TECHMATION
8070 E. Morgan Trail • Suite 150 • Scottsdale, AZ 85258-1228
office: (480) 968-9946 fax: (480) 443-0402
e-mail: techmatn@dancris.com

Application Note

Control Strategy: Selective Control Systems

Abstract

There must be one final control element for each process variable to be controlled in a system. In many systems however, the process variables to be controlled outnumber the final control elements. In these applications, the control system must automatically decide how to share the final control elements. When this is the case, selective controls can be employed to switch easily and smoothly between the variables to be controlled. The purpose of this Protuner System Analysis Note is to provide:

1. How the various selective control strategies are properly implemented and configured
2. Guidance on the implementation of external anti-reset windup to insure the unselected controller integral action is disabled when the controller is unselected
3. Information on potential control problems that might be encountered when the digital control system, being used to implement the selective control strategy, employs the incremental or velocity and not the positional form of the PID
4. Protuner control system analysis test techniques to trouble shoot the field equipment and determine the optimum tuning parameters for the controllers

Introduction

Selective controls involve the use of signal selectors which choose either the lowest, median, or highest control signal from two or more signals. Selective controls are employed in five basic application areas:

- **Protection of equipment**
- **Variable structuring**
- **Auctioneering**
- **Redundant instrumentation**
- **Valve position control**

Each of these selective control application types has its own unique implementation, control equipment requirements, and test procedure for optimization.

Protection of Equipment

In many process control systems, there is a primary process variable that needs to be controlled along with a second process variable that must not be exceeded for reasons of economy, efficiency, or safety. The following example illustrates how a typical selective control strategy is implemented for the protection of equipment. In this example, the control of the discharge from a compressor is controlled by manipulating the setpoint of the motor speed controller. The two variables that require control are the discharge airflow and pressure. The control strategy uses two separate controllers and a low signal selector to decide which controller output signal will be used for control of motor speed.

Figure 1 illustrates how the low signal selector is used to select the lower output of either the pressure or flow controller to manipulate motor speed.

Under normal operating conditions, the discharge pressure is below its setpoint and the flow controller output is less than the output from the pressure controller, and therefore selected to change the motor speed to control the discharge flow out of the compressor. Thus the pressure is allowed to drift below its setpoint during normal or high load conditions. During conditions of low loads on the compressor, the pressure controller reaches its setpoint and its output becomes lower than the output of the flow controller, and is allowed to assume control, thereby lowering the flow and controlling the pressure at its setpoint. Decreasing the motor speed decreases both the flow and the pressure, use of the low signal selector guards the system against an excess of either.

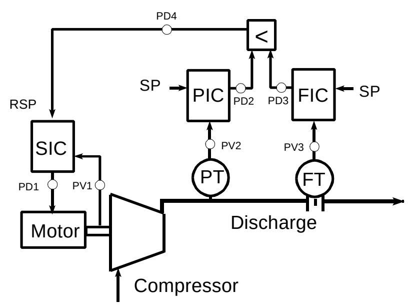

Figure 1—Motor speed is manipulated by whichever controller has the lower output

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Protection Against Windup

When one controller is selected from two or more, the others are in an open loop condition. If the unselected controllers have integral action, which is often the case, they need to be protected against windup. If not protected, integral action in the unselected controller will cause its output to saturate because its output is not able to adjust the final control element to achieve its setpoint.

One solution to the windup problem is to modify the standard PID equation by adding a term that integrates the difference between the controller output and the output of the signal selector. When the controller is not selected the controller output, and the output of the signal selector, will be different and integration occurs. The new term cancels out the normal integral action, in effect integral action is stopped until the controller resumes control. The output of the signal selector must be fed back to the modified controller, hence the name *external integral feedback.*

Unselected controllers can also be protected from windup by setting their internal high and low limits from the output of the signal selector. The high limit must be biased slightly above the selected output, and the low limit slightly below, to avoid interference with the selected controller. Unselected controllers will windup only to the extent of the bias, which may result in a small overshoot during transition from one controller to another.

If external anti-reset windup is not employed, there will be a large overshoot in the controlled variable during the transition from one controller to another, which may be unacceptable. It is therefore necessary to understand how the controllers you are using work so that you can be sure that external anti-reset windup is correctly installed.

Digital Algorithm Considerations When Configuring Protective Selective Control Strategies

How well the selective control system actually works in the field can be a function of the methodology that is employed in the implementation of the digital PID algorithm in the controller brand you are using. (See the Techmation publication: ***Implementation of PID Algorithms*** for more details.) Selective controls are limited to the positional implementation of the PID algorithm. Selecting a controller, which uses the incremental, or velocity implementation of the PID algorithm is not equivalent and can lead to serious problems, which may not be easily recognized. This constitutes a significant limitation in applying the incremental or velocity algorithm rather than the positional algorithm.

The first problem is associated with the sample intervals of the controllers whose outputs are compared. If the signal selector samples more often than one of the controllers, it will see a) output of zero at times when the control algorithm is not being processed. This is actually false information and causes the system to respond differently to increasing and decreasing signals. In the case of a low selector, the system will drive down scale at the shortest sample interval of any of the associated controllers and upscale at the longest interval. Roles are reversed for a high selector. If your controller uses the velocity or increment form of the PID algorithm, all the controllers and the signal selectors must sample precisely at the same interval, which is often not the case. This problem can result in control anomalies that are not easily recognized or overcome.

A second problem is associated with noise response. The incremental algorithm (see ***Implementation of PID Algorithms***) shows that the ∆output responds to changes in deviation from the last sample, that is, ∆e. Noise on the input signal will produce a ∆e, even in steady-state, developing a proportional ∆output. The change is even more pronounced with derivative action. Ordinarily output to the valve simply reflects the noise level, but a signal selector will pass ∆output of one sign and reject the next ∆output of the opposite sign. As a result, the changes induced by the noise are rectified by the selector, causing the valve to be driven in the direction preferred by the selector.

The offset caused by noise on the process variable measurement signal resulting from the noise rectification when an incremental or velocity controller algorithm is employed, can be estimated by the following formula:

$$offset = \frac{Ti}{h}\Delta n\left(1 + \frac{Td}{h}\right)$$

Where Ti is the integral time, Td is the derivative time, h is the controller scan rate, and) n is the peak to peak noise level on the process variable signal. As an example, a controller with 0.1 minute per repeat integral setting, a 1 second scan rate, and a 1 % signal noise on the controller output will result in an offset from setpoint of 6 %. Offset error can be reduced by reducing both the I and the D, increasing the sample interval of the controller, or by using process variable measurement filtering to eliminate the signal noise. However, it remains a fundamental defect of the incremental or velocity implementation of the PID algorithm, which you need to be aware of when implementing selective controls.

Dynamic Analysis and Tuning Using the Protuner

To analyze the dynamics of the installed system with the Protuner requires that you test the system in the proper sequence. The following steps outline the correct test sequence.

1. The first step is to test the system to determine the installed dynamics of the motor speed

control loop. The motor speed controller case is the inner loop of the cascade system and its closed loop response must be optimized before the outer loop controllers are tested. Connect the Protuner to record the PV1 (motor speed) and PD1 (output of SIC to the motor). Place SIC in manual and record the response of PV1 to a series of step changes in PD1 in accordance with the open loop test procedure for self-regulating processes as described in the ***Protuner Applications Manual***. In performing loop analysis of the test data, pay particular attention to differences in the rate of change of the motor speed to the step changes in the controller output. Many speed controllers allow the user to adjust the ramp rate of the output change. You will want to assure yourself that the ramp change rate is not set too slow, and that it is programmed for the same response for increasing and decreasing speed changes. If you see that the response is too slow, or there is a difference in the increasing and decreasing direction, make the appropriate changes and retest the loop. Once you are convinced the open loop response data is correct, window the test data and use the Tuning Procedure to determine the optimum tuning parameters for SIC. Enter the tuning parameters in SIC and place the loop in automatic closed loop control.

2. The second step in the loop analysis procedure is determining the open loop dynamics of the FIC and PIC controllers. Connect the Protuner to record the loops input and output signals. The signals you will want to record are the PV2 (pressure signal), PV3 (flow signal), PD2 (output of pressure controller), PD3 output of flow controller, and PD4 (output of the low signal selector which is the RSP or remote setpoint to the speed controller). With the speed controller in automatic, record a series of step changes in PD4 in accordance with the test procedure for self-regulating processes and the response of both the pressure PV2 and the flow PV3. Use the data to perform two loop analysis tests. The first analysis to determine tuning parameters for PIC compares the step changes in PD4 to the response in pressure PV2. The second loop analysis, to determine the tuning parameters for the flow controller FIC, compares the step changes in PD4 to the flow response PV3. Enter the tuning parameters into the controller and place the loops in automatic control.

With all loops in automatic control, with the Protuner determined tuning parameters entered in each controller, record the loop response to a series of step changes in the setpoint of the selected controller. In analysis of the data, check to be sure that the anti-reset windup is operating correctly in the unselected controller by seeing that its output signal does not integrate to 100% output but acts as a P only controller when unselected. If there is noise on the signal, check to be sure that the noise does not result in an offset in setpoint due to the use of the incremental or velocity algorithm in the control system.

Note: In some DCS systems, control signals PD2, PD3, and PD4 may be only software signals and therefore unavailable to be recorded using the Protuner 1600PC from the controller I/O rack. If this is the case, program the system to temporarily re-transmit the required points to spare outputs.

Variable Structuring

Interlocks automatically shutdown control equipment when hazardous conditions exist. Shutdowns can be avoided by designing the control system to take corrective measures before the interlock condition is reached and keeping the system running at a sub-optimal level. The implementation of this type of selective control system is called variable structuring.

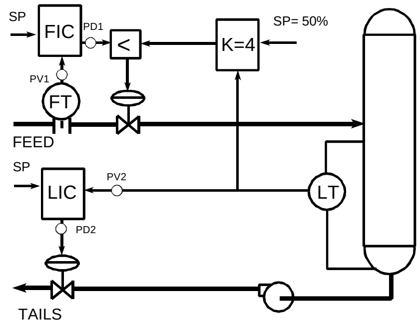

Figure 2—High level override pinches feedflow

Figure 2 illustrates the control of a distillation column base level control system where the level is normally controlled by manipulating the tails flow out of the column. If the tails line becomes restricted, the tails line looses its ability to control the level and the level rises. The control system then selects the feedflow as a secondary manipulated variable. The output of the level transmitter is fed as both the normal process variable signal to the bottoms level controller, and as an input to a reverse acting proportional only controller with a proportional gain setting of 4. The output of the proportional only controller is fed as a signal to the low signal selector to perform the logic to override the normal feed flow controller and throttle the feed flow valve to control level.

When the level transmitter output is below 75%, the output of the proportional gain 4 controller is 100% and therefore not selected by the low signal selector. In this case, the control system is performing in a normal manner. That is, the bottom level is controlled by the level controller and the column feed is controlled by the feedflow controller. When the column level rises above 75% of transmitter span, the output of the reverse acting proportional gain 4 controller starts to decrease below 100%, and will become 0% when the level is 100%. Somewhere in-between 75% and 100% of the level signal, the output of the proportional gain 4 controller will be lower than the feed flow controller and will be selected by the low signal selector. Thus, the feed to the column will be reduced so that it just keeps up with the tails restriction, and the column will not flood.

These types of variable structuring control systems are also called "overrides" or "soft constraint" controls. They are used to avoid shutdowns and in the implementation of startup systems. Analysis and tuning of the flow and level controllers are accomplished using the Protuner by performing independent control loop analysis tests on the two controllers as if the override control system was not implemented.

Controller Design and Algorithm Considerations

As discussed previously, the effectiveness of the selective control system is limited to the use of a control system where the PID control algorithms are implemented in the positional form. Along with the previously discussed problems with the incremental or velocity implementation of the PID algorithm when used for selective controls, this type of application presents another problem. That is, the incremental or velocity form of the PID algorithm cannot be used for P only control when the P only algorithm implementation does not contain a bias term. Therefore, a P only controller without bias cannot be caused to implement this type of logic. The incremental or velocity form of the PID algorithm looses track of position when integral action is not used. Some manufacturers use the velocity or incremental algorithm for PI or PID control and the positional algorithm when P or PD control is used. In any case, it is important that you understand how the PID digital controller algorithm you are using is implemented to prevent serious control problems which are not always easily recognized. It is also important, that the flow controller be protected against integral windup when unselected.

Dynamic Analysis and Tuning Using the Protuner

In this example, the Protuner would be used to test and tune the FIC and LIC controllers individually. The following outlines the basic testing procedure for the installed system. For more detail, refer to the ***Protuner Applications Manual.***

First, connect the Protuner to measure PD1 and PV1 (the output and process variable measurement of the flow loop). Place the loop in manual and record a series of step changes in the controller output and the response of the flow following the test procedure for self-regulating processes. Loop analysis of the test data will determine any control or equipment problems and the optimum tuning parameters for the controller. Enter the tuning parameters into the flow controller and test the loop in automatic to verify the closed loop response.

The second step is to determine the tuning parameters for the level controller. Connect the Protuner to measure the level controller output PD2 and the level signal PV2. Place the level controller in manual and record step changes in the controller output following the test procedure for integrating processes. The control of a level loop is a mass balance problem. Therefore, for the level to remain constant the input flow to the system must be equal to the output flow. It is often the case, when conducting a Protuner loop analysis test on a process, that the degree of plugging in the tails line is unknown. Therefore, it would seem difficult to determine if the slow, medium, or fast tuning parameters should be selected to insure an adequate gain and phase margin in the closed loop system. The best rule to determine which tuning parameters should be selected is a function of output PD% position of the loop when the system is in balance at the time of testing. If the output PD% is between 10% and 30% the tails line is unrestricted and you will want to select the slow tuning parameters to insure adequate gain and phase margins when the tails line becomes more restricted. If the output is between 30% and 60% the tails line is already potentially restricted and you would want to select the medium tuning. If the PD% is between 60% and 90%, to achieve steady state at the time of the testing, you will want to select the fast tuning parameters.

Auctioneering of Process Variable Measurements

Auctioneering is a term used to describe a control system where a controller selects the highest process variable measurement from a battery of inputs. An example is the control of the highest temperature in a reactor. The possibility exists that the location of the highest temperature may shift. **Figure 3** illustrates how a high signal selector is used to control the peak reactor temperature. In this example, temperatures all along the reactor are compared and the highest temperature is used for control.

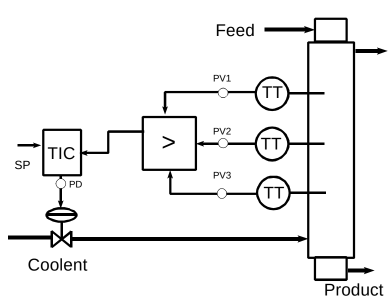

Figure 3—High selector to pick peak temperature

To determine the best possible tuning parameters for the controller that will provide good control regardless of the temperature transmitter selected, connect the Protuner to measure all three temperatures as the process variable signals and the output of the temperature controller as the process demand signal. Follow the Protuner loop analysis test procedure, by first recording the closed loop response of the system under both steady-state operating conditions, and the systems response to small setpoint changes with the as found tuning parameters in the controller. Then, place the temperature controller in manual and record the open loop response of the various temperatures to a series of step changes in the controller output. Once the test data is collected, perform the loop analysis and tuning procedure to calculate the tuning parameters for the temperature controller for all three temperature transmitters. Compare the results of all three sets of tuning parameters and choose the PID setting which will assure fast, yet stable, control regardless which temperature transmitter is selected. If the process dynamics and thus the optimum tuning parameters vary greatly depending on which transmitter is selected, you may want to consider a controller which has the option of changing its tuning parameters. In this type of controller, logic is employed to down load a specific set of tuning parameters based on which transmitter is selected.

Redundant Instrumentation

Signal selectors are also used to protect a control system from instrument failures by selecting the valid transmitter signal from among several. In this section, two examples are presented on how selective controls can be used to provide redundant process variable measurement signals.
Analyzers are generally less reliable than other instruments. **Figure 4** illustrates a system that would allow control to be maintained in the event of downscale failure of either analyzer. An upscale failure would be allowed, which would shutdown the reactor, but in a safe condition.

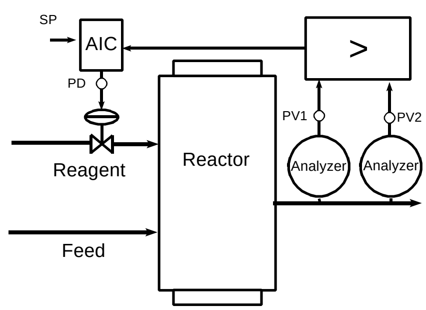

Figure 4—High selector prevents analyzer failure from damaging reactor with excessive reagent

If losing a transmitter is considered unacceptable, three transmitters must be provided. Three outputs are then compared in a median selector, which rejects the lowest and the highest signals. **Figure 5** illustrates the feed control to a reactor where it is critical to keep the feed within very tight limits.

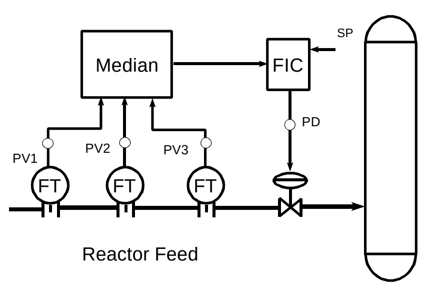

Figure 5—Redundant transmitters to protect against failures

Losing a transmitter would cause the valve to go wide open and exceed some limit. Redundant transmitters are commonly used in a hostile environment (high temperature or corrosive, dirty, or vibrating surroundings) where failure rates are high. Three transmitters measure the flow, and the median selector chooses the middle one for control. Redundant transmitters or sensors, and the use of medium selectors, keep the controls working when a transmitter fails, avoiding costly shutdowns.

Loop Analysis Testing

Loop analysis testing of selective control systems, configured to provide redundant measurement, is conducted following the same procedure as if the control system utilizes only a single transmitter. The exception is that the Protuner should be connected to measure all the various process variable signals. On occasion, when recording the Protuner loop analysis test data, a fault will be found in the transmitter not being currently selected. In analysis of the test data, pay particular attention to both the static as well as the dynamic response characteristics of the redundant measurements. A variance in the dynamic response characteristics between the transmitter can indicate faults in both the setup and installation.

Valve Position Control

In many control systems, there are several controlled variables fed from a single controlled supply. To minimize energy usage, it is desirable to keep the most-open valve nearly wide open but still in the controllable range. **Figure 6** illustrates an example where a variable speed fan is used to supply air pressure to two parallel units. Ideally, the variable speed fan should operate at minimum speed to satisfy both users.

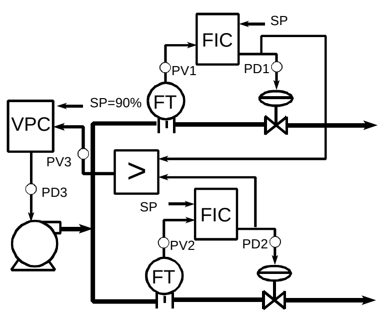

Figure 6—High selector and valve-position controller minimize fan speed

The control system configuration illustrated in **Figure 6** is designed to accomplish this. The output of the two flow loop controllers are sent to a high signal selector which passes the highest signal as the process variable signal to the valve position controller (VPC). With the valve position controller setpoint set at 90%(or some other preset value), the VPC will slow the fan speed in an attempt to keep the most open valve at 90% position. This allows the most open valve to still be in its controllable range and minimizes the power required to pass the flow demanded by the process.

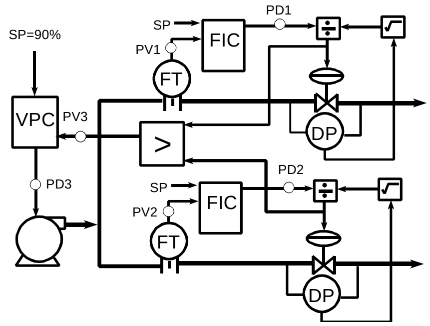

Figure 7—VPC system with dividers to improve response and eliminate interaction

Tuning the Control Loops

In tuning the control loops with the Protuner, you must be aware that the control configuration illustrated in **Figure 7** introduces a nonlinearity that needs to be understood in tuning the parallel flow loops. When valve position is controlled, the process gains of the flow loops varies directly with flow. That is, if linear valves are used for the flow valves, the installed characteristic will be equal percentage with a low process gain at low system loads and a high process gain at high loads. This is not a desirable characteristic for flow control, but an example of how performance is sacrificed to save energy.

The first step in testing the system is to connect the Protuner to the test points illustrated. Place the loops in manual and record individual control loop analysis step tests on the two flow control loops. Use the test data to analyze the static and dynamic characteristics of the individual flow loops. The results of the Protuner loop analysis on the individual loops calculates a table of slow, medium, and fast tuning parameters for entry into the individual flow controllers. If at the time of the testing, the output of the valve position controller is between 0% and 33% you should choose the fast tuning parameters, if the output is between 33% and 66% you should choose the medium tuning parameters, and if the output is between 66% and 100% you should choose the slow tuning parameters. The closed loop control will still be fast at low loads and sluggish or slow at high loads, but the flow loop tuning parameters will be optimized based on the use of a linear PID controller.

After the flow loops are tuned and in automatic control, the next step is to record the standard open loop control system analysis step test on the VPC controller. In performing the Protuner loop analysis of the test data, compare the step changes in drive speed (PD3) to the changes in valve position (PV3). The Protuner output will again provide a table of slow, medium, and fast tuning parameters for entry into the controller.

Before choosing the tuning parameters for the controller, an understanding of the closed loop requirements of the valve position controller is required. First of all, the function of the valve-position controller is to save energy at steady state. Secondly, any changes in the output of VPC, to keep the selected controller output at 90% upsets the unselected flow loops. Therefore, you want the output of the valve-position controller to change its output slowly. Therefore, you will want to choose the slowest PI tuning parameters from the Protuner loop analysis tuning table or the equivalent I only tuning parameters if you have the option for an I only controller available. If you want to use I only control, simply call Units from the Loop Analysis screen and change the controller algorithm type to Parallel. In the Parallel controller algorithm, the I and D parameters are independent and the controller gain, the integral setting for the slow PI tuning can be entered into your I only controller.

Valve Position Control Strategy to Eliminate Interaction

As discussed in the previous section, the use of a valve-position controller results in interaction between the variable speed fan and the unselected loops, as well as a nonlinearity as a function of load on the system. In some applications, where the system demand frequently changes, and sluggish response at high loads is unacceptable is addressed in the following control strategy. **Figure 7** illustrates a modified valve-position control strategy designed to linearize the flow control loops and eliminate interaction. To compensate for the loop gain variation, the differential pressure is measured across each flow control valve. The square root of the differential pressure is then divided into the actual controller output of each flow controller as the control signal to the valve. Thus, the denominator of the divider will vary inversely with load just as the loop process gain varies directly with load. The loop process gain thus remains constant with flow. The compensator allows fast tuning of the flow loops and speeds up the response of the entire system by closing the VPC loop without passing through the flow controllers. This allows the selected valve position to return to setpoint following changes in its flow setpoint, without disturbing the other flow loop.

This configuration thus compensates for the nonlinearities and eliminates the interaction in the system. The cost is additional dp transmitters for each flow loop.

Conclusion

The function of a control system is to control what the plant produces. Selective control systems, when installed, setup, and tuned properly, allow the automatic control system to choose either the lowest, highest, or medium, control signal from two or more signals switching easily and smoothly between them.

Optimum control of these types of systems requires more than simply tuning the controllers. Effective control also requires system analysis testing to determine the dynamics of both the selected and unselected variables, correct implementation of anti-reset windup protection, and in the case of digital controllers, the use of the positional controller algorithm. Many of the problems identified in field testing installed selective control systems, were determined to be associated with improper setup of the anti-reset windup protection, hard to recognize problems associated with the use of control systems which employ the incremental or velocity form of the PID algorithm, equipment problems, and lack of knowledge of the true system dynamics.