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An Overview of Control Systems Applied to a Gas Process Plant

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Abstract

This paper outlines the control engineering methods and principles applied to a gas process plant. The discussion is divided into some engineering aspects—needs analysis, methods, specifications and requirements of a control system. The various control modes(proportional, derivative, integral and PID) are discussed as these are most commonly used in oil and gas production plants. Specifications of different control systems and HART principles are mentioned. This will bridge the gap between theoretical study and application of control system courses at undergraduate level. Most of the students frustrate that the courses they studied have no practical use. This article will enhance their method of learning and will be a tool for connecting students and professionals in process engineering fields.

Key-words: *PID Control, SISO, PLC, Servo-mechanism, HART.*

1.Introduction(Overview of UG Courses on Control Systems):

The standard course on control system at undergraduate level deals with introductory concepts such as open- loop versus closed- loop feedback system, input-output relationship, transfer function, DC machine dynamics, performance criteria, sensitivity and accuracy, analysis of control systems—time and frequency domain. Moreover, stability of control system deals with bode plot, Nyquist and root-locus technique, frequency response analysis, non-linear control system, controllability etc. Some pre-requisite courses on Mathematics such as Laplace transforms, Matrices etc. are studied. The subject matter included in the course are useful to design and analysis of control systems or devices/equipments used in a process plant. While analyzing the performance of a system or it's parameters by using programming tools, we've to know the ins and outs of the system. The study of automatic control is a complex subject. Exact solutions to particular control problems require detail process knowledge, not only of the physical and chemical characteristics of the fluids, but also of the mechanical aspects of the process—equipments (pumps, heat exchangers etc.), piping systems and the control loop itself. Mixed control modes are used in the process plant to control different valves(level control valves, pressure control valves), to control temperature and flow by electronic indicator(indicating controllers) situated in the control room and pneumatic sensing or measuring element in the process field area. Remote analogue control loops generally employ electronic single loop controllers, local level control loops employ pneumatic controllers, and all switching logic and ESD functions are accomplished with a Programmable Logic Controller(PLC). One thing to mention here, this is an introduction into the complex field on control system keeping in mind that once basic principles are sufficiently clear, it will be relatively simple to understand and operate more complex systems. However, details of PLC functions is beyond the scope of this article.

2. Process Description:

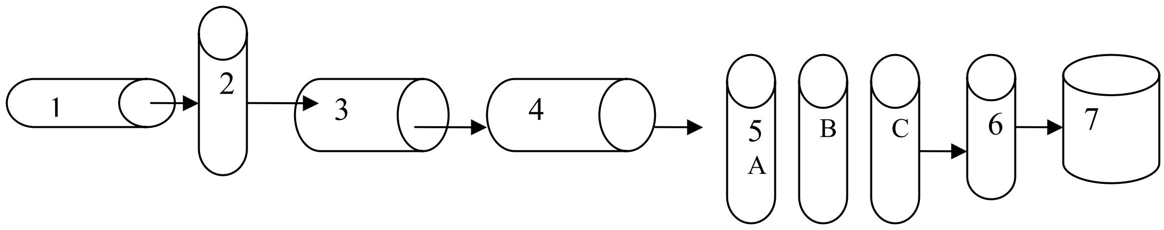

Fig.1 Gas dehydration and condensate recovery process : 1-Inlet knock-out separator 2-inlet separator, 3-regen heater, 4-heat exchanger ,5-desiccant towers, 6-regen scrubber, 7-tank

Before describing how the control engineering is applied to the gas process plant, let us describe the process first, in brief. The complete process plant consists of four basic steps: inlet gas treatment, gas dehydration, regeneration gas treatment and cooling gas treatment

Inlet Gas Treatment

The inlet gas is drawn from various wells. After passing the flow lines, the gas flows via ESD valves into knock-out separators where water, condensate and solid material(if any) are separated out from the gas. Because the pressure of the gas in the knock-out separators is higher than in the production manifold, the gas must be throttled which is achieved in the flow control valves. Then the gas first passes to the inlet separator, and then, before it flows to the desiccant towers, is filtered in the filter separator to remove any solids and entrained liquids- particularly, water which can affect the silica gel desiccant performance. Then it passes to the plant associated (heavy) condensate separator.

Gas dehydration

The three desiccant towers operate in different modes at any given time. Thus, while the first tower is in the drying mode, the second is in the regeneration mode and the third is in the cooling mode. The operating mode for the towers change with an approximate ½ hour interval cycle. The operating mode switch-over of the towers is controlled by a timer-activated automatic sequential control system programmed in a PLC. The filtered gas is routed to the desiccant towers and enters the tower in the drying mode from the top. The towers contain a bed of silica gel –based desiccant and , while passing through the bed, the water and C5-plus the heavier hydrocarbon components present in the gas stream, get adsorbed onto the desiccant. The contact with the desiccant bed renders the gas stream sufficiently dry to meet the dew point specifications (both water and hydrocarbon) required for the pipeline quality. The dried gas flows out from the bottom of the tower and is routed to the dust gas filter.

Regeneration Gas Treatment

The tower in the regeneration mode undergoes heating of the desiccant bed with hot regeneration gas. This gas is a side stream of approx.30% of the feed gas to the desiccant towers and heated in the regeneration gas heater to a certain temperature. The hot gas, while passing over the desiccant bed, vaporizes the adsorbed water and hydrocarbons from the bed. From the tower, the regeneration gas flows through the gas-gas exchanger, regeneration gas cooler in series to cool it down to a designated temperature.

Cooling Gas Treatment

The cooling gas treatment is performed in a similar manner to that of regeneration gas using cooler fans etc.

3. Needs Analysis

Before selecting or choosing a controller type or mode, we have to analyze the characteristics of the complete process, the individual process variables or parameters and other factors including ambient conditions(dew point, humidity), instrumentation and measurement philosophy etc. From this analysis or simulation by using software, we can decide whether it will be an electronic integrator, totalizer, counter, recorder or other type of electronic indicator. We first look at the parameters to be controlled from the control room. For information, this is notable here that this is not the exact designing approach , only for illustration.

Major process variables/parameters affecting the performance of solid desiccant: feed gas temperature, feed gas specific gravity, cycle time, outlet gas dew point, desiccant capacity, desiccant bed pressure drop.

Pressure: individual well pressure(inlet knock-out separator), manifold pressure, heat-exchanger shell out pressure.

Differential pressure: of individual desiccant towers, heat exchanger.
Temperature: individual well temp., outlet temperature of knock-out separators, water bath(inlet heater) temperature, regen gas temp., sales gas temp.
Level: level glasses used for related equipments in the process area.
Flow: plant inlet flow, regen gas flow(quantity), cooling gas flow etc.

4. Automatic, Closed loop versus Open loop Control System

An Automatic Control System comprises of an arrangement of elements which are inter-connected and interact such that some controlled condition (e.g. temperature, flow or pressure) forming part of the system is maintained in a prescribed manner. The important elements of a process-control loop are the process, measurement, evaluation, and the control element.

If this system was to be controlled manually by an operator, the system in block form would work as shown in Fig. which becomes a 'closed loop' in the sense that any disturbance to the temperature will pass round the loop from element to element until the human brain compares the desired temperature with the temperature as indicated, and corrective action is applied manually.
To control temperature at near about set value without much offshoot, operator action would be as follows : Whenever he finds any difference between measured and set value, he would open or close the valve initially by an amount proportional to the error by his experience. He would then wait for the response or its effect.

This is because system has some capacity and resistance which take time in transferring the cause to effect. After sometime he would again open/close the valve by lesser amount and again wait for the effect and repeat such action with smaller and smaller opening /closing subsequently till the desired value is reached.

Since operator can't do such a function continuously and correctly due to his limitations, an automatic closed control loop has to be employed which would be doing exactly similar functions continuously and endlessly. The closed control loop is also known as servo mechanism and the various elements are process itself, sensor, settler, controller, power amplifying device, and regulating device such as control valve. Regardless of the number of elements used, the loop will contain at least four basic elements : (a) detecting, (b) measuring, (c) Controlling and (d) final control element. Often, a transmitting element is added to these

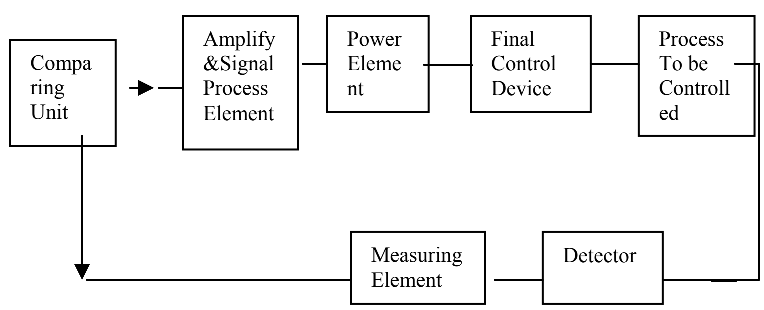

Fig.2 Single Loop Feedback Control System

In the closed control loop the controller mechanism takes the place of the human eye and the correcting unit is substituted for the human hand. Fig.1 shows in block schematic form the closed control loop. It would be noted that the command signal θi generated by the setter is applied to the controller and compared with the instantaneous value of the process parameter to be controlled(θo). The output of the comparing unit represents the difference of θi and θo known as error which is amplified and processed by the controller as per its settings. The output of the controller is fed to a power element/motor element. The motor element is the correcting unit which adjusts the final controlling device in response to a signal from the controller and thus amplifies it to a level sufficient to actuate the final controlling device which adjusts the output to match with set value.

Open Loop Control System : Control without feedback is called an open loop system. It is many times advantageous to make use of an open loop to give an approximate correction for changes which will ultimately affect the true controlled variable.

5. Methods/Modes of Control System

There are five main modes of control which can be used to control the process at the desired value despite the difficulties, occasioned by the characteristics of the plant and process.

(i) Two step or on/off
(ii) Proportional
(iii) integral
(iv) Derivative
(v) Proportional plus Integral plus Derivative (PID)

Two step/On-Off : The simplest form of automatic control used is the two-position or on-off type control. Two position control is normally used when the controlled process variables need not be maintained at precise values. This type of control action regulates the flow of input energy by either fully opening or fully closing the valve. The controller operates the valve when the controlled variable rises or falls above or below the set point. In on-off control, the output is dependent on the error. An example is alarm and shut down functions.

Proportional: It's name is derived from the fact that controller output is proportional to the difference between the measured variable and the set point, i.e. the error signal. In proportional mode of control, the control valve or regulating unit can take up any position right from fully open to fully closed, which results in a stable control. Proportional control produces an overshoot followed by an oscillatory response, which levels out at a value that does not equal the set point ; this ultimate displacement from the set point is the offset.

Integral : Integral or reset action is defined as a controller response which is proportional to the extent and duration of a signal deviation. In the proportional control, valve begins to move as soon as there is a deviation and will come to rest after traveling a distance, proportional to deviation. Further, the speed of valve travel is proportional to the rate at which the deviation is increasing or decreasing. In integral action, the valve speed changes continuously depending upon the error. With this control, the valve is only at rest when the control variable is at the set point.

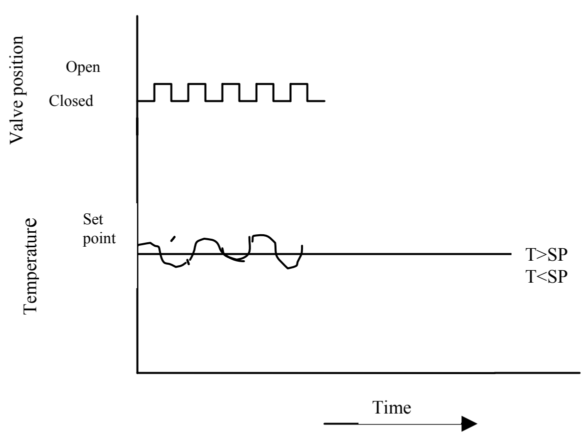

Fig.3 Simple two-position (On-Off) Control System

Derivative Control: It is defined as that part of a controller response which is proportional to the rate of change of input. If, during control the variable rapidly approaches the set point, it is bound to result in a large overshoot. Accordingly, a large movement of valve in opposite direction is essential to reduce the overshoot. In derivative control, the valve is no way concerned with the set point, but moves an amount purely according to the direction and the rate of change of deviation. If the variable makes a sudden step movement, its rate of change is infinitely fast and the valve will, therefore, travel at once to its full travel position. If, on the other hand, the variable moves gradually at a constant rate, the valve will move on an amount proportional to that rate and will not move again until the rate of change of deviation alters. Derivative control is never used alone, but normally in conjunction with proportional or proportional plus integral control.

PID : The proportional-integral-derivative(PID) controller is by far the most commonly used controller. About 90 to 95% of all control problems are solved by this controller, which comes in many forms. It is packaged in standard boxes for process control and simpler version for temperature control. It is a key component of all distributed systems for process control. Specialized controllers for many different applications are also based on PID control. The PID controller can thus be regarded as the "bread and butter" of control engineering. It has gone through many changes in technology. The early controllers were based on relays and synchronous electric motors or pneumatic or hydraulic systems. These systems were then replaced by electronics and, lately, microprocessors.

6. Specifications of Control System : Generally, control system specifications can be divided into two categories : performance specifications and robustness specifications. All though the boundaries between the two can be fuzzy, the performance specifications describe the desired response of the nominal system to command inputs. The robustness specifications limit the degradation in performance due to variations in the systems and disturbances.

Performance specifications for SISO LTI systems :

Transient Response Specifications : In many practical cases, the desired performance characteristics of control systems are specified in terms of time-domain quantities, and frequently, in terms of the transient and steady-state response to a unit-step input.. The unit step signal, one of the three most commonly used test signals(the other two are ramp and parabolic signals), is often used because there is a close co-relation between a system response to a unit step input and the system's ability to perform under normal operating conditions. And many control systems experience input signals very similar to the standard test signals. If the response to a unit step input is known, then it is mathematically possible to compute the response to any input. Both the transient and steady-state specifications require that the closed-loop system is stable.

The transient response of a controlled system often exhibits damped oscillations before reaching steady-state. In specifying the transient response characteristics, it is common to specify the following quantities : (a)Rise time (b)Percent overshoot (c)Peak time (d)Settling time (e)Delay time

Frequency –Domain Performance Specifications

In control system design by means of frequency-domain methods, the following specifications are often used in practice : (a)Resonant peak (b)Bandwidth (c)Cut-off rate.

Robustness Specifications for SISO LTI Systems:

(a)Relative Stability –Gain and Phase Margins (b)Sensitivity to Parameters (c)Disturbance rejection and Noise Suppression

Miscellaneous Specifications : There are many other aspects of a control system that are often specified. There are usually constraints on the allowable cost of the controller. In some applications, the size, weight and power required for the controller's operation are restricted. Control system reliability is also often specified. The simplest such specification is the life expectancy of the controller. The allowable ways in which a controller may fail are also often specified, especially in applications involving humans.

7. Analyzing Control Problems

The proper solutions to control problems are not always obvious. Solutions that seem obvious are not always the best. In order to evaluate the various alternatives, some pertinent questions may furnish clues to proper applications. Among the questions that need answering are these:

1. Which variable should be controlled?
2. Which detection method should be used for that variable?
3. Where should the detector be located?
4. How should system cost versus system efficiency be evaluated?

8. Requirements of a Control System /Performance Criteria

The essential conditions for a good control are : small deviation from set value after a disturbance, high sensitivity, narrow proportional band, minimum offset, quick return to set value after a disturbance. These conditions can be achieved by proper study and analysis of plant and process.

9. HART Communication

The HART (Highway Addressable Remote Transducer) protocol gives field devices the capability of communicating instrument and process data digitally. This digital communications occurs over the same two-wire loop that provides the 4--20 mA process control signal, without disrupting the process signal. In this way, the analog process signal, with its faster upgrade rate, can be used for control. At the same time, the HART protocol allows access to digital diagnostic, maintenance, and additional process data. The protocol provides total system integration via a host device.
The HART protocol uses the frequency shift keying (FSK) technique based on the Bell 202 communication standard. By superimposing a frequency signal over the 4-20mA current, digital communication is attained. Two individual frequencies of 1200 and 2200Hz are superimposed as a sine wave over the 4-20mA current loop. These frequencies represent the digits 1 and 0 . The average value of this sine wave is zero, therefore no dc value is added to the 4-20mA signal. Thus, true simultaneous communication is achieved without interrupting the process signal.

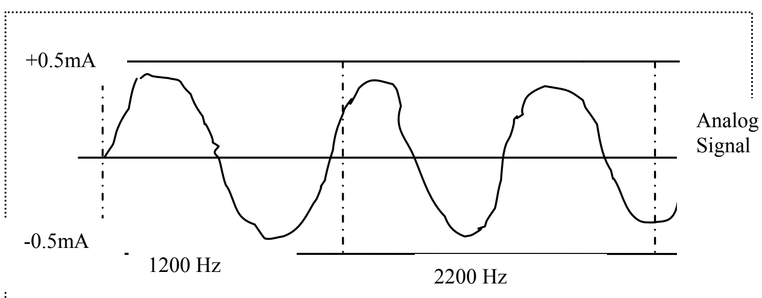

Fig. 3 HART FSK Technique

10. Conclusion

In this article, five types of control, HART, specifications and requirements of control system have been discussed. Once the control system methods and principles are properly understood, attention may be paid to control circuit design by using electronic devices or microprocessor as per need. To do so, control system requirements, specifications and standards currently used must be known. Many computer software packages are available for use in solving problems in process dynamics and control. Some are : TUTSIM, Program CC, ACSL, SIMNON etc.

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