Override Control and External Reset Feedback
A Develop Your Potential Article for CONTROL magazine
R. R. Rhinehart
2023-02-13
Scheduled for 3Q 2023

An example:

Figure 1, from Harold Wade's CONTROL magazine article (December 2005), depicts a fired furnace heating a process fluid. The primary controller is the process fluid temperature controller (TC) in the lower right. If the process fluid is not hot enough, then the controller sends a signal to open the fail-close (air-to-open) flow control valve (FCV). However, the temperature of the internals in the heater are of possible concern. The TC in the upper right monitors tube temperature; and if it is too high, that override controller sends a low signal to the valve to reduce the tube T. The select block "<" executes a less-than test, selects the lower of the two signals, and sends the lower to the FCV.

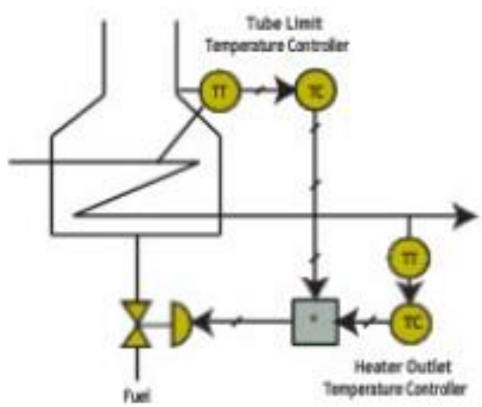

Figure 1 (from Wade, H. L. "Under the Hood of Override Control", Part I, CONTROL, Vol. XVII, No. 12, December, 2005, pp43-45)

We'll use some numbers to explain controller interaction. To follow this story, you might want to place the T and manipulated variable (MV) values on Figure 1. The process T set point (SP) is 430°F. The process T is at the set point of 430 °F, and the primary controller output, MV, is 55%. At this firing rate, the tube T is 550°F which is below the 600°F safety limit. Because of this, the override/safety/secondary controller thinks "The temperature is below my set point. We need more fire" and integrates up to an output of 100%. Since 55% is less than 100% the select block chooses 55% and tells the valve "Go to 55% open." At 55% open, the process temperature is just right. Everyone is happy but the secondary controller, who thinks, “Nobody ever listens to me.”

Now, over time, the process tube begins to get fouling (soot, scale, char, whatever), or the inflow feed T drops, or process flow rate increases; and, as a consequence, the process T drops. The process T controller fixes the process T by increasing its output to 60%. But now, with the higher firing rate, the tube T rises to 599^{o}F, which is still below (but barely) the safety limit of 600 ^{o}F, so the safety controller remains asking for more heat, and remains wound up at 100%. The select block selects the lower of the two signals and sends 60% to the valve. Again, everyone except the secondary controller is happy. The tube T is below the safety limit, and the process T is at set point.

But, the disturbance continues, and the primary controller needs to increase its output to 61%. It is still selected, because 61% is less than 100%, and at 61% the process T is held at the 430^{o}F set point, but the tube T rises to 605^{o}F. So, the safety controller drops its output to 99%. Since 61% < 99%, the select block still sends 61% to the FCV.

As time continues, the primary controller progressively raises its output to 63% then 65% to keep the process T at its set point. But this raises the tube T to 610^{o}F then 615^{o}F which accelerates the safety controller integral reduction, and its output drops from 99% to 95% to 80% to 70%. And still the select block chooses the primary output of 65%. Meanwhile, not everyone is happy. The tube T is above the safety limit.

As time continues, the safety controller output drops to 65%, tied with the primary controller output. Then the secondary controller drops to 64%, and finally the FCV is told to close a bit. Finally, the safety controller is in charge, but the tube T has risen to 618^{o}F. The override controller progressively lowers the FCV to 54%, returning the tube T to, and keeping it at the limit T. This action is keeping the process T as near to the set point as possible, but not overheating the tubes. However, for a time the tube T had been above the safety limit.

How far above the limit and for how long above the limit depends on controller tuning and process gains. But it is not something you want.

Oh yes, now, with too low a firing rate to sustain the process T, the process fluid exits at 417^{o}F, below the set point. And the primary controller winds up to 100%. If the fouling or inlet T or process flow rate issue is resolved, then the process T will rise to 452^{o}F, which is above the set point, and the primary controller integral will keep the output excessively high until it winds down to a value below the 57% signal from the secondary, when it is selected and returns to being in control.

Whichever controller is selected (in charge) the other (which is not in charge) will wind up. This causes a delay in the should-take-over-point and a persistance of the undesired outcome.

These type of control applications are variously termed override, safety, select, or switch control strategies. The override controller is variously termed safety, secondary, or auxiliary.

Override Applications:

Override application categories include:

Health, Safety, & Loss Prevention
- LEL, UEL, Dust in air
- Excess O_2 in flue gas
- Toxic vapors in air
- Cavitation or flashing in pumps, valves, and orifices
- Pressure or Vacuum in columns and tanks
- High Temperature (structural integrity)
- Low temperature (embrittlement of rubbers and gaskets)
- Level in tanks (overflow)

Product/Process Quality
- High Temperature (char, degrade, melt, diffuse)
- Low Temperature (crystallize, phase separation, condense)

Equipment Operation
- Choked valves, pipes, orifice
- Weeping, flooding, dry packing on trays
- Level in tanks (whirlpool gas in exit)

And, the solution discussed here, external reset feedback is also applicable to Feedforward (a prior article in this series), and Cascade and Ratio control strategies (upcomig topics).

Alternate Override Strategies:

1. Figure 1 has two controllers on the process. An alternate is to have only one controller, the process temperature controller in the lower right, and when the tube T violates a limit place the primary controller in MAN and override the signal to the valve with a lower signal to the valve. But what signal value? If too large then the tube T remains excessive. If too small then the tube T is well below the safety limit, but the process T remains much lower than it could be.
2. We'd like the process T to remain as close to the set point as possible. So, keep the two controllers as shown in Figure 1, and select which controller sends its signal to the valve. If the tube T is below the limit, place the auxiliary controller in MAN and use the primary controller in AUTO. When the tube T exceeds the limit, place the primary controller in MAN and the auxiliary controller in AUTO. If the controllers are properly iniitalized in

MAN there will not be a bump in transfer. Now, the auxillary controller will keep the tube T at the limit, minimizing the deviation of the process T from its set point. Then when the tube T falls below the limit, reverse the controller modes. An undesirable aspect is chatter in mode switching when the tube T is near the limit and noisy. One could place a deadband on the switch point to eliminate the chatter.

3. You could tune the controllers for very rapid wind down. Use a small integral time. Compensate with a small proportional gain. But this may undo desirable controller tuning for regulatory or servo action.
4. You could tune the controllers with a large proportional gain so that when the error sign changes the P action dominates the integral. But this may undo desirable controller tuning for regulatory or servo action.
5. One PID product I was aware of a while back has an option, "When the integral reverses after hitting a limit make it 16 times faster." I have no experience with this. It seems like a reasonable fix, but the 16 times is arbitrary.
6. You could enter a lower than needed safety set point. Then the excess due to delayed switch-over to the secondary PV might still be within the safety limit. But then the override would cause an extra deviation from the process. And the return of control to the primary still has the undesirable switch-over time and excess.
7. You could change the wind up limit of each controller. In the example above, the transfer should have happened at 63%, so the safety controller integral should be limited to 63%. But how can one know that value *a priori* and change it as appropriate to continually changing conditions?
8. The reset feedback solution described here is to use a filter rather than an integral to determine the controller bias, and to use feedback to reset the bias.

Reset Feedback method:

Start with Figure 2, PI control with calculus representation in the block diagram.

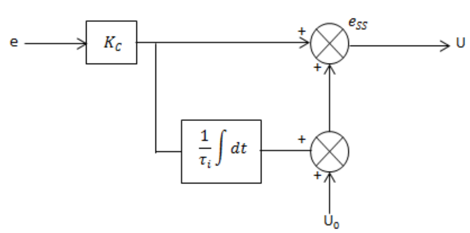

Figure 2 A Block Diagram of PI Control

The diagram says, "To get the output of the controller, add to the proportional term (calculated as $P = K_c \cdot e$) to the adjustable bias value (calculated as $B = U_0 + \frac{K_c}{\tau_i}\int e \cdot dt$)". Laplace notation for the diagram says the same thing.

$$\hat{u} = K_c\left(1 + \frac{1}{\tau_i s}\right)\hat{e} = K_c\hat{e} + \frac{K_c}{\tau_i s}\hat{e} = \hat{P} + \hat{B} \qquad (1)$$

Mathematically, Equation (1) is the same as

$$\hat{u} = K_c\hat{e} + \frac{1}{\tau_i s + 1}\hat{u} = \hat{P} + \hat{B} \qquad (2)$$

You might enjoy the algebra to convert Equation (2) to (1). Or "Trust me. I'm a doctor."

Equation (2) says, "To get the output of the controller, add to the proportional term ($\hat{P} = K_c \cdot \hat{e}$) to the adjustable bias value ($\hat{B} = \frac{1}{\tau_i s+1}\hat{u}$) which is calculated by a first-order filter of the controller output." Equation (2) also says, "I appolgize for using Laplace notation."

Numerical code for this procedure could be done as

$$\begin{aligned} &e = SP - PV && \text{'actuating error} \\ &P = K_c \cdot e && \text{'proportional term} \\ &B = \left(\frac{\Delta t}{\tau_i}\right)MV + \left(1 - \frac{\Delta t}{\tau_i}\right)B && \text{'adjustable bias is the filtered MV} \\ &MV = P + B && \text{'add P to bias} \end{aligned} \qquad (3)$$

In MAN mode the adjustable bias, B, is initialized with the current output ($B = MV$), and SP is initialized with the current PV value ($SP = PV$).

Laplace transformed Equation (2) or the implementable Equation Set (3) is called **internal reset feedback**. It **feeds back** the controller output (the **internal** value) to **reset** the controller bias, B.

If the controller is in charge, then the method represented by either Equation (2) or (3) to calculate the controller output is exactly the same as PI control with the integral (within numerical approximation). But if the controller is not in charge, then it still winds up to the 0% or 100% limit.

To limit wind up of the adjustable bias to the right value for the situation, the method is to use **external reset feedback, (erf)**. The right value is the selected output, the value actually implemented. Use the selected output as the reset feedback signal to adjust the bias, instead of using the controller's own internal value.

Numerically this would be done as

$$\begin{aligned} &e = SP - PV && \text{'actuating error} \\ &P = K_c \cdot e && \text{'proportional term} \\ &B = \left(\frac{\Delta t}{\tau_i}\right)MV_{selected} + \left(1 - \frac{\Delta t}{\tau_i}\right)B && \text{'bias is the filtered selected MV} \end{aligned}$$

$$MV = P + B \qquad \text{'add P to bias} \qquad (4)$$

Figure 3 illustrates the two PI-equivalent controllers (primary and safety) with the erf signal being filtered to determine the controller adjustable bias.

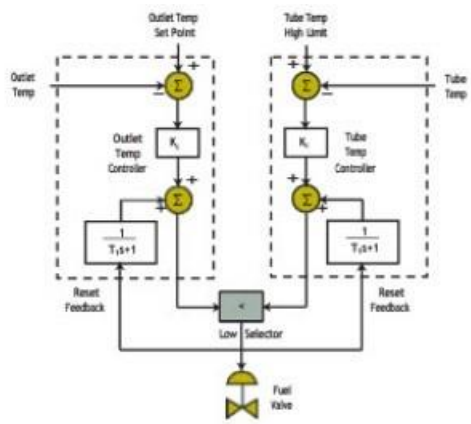

Figure 3 (from Wade, H. L. "Under the Hood of Override Control", Part I, CONTROL, Vol. XVII, No. 12, December, 2005, pp43-45)

Returning to the opening illustration, just prior to the point where the tube T controller should take over, the selected output is the process T controller's output of 62%. The process T is at 430°F, and the tube T is at 599°F. Using erf to determine the controller bias, the erf signal to the override controller has lagged to the selected 62%, which means that its bias is at 62%. The safety controller proportional term is its gain times the temperature deviation (600-599) which might be + 1%. So, its output is 63%. Now, the instant that the tube T exceeds 600°F, when the actuating error becomes -1%, the override P action will reduce its output to 61% and at that instant, the select block will choose the safety controller.

Benefits are:

- There is no delay in time to let an integral wind down.
- There is no period of safety violation.
- Regardless of the application or current context, the switch is at the right point, the human does not have to specify what that point is.

Notes:

ERF versions of PI control tune just like standard PI controllers. The reset feedback filter is equivalent to integrating the actuating error.

The equations are a bit more complicated when derivative mode is included in the PID controller, and a bit different with the parallel and series options. The manufacturer has several choices to mathematically model and then to digitally handle the extra feature. Any erf version of a controller should be the same as its PID original to a user. As a user, you just choose the erf option and specify what is to be used as the erf signal.

The select block might be greater than, depending on the process gain and whether a valve is ATO or ATC.

To tune either controller, that controller must be in charge. When tuning, bypass the select block so that the output of the controller you are tuning goes directly to the process.

- - - - - - -

Russ Rhinehart started his career in the process industry. After 13 years and rising to engineering supervision, he transferred to a 31-year academic career. Now "retired", he enjoys coaching professionals through books, articles, short courses, and postings on his web site www.r3eda.com.