full brightness or anywhere in between. PI controls the steam flow from zero to full flow or anywhere in between on a continuous basis.

PID Control

PID control has proportional, integral, and derivative algorithms available for use to maintain the setpoint of the process. Steam applications use the proportional and integral part of the PID. The derivative algorithm is used very seldom and then only by someone very experienced in control algorithms. If the heat transfer equipment, control valve, and the controller are properly selected, then proportional and integral are the only parameters required to maintain a highly accurate process result.

Applications of Control Schemes

Steam Pressure Control
The majority of industrial steam systems will have a pressure-reducing valve application. High pressure steam is reduced to lower pressure steam for a process or heating application. Used throughout all types of industries, some plants will have from one to over one hundred different pressure-control valves. The feedback control scheme is simply a pressure transmitter or a sensing line coming back to the valve.

In a simple regulator type control system for pressure control (shown below), a sensing line is providing the feedback to the external pilot, which is the controlling device. The main valve is the final controlling element.

A control valve layout using a pressure transmitter as the feedback sensing device and the controller provides the correct control action (shown below). The pneumatic valve is the final controlling element.
Many applications require the use of one or more valves to achieve the necessary turndown.

Control valves that are used in any type of control scheme should utilize a secondary pressure drop if the control valve is in a sub-critical flow operation. The diagram below shows the use of a simple orifice plate after the control valve to provide a secondary pressure drop. This type of installation has been used for over 60 years. The inlet pressure to the control valve is $P_1$, the pressure between the control valve and the orifice is $P_2$, and the final control point or outlet pressure to the control valve is $P_3$. Orifice plates, when properly sized and installed, prevent the valve from operating at a sub-critical flow and causing premature failure.

**Feedback control with muffling orifice**

![Diagram of feedback control with muffling orifice]

**Backpressure Control**

The backpressure control is a type of feedback control scheme. The typical application is smaller boilers without large steam reservoir capabilities for instant steam load demands. High instantaneous demands for steam can cause unwanted shutdowns of the boiler. Using backpressure control prevents the shut down. A transmitter sensing the inlet pressure to the valve identifies a reduction of pressure beyond the predetermined setpoint and the valve begins to close down to maintain the steam set pressure on the inlet of the valve. This action overrides any pressure requirements or needs on the downstream side of the valve.

![Diagram of backpressure control]

**Backpressure control**
### Feedforward Control

The following drawing shows a feedforward/feedback control system. The orifice steam flow meter is providing the feedforward information to the controller. The pressure transmitter is providing the feedback to the controller. The pneumatic control valve is the final element.

![Feedforward control](image)

### Ratio Control

Another way to accomplish the goal of meeting large steam flow requirements is the use of multiple valves. Multiple valves can provide better control in meeting the process requirements. In a two-stage pressure control scheme, the stages use a feedback control scheme and then ratio the controller output to the valves. In the diagram below, the system is the ratio or position of the primary and secondary valve depending on the required flow rates. Parallel positioning valves are quite commonly used in process heating applications where load conditions vary greatly from the very coldest part of the season to the very warmest time of the season.

![Ratio control](image)
Differential Control

Differential control as shown below provides the condensate removal of a rotating cylinder dryer. This goal is accomplished by maintaining a lower steam pressure (pressure transmitter no. 2) than the inlet steam pressure (pressure transmitter no. 1).

Heat Transfer Feedback Control

Probably the most simple and most common control scheme used in heat transfer is simple feedback control. This is the simplest system, but this control scheme does not account for any upsets or disturbances or unknown factors that might occur in the system and affect the heat transfer process.
Heat Transfer Feedforward Control

This control scheme uses feedback to control temperature, and uses pressure as the feedforward. A disturbance or change in process immediately causes a pressure drop to occur in the heat transfer due to the collapsing of the steam. The steam pressure feedforward anticipates the temperature change at the outlet product flow prior to this occurring. This provides anticipation of process changes.
Heat Transfer Feedback, Feedforward, Cascade Control

The control system in heat transfer can have feedback (temperature) feedforward (steam pressure) and cascade in the product flow into the control scheme. Using all possible variables in the heat transfer control can provide the highest degree of accuracy.

Feedback Condensate Control

Condensate feedback control scheme is used in condensate removal and is typically a simple level transmitter, controller, and control valve. This system is used on a heat transfer application as shown below.

In process flow operations where condensate flow rates are 8,000 lbs/hr or higher, steam traps are not recommended. The recommendation is to use a level transmitter, controller, and control valve with a feedback control scheme. This feedback control
scheme gives you the ability to remove the condensate from the heat transfer process on a continuous basis. In these high flow rates, a control valve provides a high degree of accuracy and control in the removal of condensate from heat transfer.

**Control vs. Cost**

The ultimate process control scheme is one that provides the system the most information possible, but to do this there is also a cost factor that must be evaluated. The more information being provided to the control scheme, the more cost for the field devices and the more complex the controller, control strategy, wiring, etc. Therefore, the user must understand there is cost justification to consider in identifying the correct control scheme for the process application.

**Conclusions**

Control strategies, when evaluated from basic inputs and outputs, are simple and straightforward. Control schemes should be determined based on the control necessary, the cost, and the process.

**Recommendations**

1) Outline your objectives and goals clearly before starting the selection process;
2) Select the correct control scheme for the process; and
3) Select the proper equipment for the application.