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Fundamentals: Not Only for Beginners

By Renee Bassett, *InTech* **Chief Editor**

More than 11 million people currently are employed in manufacturing in the U.S., and according to the U.S. Chamber of Commerce, the latest data shows 9.9 million manufacturing job openings. On top of that, about 17 percent of the general U.S. population is 65 years old or over—a figure that is expected to reach 22 percent by 2050. Globally, given the retirements, shortages of qualified new workers, and millions of existing workers whose job requirements may be changing, training is more important than ever and fundamentals are essential. That's why this July 2023 issue of *InTech* focuses on automation fundamentals.

Fundamentals have been a staple of ISA Training, so I talked with Matt Rothkopf, ISA's manager of learning consultation, about a course that has become a best-seller among ISA's wide range of training, certifications, and publications designed to enable industrial companies and their workers to adapt to changes and challenges.

Fundamentals of Industrial Process Measurement and Control (FG05M) is a modular, self-paced, computer-based training course derived from the FG05 Traditional, or classroom, course that ISA has offered for more than 30 years. Course content has evolved over the years, says Rothkopf, but it is "foundational." It defines what to measure—primarily temperature, pressure, level, and flow, plus other things—how to measure it, what technologies exist for measurement and control, and other basic building blocks of how industrial process works.

Rothkopf points out that the course is fundamental, but not necessarily only for beginners. "For someone who has successfully operated as a technician for 5+ years, it would be more of a review. I would typically direct a more seasoned professional like that to a more advanced course. But for someone changing positions, or who might have technical but not necessarily industrial experience, this course can provide essential context," he says. "It covers essential concepts and terminology, which is good for someone with less experience who will be undertaking more intensive training, like ISA's very popular Bootcamps."

The workforce is aging out and businesses have learned that they cannot hire their way out of experience shortages. They have to organically grow their workforce with formal training and structured programs. ISA is the place to find programs ranging from on-site, instructor-led training to self-paced online courses.

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Fundamentals of PID Control

Proportional-integral-derivative (PID) is the most common industrial technology for closed-loop control.

By Jon Monsen

A proportional-integral-derivative (PID) controller can be used to control temperature, pressure, flow, and other process variables. A PID controller combines proportional control with additional integral and derivative adjustments to help a controller automatically compensate for system changes.

Proportional
Using the error to reduce the error

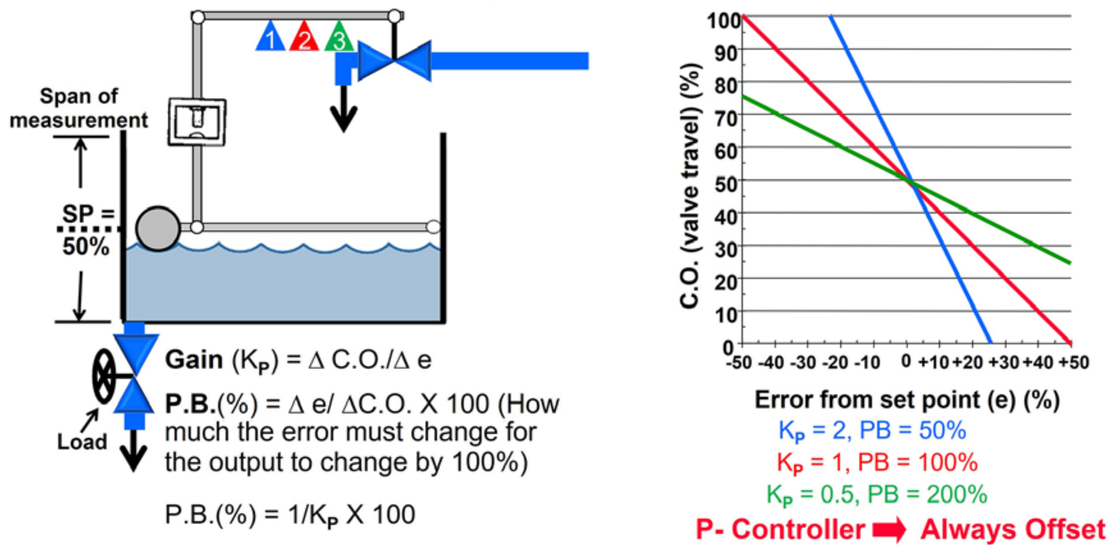


Figure 1. Proportional only controller.

The basic control mode is "proportional," which "uses error to reduce error." The diagram in Figure 1 illustrates how proportional functions. Shown is a mechanical proportional controller consisting of a float that operates a valve to maintain the level at the desired setpoint (SP) of 50 percent.

Consider what would happen if the fulcrum point was set at the left most position (for now ignore the other two fulcrums). The operation of the controller is graphically represented by the blue line with the steepest slope. The horizontal axis is the percent error from the setpoint of 50 percent full. The vertical axis is valve position. If this were a pneumatic or electronic controller, the vertical axis would be the controller output signal, but because this is a mechanical controller, the controller output is the valve position.

The definition of gain of any device is "change in output divided by the corresponding change in input." For a proportional controller, the output is the controller output (abbreviated "C.O."). The input is the error between setpoint and measurement. Throughout this article, "e" is the error between the setpoint and the process variable measurement. The symbol for gain is usually "K." Here, the focus is on "proportional" gain, so the symbol is "K" with a subscript "p" for "proportional."

For the fulcrum in the left-most position and the resulting graph of error versus valve position with the steepest slope when the error changes from minus 25 percent to plus 25 percent (a total of 50 percent), the valve position changes by 100 percent. The proportional gain is 100 divided by 50, or 2. With the fulcrum in this far left position, the result is the largest change in valve position for a given change in float position. Of the three fulcrum positions, this one will give the highest gain (or the greatest sensitivity).

If the fulcrum is moved to the center position, the valve travel does not change as much for the same amount of error, and the action of the controller is represented by the red line on the graph. In this case, a change in error from minus 50 percent to plus 50 percent (a total of 100 percent) causes the valve travel to change by 100 percent. So, the gain is now 100 divided by 100, or 1.

Moving the fulcrum to the far-right position yields the least sensitivity. The controller's action is represented by the graph with the green line. In this case, a change in error from minus 50 percent to plus 50 percent (a total of 100 percent) causes the valve travel to change by 50 percent. The gain is now 50 divided by 100 or 0.5.

Sometimes, instead of talking about proportional gain, people talk about "proportional band," abbreviated "P.B." in the figure. Mathematically, the proportional band is the reciprocal of the proportional gain times 100 and expressed as a percent.

"Offset" is the difference between the setpoint and the actual measurement—in this case, tank level. If the valve is not in the right position for the load from the very beginning, or once there is a change in load (in this example, the flow out of the tank), there will be some offset. For the valve to open farther so that the inflow will match the new higher outflow, the float will have to be lower than it was originally.

This is a characteristic of all controllers that only have the proportional mode. The proportional mode uses the error to reduce the error, so it is necessary for there to be an error (in control terms called "offset") for the error reduction to occur.

The two graphs on the left in Figure 2 show the relationship between the measurement and the controller output from a proportional controller. As soon as an error (e) occurs between the measurement and the setpoint, the controller output changes

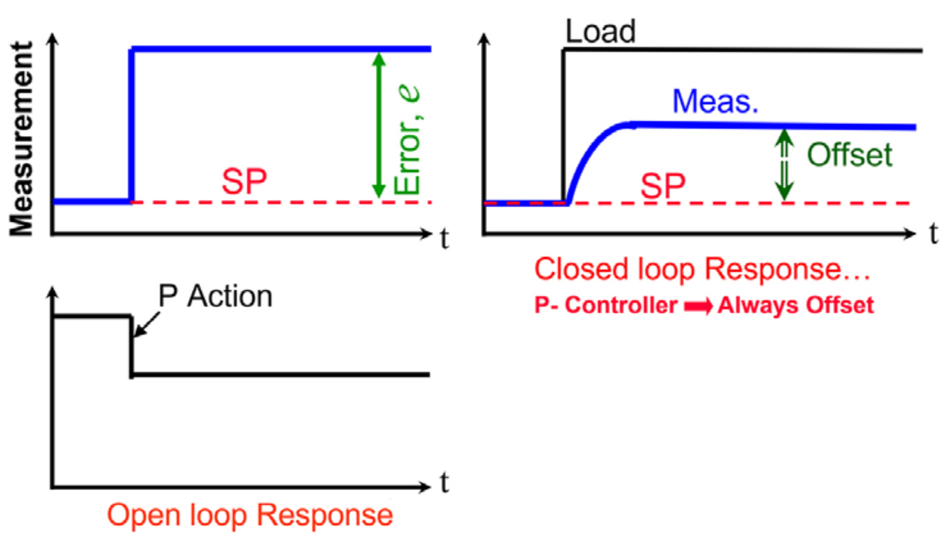


Figure 2. Proportional only controller response to a change in load.

to exactly mirror the error, except that the magnitude of the controller output change depends on the proportional gain of the controller. In this case, the proportional gain is less than one since the change in output is less than the change in error. The direction of the controller output change is chosen to be in the direction that will tend to correct the error. The graphs on the left show the "open loop" interaction between error and controller output—in other words, how the controller responds to an error—but the output is not connected to the process. Shortly, graphs will show what happens when the loop is closed, and the controller is regulating the process.

The graph on the right of Figure 2 shows how a first-order process would respond to a step change in load while being controlled by a proportional controller. The important point here is that with proportional control, the error is being used to reduce the error, so there will always be some residual error, which we call offset.

The water heater shown in Figure 3 illustrates the behavior of the various control modes. Although the water heater consists of several dynamic subsystems (control valve, the heating vessel, the temperature element, and the temperature transmitter), when a step test is performed with the controller in manual, the response (for all practical purposes) can be treated as a first-order response with dead time.

To get a reference point for evaluating the performance of the controller, the controller has been left in manual, and then a step change in load was introduced. This was done by suddenly decreasing the demand for hot water. Since the steam flow does not change, the measured temperature increases to a new value following the approximately first-order plus dead time response is shown by the green line in Figure 4.

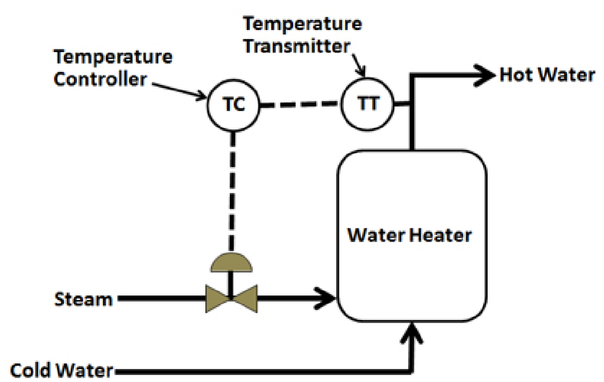


Figure 3. A simple control loop.

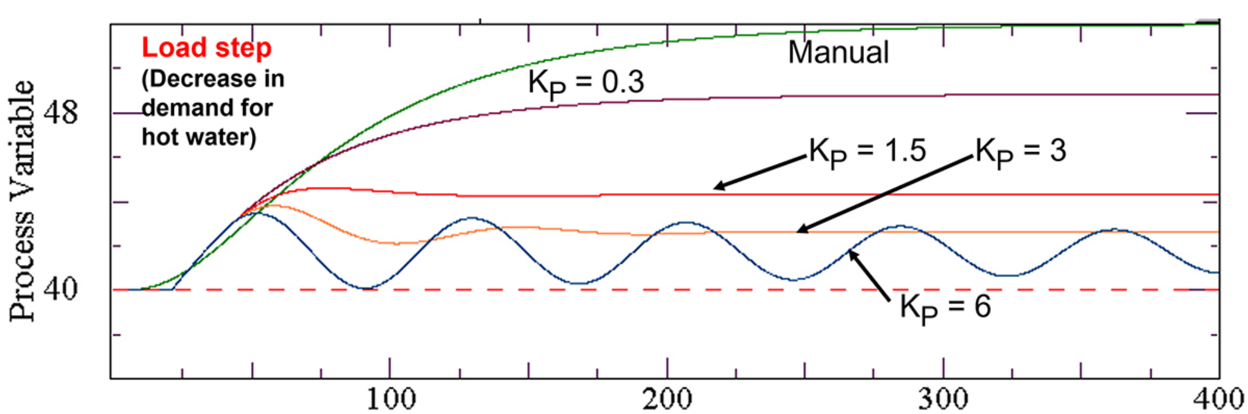


Figure 4. Process variable response to a load step change with varying proportional gain settings.

The controller is next placed into automatic mode with a small amount of proportional gain (K_p = 0.3). The controller reduces the error slightly, but there remains a large residual error, or offset.

Increasing the proportional gain to 1.5 causes a smaller offset. Further increasing the proportional gain to 3 gives an even smaller error and thus better control. Note that there is a small oscillatory transient at first. At this point, it is tempting to assume that the higher the gain, the better the control, and that it might be possible to decrease the offset to a very small value by setting a very large proportional gain. However, when we try increasing the gain to see what happens, at some point, with increasing proportional gain, the system becomes unstable.

Integral, when proportional gain is not enough

If some offset cannot be tolerated, some way of supplementing the proportional control mode must be ascertained. To remove the offset of the proportional control mode, the integral (sometimes called reset) mode is introduced.

In calculus, the "integral" of a function is "the area under the graph" of that function. Figure 5 shows an arbitrary complex function of time and its graph. If the exact function that produces this graph is known, the area under the curve could be determined, but it often takes methods that students spend a whole year in calculus learning. Fortunately, this is a simple function, and one that is easy to calculate the area under the graph without any advanced techniques is all that's needed to make sense out of how the integral control mode works.

A time function whose value is always 1.0 is shown in Figure 6. Since the function's value remains constant, the area under its graph is always a rectangle, and the area of a rectangle is easy to calculate without using advanced techniques.

Imagine starting at time equal to zero, and then watching what happens as time progresses. At exactly time = zero, the length of the rectangle is zero and its width is 1. The area is zero times one or zero. After one second has passed, (time is now equal to 1 second), the length of the rectangle is 1,

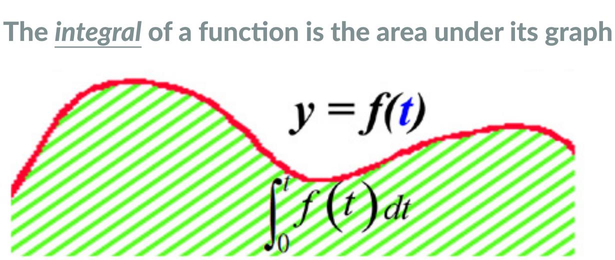


Figure 5. Definition of the mathematical integral.

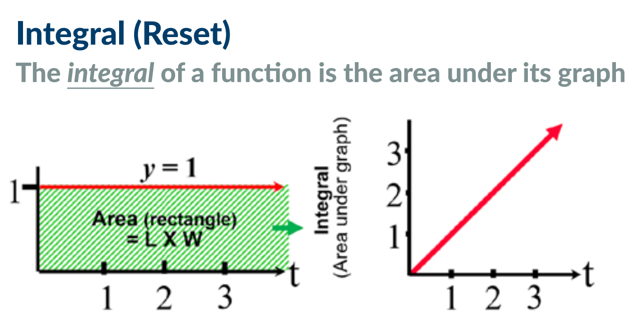


Figure 6. In an open loop, the integral of the error continues to increase with time.

and the width is 1, so the area is 1 times 1, or 1. The graph on the right shows how the integral (area under the curve in the left-hand graph) has changed during the first second. As time continues to progress and the area of the rectangle increases, the graph on the right continues to track what the rectangle's area is at any moment. Since the area under the curve is increasing in a linear fashion with time, the graph of the integral is a ramp, also increasing in a linear manner with time. Adding the integral control mode to the proportional mode makes it possible to remove the offset left by the proportional mode. This controller has been configured so that both the proportional and integral actions are downward instead of upward because that is the direction that will eliminate the error.

Figure 7 shows how a proportional plus integral controller reacts to a step change in load in an open loop (the controller output is not connected to the process). At the moment the error first occurs, there is an immediate proportional action in the controller output. Then the controller output starts ramping down (integral action) in proportion to the area under the graph (error times the constantly increasing time). The parameter that is set into the controller to tell it how strongly the integral action is to act on the controller output is called the "integral time," or T_I. The integral time is the time it takes the integral action to repeat the correction produced by the proportional action. A short integral time means the controller ramps its output quickly to eliminate the error, and a long integral time means the output ramps slowly to eliminate the error (or offset). The units are minutes (or seconds depending on the controller manufacturer) per repeat. Some controller manufacturers use "integral gain," which is the reciprocal of integral time. In that case, the units are repeats per minute (or second).

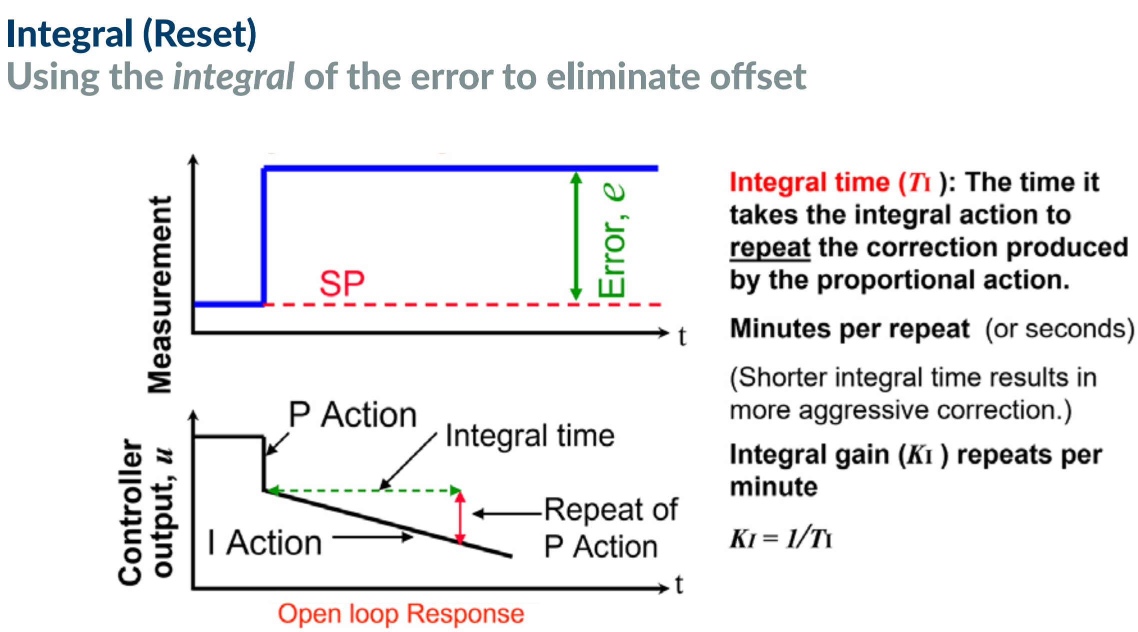


Figure 7. Proportional plus integral controller response to a load change in an open loop.

Figure 8 is the same graph as Figure 4, but starting when the proportional controller was running in closed loop with a proportional gain of 1.5. When considering the effect of various values of proportional gain, there was better (but slightly oscillatory) control with a gain of 3, but because it is known that this integral action is destabilizing, and would have resulted in an oscillatory response, the slightly lower proportional gain was chosen for this example.

In Figure 8, some integral action has been added. Initially, the proportional action eliminates part of the error, then the integral, or reset, action continues to drive the control valve until all the offset has been removed. In closed loop, once all the error has been eliminated, the proportional action settles out at the new value required to hold the error at zero, and since there is no error, the integral of the error is zero, thus there is no further integral action.

Derivative, when error must be eliminated faster

The next question might be: can the integral time be decreased to make the error be eliminated more quickly? As with proportional gain, some integral is good, but too fast an action destabilizes the process.

Before discussing the derivative (sometimes called rate) control mode, consider this brief review of the meaning of the derivative. In calculus, the derivative of a function can be interpreted as the instantaneous slope of that function's graph at any point. Students spend the better part of a year in calculus class learning how to do this for all sorts of functions. Fortunately, for purposes of discussing the derivative control mode, all that's needed is to review the behavior of the derivative of straight lines.

Integral (Reset)

Using the *integral* of the error to eliminate offset

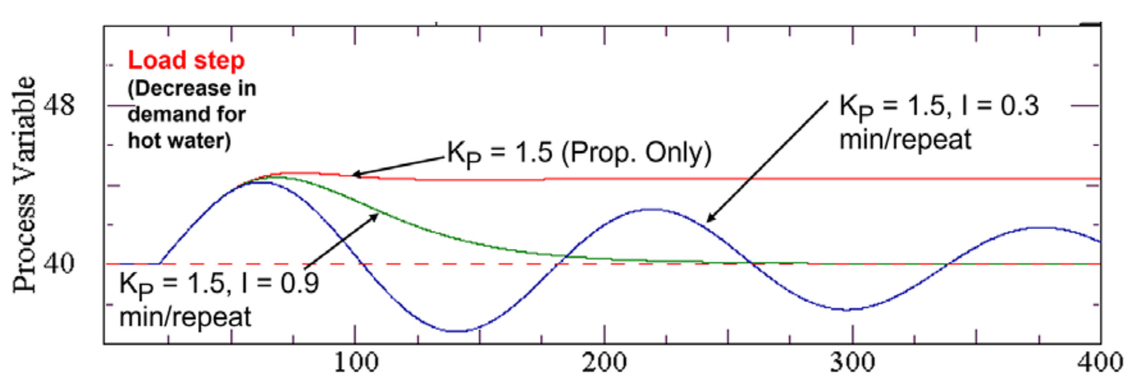


Figure 8. Process variable responses to a load step change with various integral settings.

The graph of a function of time whose shape consists entirely of straight lines with different slopes is shown in Figure 9. Starting at time = zero and continuing for a while, the functions value is zero. Its slope is also zero and thus its derivative is zero, as shown in the lower graph. The value of the function suddenly begins increasing at a steady rate. Its derivative (slope) instantly becomes a finite (and constant) value, again portrayed in the lower graph. Next, the function continues to increase, but at a lesser rate (its slope still has a finite and constant value, but a smaller one). Again, this smaller, but constant rate of change (slope or derivative) is graphed in the lower graph. Finally, the time function stops growing, and levels off at a constant value. At this point, there is no more change in the function's value (its rate of change or slope or derivative becomes zero) and is graphed on the lower graph of derivative as a derivative of zero.

The *derivative* of a function is the slope (or rate of change) of its graph.

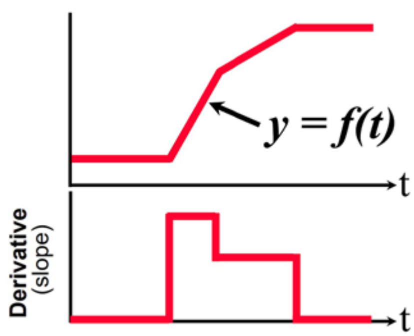


Figure 9. Definition of the mathematical derivative.

When examining the proportional control mode and the integral control mode, their actions are based on the assumption that a fairly fast control process was discussed. The discussion was made simpler (without loss of meaning) by assuming that upon a process disturbance, the measurement made a step increase (like in the line in the upper graph in Figure 2).

Some processes, such as the water heater used as an example, respond slowly to process upsets. In such a case, the ramp in the upper graph of Figure 10 is a simplified but more realistic depiction of what happens

Derivative (Rate)
Using the *derivative* of the error to anticipate future error

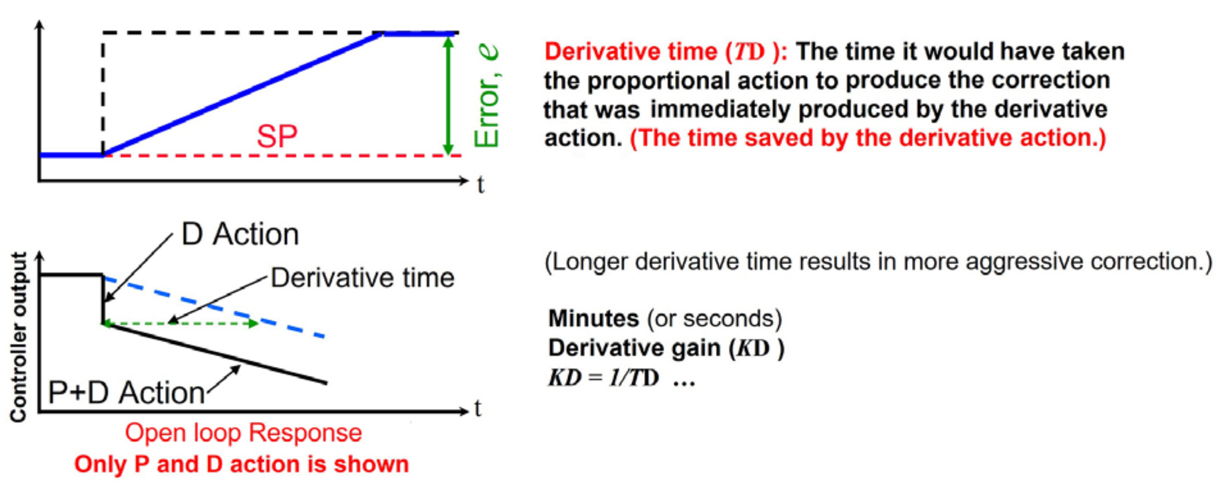


Figure 10. Proportional plus derivative controller response to a load change in an open loop.

when in open loop, that is, the controller output is not connected to the process. In this example, the process upset could have been a nearly instantaneous decrease in the demand for hot water from the water heater. At the point where the ramp just starts, the damage has already been done and the process is heading toward a large error. The problem here is that because the process responds slowly, the controller does not immediately see the large error that is on its way. The controller only sees a small error at first.

In the upper graph of Figure 10, the error starts out being very small, and with proportional only control, the controller's output would only be a small correction at first represented by the sloping dashed line. In a slow process, the disturbance was likely a large one, but because the process responds slowly, the large disturbance is not seen right away. At the point where the measurement begins to deviate from the setpoint, the slope of the measurement (its derivative) makes a sudden jump from zero to a value equal to the slope of the measurement's graph. This provides an instantaneous jump in the controller output, in anticipation of the large error that isn't seen yet but is coming. The proportional correction gets added to the derivative correction, so that after the initial "boost" of the derivative, the controller output continues with a correction proportional to the error. (To avoid unnecessary complication to the explanation, the integral action was not included in the discussion of derivative action.)

The parameter set into the controller to tell it how strongly the derivative action is to act on the controller output is called the "derivative time," or T_D. The derivative time is the time it would have taken the proportional action to produce the correction that was immediately produced by the derivative action. (This description presumes the error remains constant, independent of any control action.) A short derivative time means the controller adds only a small derivative output to anticipate a future error. A long derivative time means the controller adds a large derivative output to anticipate a future error. The units are minutes (or seconds depending on the controller manufacturer). Also, some controller manufacturers use "derivative gain," which is the reciprocal of derivative time. In that case, the units are 1 divided by minutes (or seconds).

Adding the integral control mode to the proportional mode makes it possible to remove the offset left by the proportional mode.

Some controllers take the derivative from the measurement rather than the error. This prevents a large derivative correction (called a "derivative kick") if the setpoint is manually changed suddenly. Noise spikes in a noisy measurement can cause undesired large outputs form the derivative mode. Derivative correction must be used with caution when the measurement is noisy. Filtering the signal before it goes to the derivative function can help.

Using the *derivative* of the error to anticipate future error

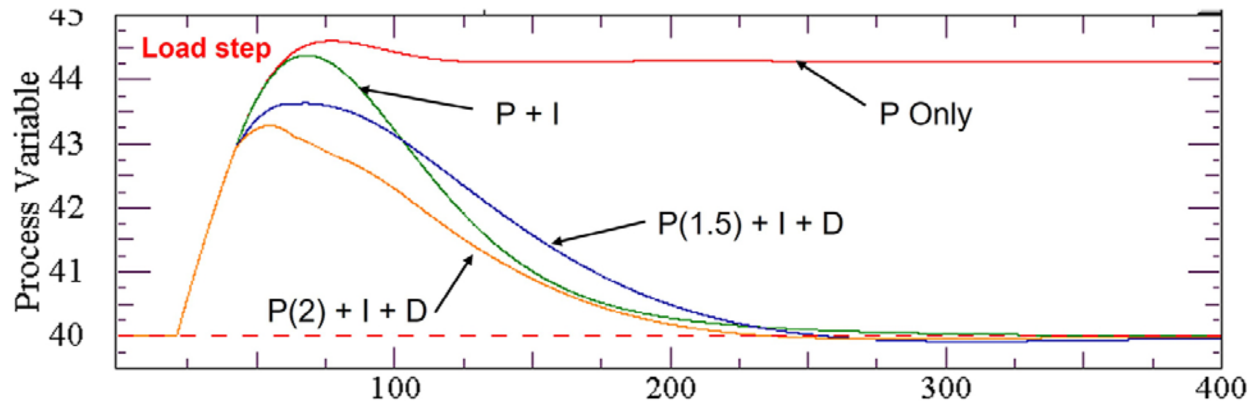


Figure 11. Process variable responses to a load step change with various derivative settings.

In Figure 11, the upper two traces show what could be accomplished with proportional only and with proportional plus integral (P+I). Here, derivative (P(1.5) + I + D) has been added to the earlier P+I to further reduce the maximum error.

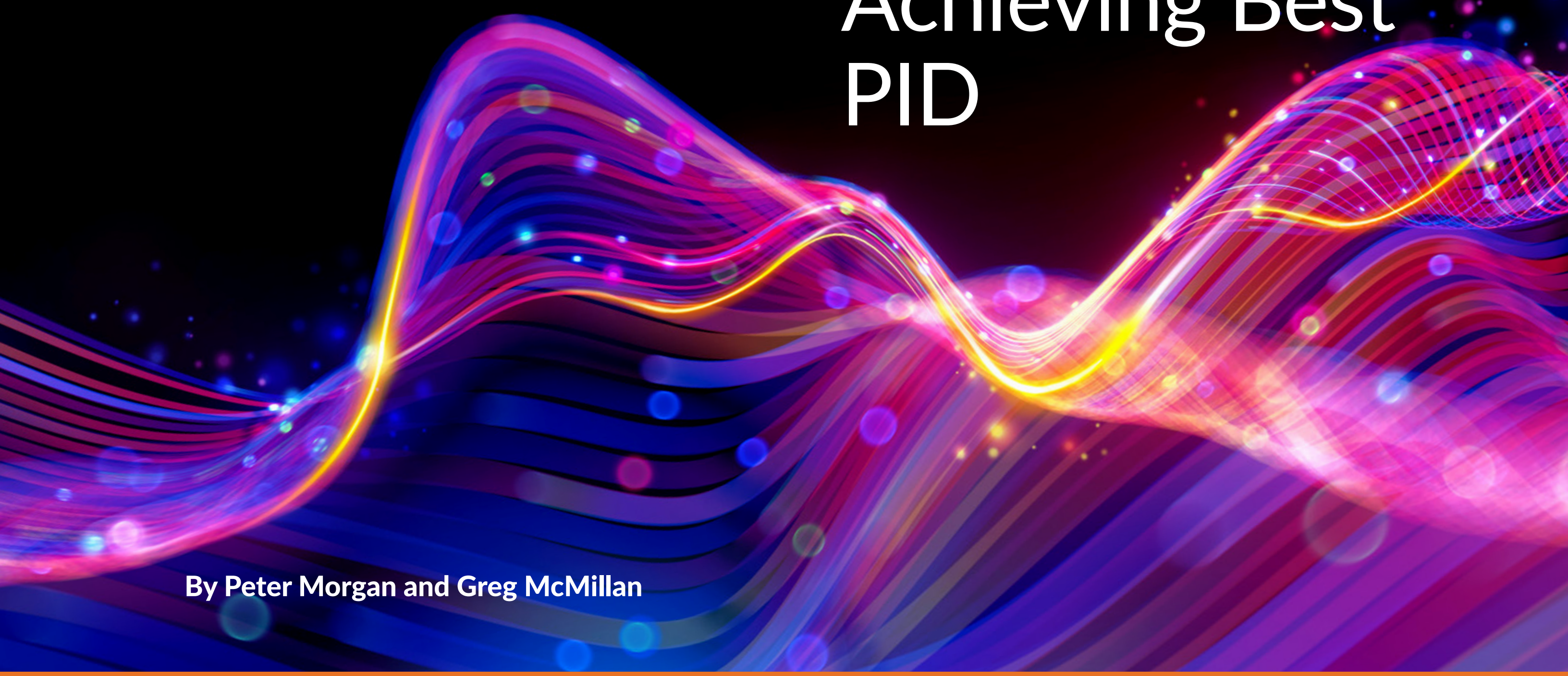
The derivative mode—unlike the integral mode, which tends to destabilize control—adds stability. Because of this, it is possible to increase the proportional gain from 1.5 to 2. If the gain had been increased to 2 with just integral, there would have been a response with too much oscillation in it. However, with the stabilizing effect of the derivative, the result is a response that is better than what we would have gotten with just P+I or with P+I+D using the proportional gain that would have been optimum had the derivative not been added.

Derivative controls may also be sensitive to fast, short-term process signals, including sensor noise or process noise. For example, if there were waves in the tank, the level signal would be constantly moving up and down, and the derivative action could amplify those waves into valve movements. For this and other reasons, derivative action is much less common in practice, and P+I controllers are most often seen.

ABOUT THE AUTHOR

Jon Monsen, PhD, PE, is a control valve technology specialist with more than 45 years of experience in the control valve industry. He has lectured nationally and internationally on control valve application and sizing. Monsen hosts a website, www.Control-Valve-Application-Tools.com, where he shares articles, training, professional development materials, and Excel worksheets that might be of interest to those who use or specify control valves.

ISA-TR5.9-2023: Realizing and Achieving Best PID



By Peter Morgan and Greg McMillan

New ISA technical report distills thousands of pages of PID references for improving process performance.

Even though controllers using the proportional-integral-derivative (PID) algorithm have been used for more than a century, a standard describing PID fundamentals, terminology, best practices, and special functions does not exist. ISA's new ISA-TR5.9-2023 Proportional-Integral-Derivative (PID) Algorithms and Performance technical report, released this year, lays the foundation for that standard.

The technical report captures the expertise of prominent PID practitioners and distills the tens of thousands of pages of references found in the bibliography into a guide designed to help all realize and achieve the largely underutilized PID potential for improving process performance. Sections within this larger-than-usual report include Scope; Normative References; PID Algorithm; PID Structures; External-reset Feedback; PID Performance; PID Signals; Annex A Signal Characterization; Annex B Dynamic Simulation; Annex C Valve Positioners; Annex D Dead Time Compensators; Annex E Enhanced PID; Annex F First Principle Process Relationships; and Bibliography. This excerpt is from the Historical Perspective section.

The proportional plus integral plus derivative (PID) control algorithm is the workhorse of virtually all closed-loop control applications. It has been the go-to algorithm since its inception in the early 20th century. Generations of control practitioners have used it. The algorithm has seen (and survived) implementation on every technology platform ranging from pneumatics, electronic analog, centralized digital control, distributed control systems (DCS), programmable logic controllers (PLCs), and distributed loops on Fieldbus and other distributed bus platforms.

The technology platform timeline starts with mechanical/hydraulic and progresses through DCS.

Mechanical/mechanical hydraulic. The PID controller's history would be incomplete without mentioning James Watt's flyball governor introduced almost 250 years ago (1788) for steam engine speed control by regulating steam flow. Providing proportional action only, the flyball governor might be considered the genesis of PID control, waiting only for technology to develop to allow for error correction (integral action) and dynamic compensation (derivative action). Not surprisingly, since the focus toward the end of the 19th century was engine speed control, H.N. Throop, in 1857, devised a governor to incorporate adjustment based on acceleration and speed, thereby introducing the first proportional plus derivative controller. Although it was widely known that the offset was a limitation of the flyball governor and isochronous control was not possible without integral action, the various ingenious mechanical and hydraulic methods designed to achieve integral action proved impractical for continuous use until the 1900s.

The proportional plus integral plus derivative (PID) control algorithm is the workhorse of virtually all closed-loop control applications.

Electro-mechanical. In 1911, Elmer Sperry applied proportional plus integral action to automate ship steering. Through observation, Sperry determined that the ship's course could be held by adjusting the rudder position in proportion to the error in the bearing with additional feedback based on the rate of change in the bearing. Because rudder position determines the rate of change in the ship's bearing through ship dynamics, the net effect is equivalent to P plus I action (although not known as such at the time). Interestingly, two notable features of Sperry's controller were that the algorithm was the velocity form of PI as we know it today, and the structure was "proportional action on PV."

In 1923, Nicolas Minorsky (in addition to providing the first analysis of Sperry's ship steering system) introduced the second derivative of the ships bearing as a third element and, in so doing, implemented the first PID velocity algorithm.

Pneumatic. PI and eventually PID control actions have been (and still are) implemented in pneumatic controllers through the imaginative use of bellows, levers, and orifices. For integral action, any persistent error is corrected by a continuous adjustment in output pressure that is proportional to the error through the action of the positive feedback bellows. For derivative action, a rate-of-change in error results in a proportional adjustment in output pressure through the action of the negative feedback bellows.

In 1922, the flapper nozzle was patented. The flapper nozzle converted small nozzle displacements to large pressure changes at the output to balance reaction forces exerted by the feedback bellows with the force equivalent to the control error. The flapper nozzle foreshadowed the use of the electronic high-gain operational amplifier in the implementation of the PID algorithm in electronic analog control systems.

Throughout the 1930s, there was much effort to improve the pneumatic controller's characteristics. Linearity, for example, was improved by the introduction of the pneumatic relay. In the mid-1930s, the first pneumatic controller with derivative action was implemented by throttling the flow to a negative feedback bellows.

The year 1933 may well have been the first application (by Taylor Industries) of external-reset feedback by supplying the integral bellows with air from a transducer providing a pressure analog of valve position. Several contemporary platforms offer this feature's equivalent for its advantage in dealing with external limits and lost motion.

Electronic analog. Development of the integrated circuit high gain operational amplifier (OP amp) in the 1960s allowed the PID algorithms to be readily implemented using resistor and capacitor (RC) networks without the functional limits and nonlinearities associated with the pneumatic controller. Notably, all three forms of the PID algorithm could be implemented without limitations. The electronic analog implementation provided features such as gain adaption, deadband, feedforward, and bumpless transfer. It allowed the implementation of application-specific strategies through modules with specific functions such as high/low selector, rate limit, and so on.

Most of the PID capability has been underutilized due to the lack of knowledge of PID algorithms and performance implications. This situation has been severely aggravated by the loss of expertise.

Foxboro chose to implement the P+I term for the series algorithm by using positive feedback for integration, applying a first-order lag to the controller for use as the feedback signal, thus replicating the action of the positive feedback bellows of the pneumatic controller. This provided the benefit of simplifying the implementation of provisions to prevent integral windup when the controller output is in limit, and when the feedback signal is derived as the position of downstream elements (so-called external reset), improved response when the final element is in rate limit or prone to travel deadband.

The PID velocity algorithm, whose output was a velocity (speed and direction) command, was implemented using a variety of integrating devices as the final element allowing fixed pulse-width variable-frequency or variable pulse-width variable space output forms.

Convergent development of electronic analog computers using the same OP amps used in the electronic PID controller allowed real-time (and faster than real time) performance and stability studies to be performed for complex plant/processes employing PID algorithms.

Direct digital control. The mid-1960s direct digital control (DDC) used mainframe computers (sometimes redundant) to implement a PID control velocity algorithm, for example, for nuclear reactor rod control.

DCS. In 1975, the first DCS was introduced (by Honeywell and Yokogawa) with widespread technology adoption through the late 1970s. With the integration of Boolean logic and regulatory control, the precision of the DCS in the execution of strategies and virtually no limit to functionality (for example the implementation of override control), the platform allowed complex strategies to be easily configured and made possible innovative PID implementations such as the 2DoF (two degrees of freedom) PID structure and PID tuning parameter optimization. Notably, the platform allowed the PID algorithm form to be user selectable since the digital implementation severed the dependence on hardware/module physical design.

To circle back to James Watt's flyball governor, it is entertaining to note that proportional (droop) control is still the favored method of governing turbogenerators on interconnected systems but is implemented in digital systems using a PID control algorithm to proportionally adjust generator output according to turbine speed variation. In this case, the PID controller acts to eliminate variation in the droop due to the nonlinear characteristics of the governor valve.

Adopted naming convention

Technical Report TR5.9 recognizes three commonly used PID algorithms. These forms have been variously described by vendors and practitioners, sometimes based on an interpretation of behavior in either the time domain or frequency domain, other times on mathematical forms, such as the Laplace transform. The lack of a consistent naming convention has led to some confusion within the industry, which could only be resolved by examining the structure of the offered algorithm. The TR5.9 working group establishes in the report, a naming convention that will avoid the widespread confusion that exists today.

In the following equations for each PID form, PV, SP, and CO are assumed to be expressed in dimensionless values as percent of engineering unit (EU) range, the norm for industrial systems. The few industrial PID algorithms that use a PV, SP, and CO in engineering units are disruptive of tuning methods and without great care can lead to tuning problems.

Parallel. Proportional, integral, and derivative terms are individually added to form the controller output with a time domain equation of:

$$CO(t) = k_c\varepsilon(t) + k_i \cdot \int_{t_i}^{t} \varepsilon(t)dt + k_d \frac{d\varepsilon(t)}{dt}$$

Where:

$\varepsilon = PV\text{-}SP$ is the control error for a direct acting controller.

$\varepsilon = SP\text{-}PV$ is the control error for a reverse acting controller.

CO is the controller output.

k_c is the controller proportional gain (dimensionless).

k_i is the controller integral gain (reciprocal of time, for example per second, per minute, or per hour). Note that some vendors refer to the units for this parameter as repeats per minute drawing on the behaviour of the controller for a constant error.

k_d is the controller derivative gain (time unit, for example seconds, minutes, or hours).

t_i is the time at the last initialization of the integrator, for example when the controller was last in manual.

Standard. Gain adjustment applied to proportional, integral, and derivative terms to form controller output.

$$CO(t) = K_c\left(\varepsilon(t) + \frac{1}{T_i}\int_{t_i}^{t} \varepsilon(t)\ dt + T_d \frac{d\varepsilon(t)}{dt}\right)$$

Where:

$\varepsilon = SP\text{-}PV$ is the control error for a direct acting controller.

$\varepsilon = SP\text{-}PV$ is the control error for a reverse acting controller.

T_i is the controller integral action time (time units for example seconds, minutes, or hours).

T_d is the controller derivative action time (time units for example seconds, minutes, or hours).

The standard and series algorithms are close in form to that for the equivalent pneumatic controller since the gain on a pneumatic controller is adjusted by positioning the flapper pivot point, which equally affects the integral and derivative bellows.

It is important to note that the nomenclature "standard" is not meant to imply that this version of the PID controller is to be the standard, preferred, proper, or best practice. It is a conventional and frequently used form that gained widespread use through early adoption in electronic analog systems.

Series. The derivative term applied before proportional plus integral terms is represented by the following equations:

$$\varepsilon'(t) = \varepsilon(t) + T_d \frac{d}{dt}\varepsilon(t)$$

$$CO(t) = K_c\left(\varepsilon'(t) + \frac{1}{T_i}\int_{t_i}^{t} \varepsilon'(t)\ dt\right)$$

Or

$$CO(t) = K_c\left(\left(1 + \frac{T_d}{T_i}\right)\varepsilon(t) + T_d \frac{d}{dt}\varepsilon(t) + \frac{1}{T_i}\int_{t_i}^{t} \varepsilon(t)\,dt\right)$$

Where:

$\varepsilon = PV\text{-}SP$ is the control error for a direct acting controller.

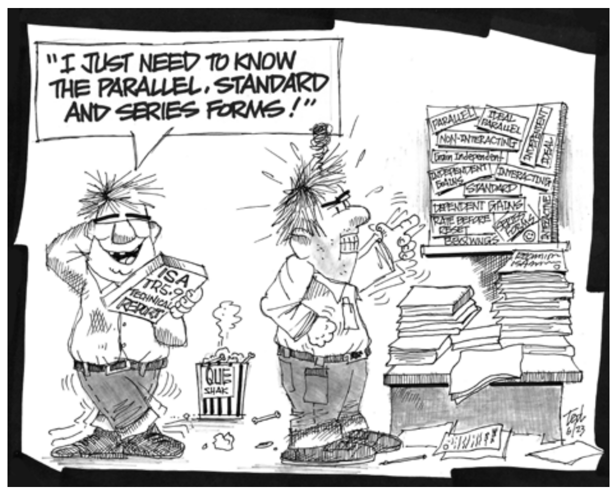
$\varepsilon = SP\text{-}PV$ is the control error for a reverse acting controller.

Like the standard algorithm, gain adjustments apply to proportional, integral, and derivative terms; the derivative term is best described as a "phase advance" term acting on the error prior to it being processed by proportional and integral terms. Note that if the derivative action time, T_d is zero, the series from is identical to the standard form.

Features and opportunities

PID has been proven to be the most effect algorithm for minimizing the impact of unmeasured process input disturbances (load disturbances) that have by far the most prevalent detrimental effect on loop performance. Recent advances in algorithm features have enabled the best load disturbance rejection while meeting other objectives. For example, after tuning for load response, setpoint lead-lag, or setpoint weights can enable the best setpoint response. The scheduling or adaptation of tuning settings enables PID to better handle the inevitable nonlinearities.

External-reset feedback (ERF) from the positive feedback implementation of integral action lost in the transition from pneumatic to electronic controllers has been retained by one supplier and restored by another. ERF has been recognized as having inherent capability in minimizing oscillations from unnecessary crossings of the split range point, slow valves, and slow secondary loops plus offering better override control, valve position control, and dead time compensation. ERF has also led to an enhanced PID that can handle large and variable analyzer cycle times and signal failures.



Cartoon by Ted Williams

ISA Standards and Technical Reports

ISA standards help automation professionals streamline processes and improve industry safety, efficiency, and profitability. More than 150 standards reflect the expertise of more than 4,000 industry experts around the world. One of the many benefits of ISA membership is free viewing of most ISA standards and technical reports. The ISA-TR5.9-2023, Proportional-Integral-Derivative (PID) Algorithms and Performance technical report is available for purchase from ISA.

Most of the PID capability has been underutilized due to the lack of knowledge of PID algorithms and performance implications. This situation has been severely aggravated by the loss of expertise and the inconsistencies in the nomenclature and implementation most notably of the PID form. Particularly detrimental is the misconception that the PID algorithm works with signals in engineering units and that disturbances are on the process output. ISA-TR5.9 can put us all on the right track.

ABOUT THE AUTHORS

Peter Morgan has more than 40 years' experience in the design and commissioning of regulatory and discrete control systems for the power and process industries. Among his publications are instructive articles on Fuzzy PI, Layer of Protection Analysis, and Markov modeling for reliability analysis. Peter is a Professional Engineer, an ISA senior member, and a contributing member of the ISA 5.9 PID Standards Committee.

Gregory K. McMillan is a retired senior fellow from Solutia and an ISA Fellow. He is presently working part-time as a senior principal software engineer in Process Simulation Development at Emerson Process Systems and Solutions. McMillan was an adjunct professor in the Washington University Saint Louis Chemical Engineering department from 2001 to 2004. He received the ISA Kermit Fischer Environmental Award for pH control in 1991, received the *Control* magazine Engineer of the Year Award for the Process Industry in 1994, and was inducted into the *Control* magazine Process Automation Hall of Fame in 2001. Greg would like to acknowledge cartoonist Ted Williams, a longtime friend who did all the cartoons in Greg's numerous humorous ISA books dating back to the 1980s. He has illustrated Greg's Control Talk columns for the last 20 years and provided the cartoon on page 25.

McMillan was honored by *InTech* Magazine in 2003 as one of the most influential innovators in automation, and received the ISA Life Achievement Award in 2010. He is the author of numerous ISA books on process control, his most recent being Advances in Reactor Measurement and Control, and New Directions in Bioprocess Modeling and Control, second edition. McMillan is the founder and co-leader with Hunter Vegas of the ISA Mentor Program for industry practitioners and started and guided the ISA Standards and Practices committee on ISA-TR5.9-2023 PID Algorithms and Performance technical report. McMillan received the ISA Mentoring Excellence award in 2020. He has a Bachelor of Science degree in engineering physics from Kansas University and a Master of Science degree in control theory from Missouri University of Science and Technology.

Understanding Control Valve Flow Characteristics

By Joao Bassa

Learning the basics can ease loop tuning frustration and ensure stability.

During plant operations, it seems that tuning control loops is an ongoing task, which can be a continual frustration to control engineers and technicians. Process control valve flow characteristics make regular loop tuning a necessity. Understanding the basics can ease the frustration and ensure loop stability. But first, some basics about why this happens.

Controlling the desired variable

Typically, process control loop feedback strategies use "flow" as the manipulated variable to control the desired variable. To achieve this, a controller output signal is sent to a control flow valve that will deliver the necessary flow amount (manipulated variable) to keep the controlled variable as close as possible to the setpoint.

The ideal expectation is that the flow through the control valve is proportional to the controller output signal such that the loop feedback "gain" remains nearly constant for all process flow conditions and the loop's required tuning parameters remain the same for all operational conditions. However, this does not happen in all cases.

Referring to the temperature control example in Figure 1, the steam inlet pressure is usually constant. Therefore, the pressure differential (Δp) across the valve is also almost constant, and the steam flow amount through the control valve is approximately proportional to the valve opening position (if the valve characteristic is linear) or, consequently, proportional to the controller output signal. This is the desired control loop operation.

Controlling flow through a centrifugal pump

Referring to the pump flow control example in Figure 2, the pump outlet pressure will decay as the amount of flow increases. In addition, the pipeline pressure drop will increase as the flow increases. Consequently, the Δp across the valve will be reduced as the flow increases. The amount of flow through the valve will not have a proportional relation to the valve opening position if the same valve type as in the temperature control example (Figure 1) is used. That means the relationship between the controller output signal versus the control valve flow rate will be changing throughout all the different operational conditions and the loop tuning parameters will need to be retuned, depending on the actual process operational condition.

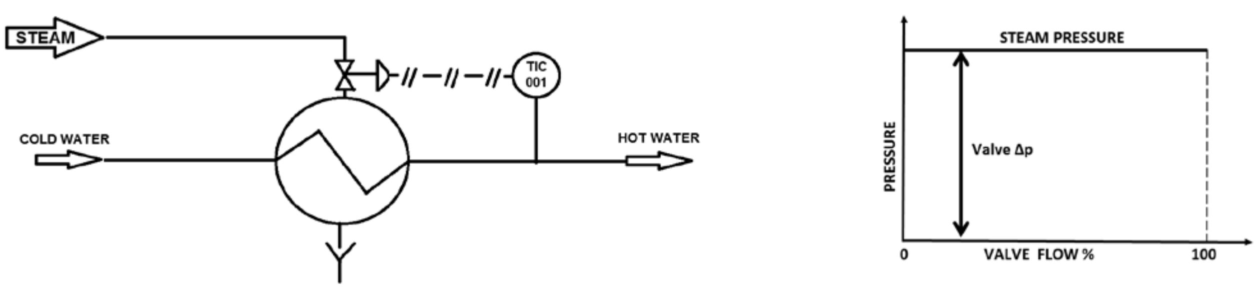


Figure 1. Example of a temperature control loop.

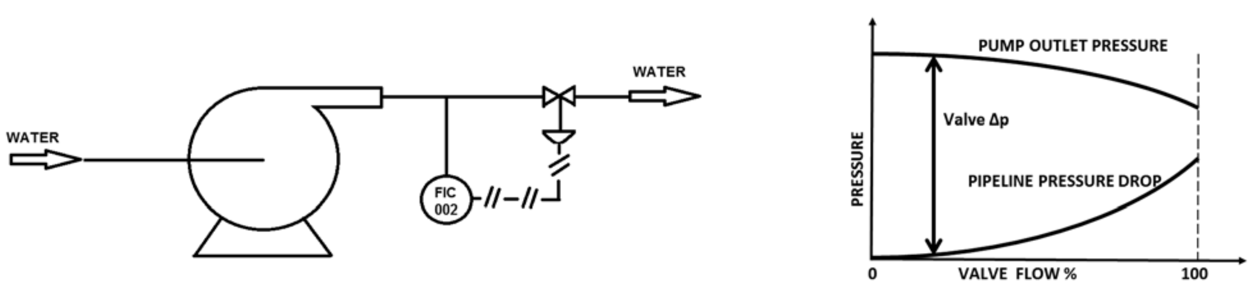


Figure 2. Example of a centrifugal pump flow-control loop.

Some modern digital control systems have self-tuning/auto-tuning functionality that can reduce or minimize the inconvenience of loop tuning. However, the correct valve flow characteristics selection will save a lot of trouble and money.

Control valve flow characteristics

For continuous process control valves, there are three inherent flow characteristics that can be specified when ordering the valve. It is important to note that there is a difference between "inherent valve characteristics" and "installed valve characteristics."

The "inherent characteristic" of a valve (Figure 3) is the characteristic published by the manufacturer, based on tests performed in a system where great care is taken to ensure that the pressure drop across the test valve is held constant at all valve openings and flow rates. The "installed characteristic" (Figure 4) is the relationship between valve position and flow in the specific system being considered, considering any changes in the *Δp* available to the control valve due to the approximately flow squared relationship between flow and piping pressure losses and/or a centrifugal pump head curve.

The three control valve characteristics are:

- Linear
- Modified parabolic
- Equal percentage

Inherent control valve flow characteristics are established assuming a constant *Δp* across the valve. If the valve *Δp* is reduced as the flow increases, meaning that there is a valve

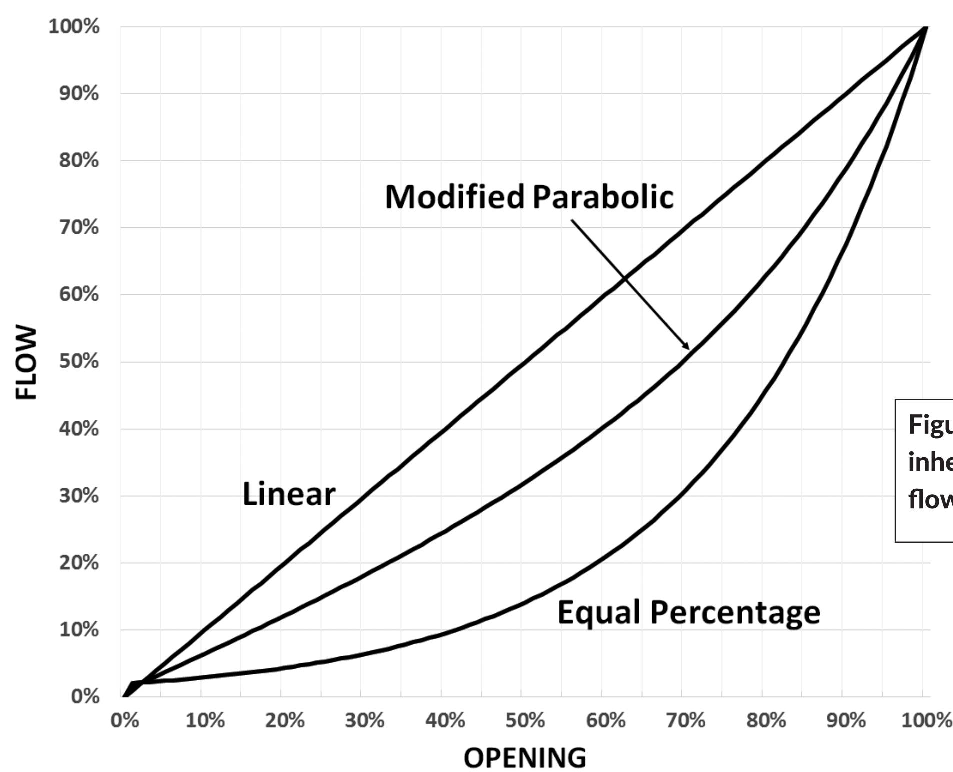


Figure 3. Typical inherent control valve flow characteristics.

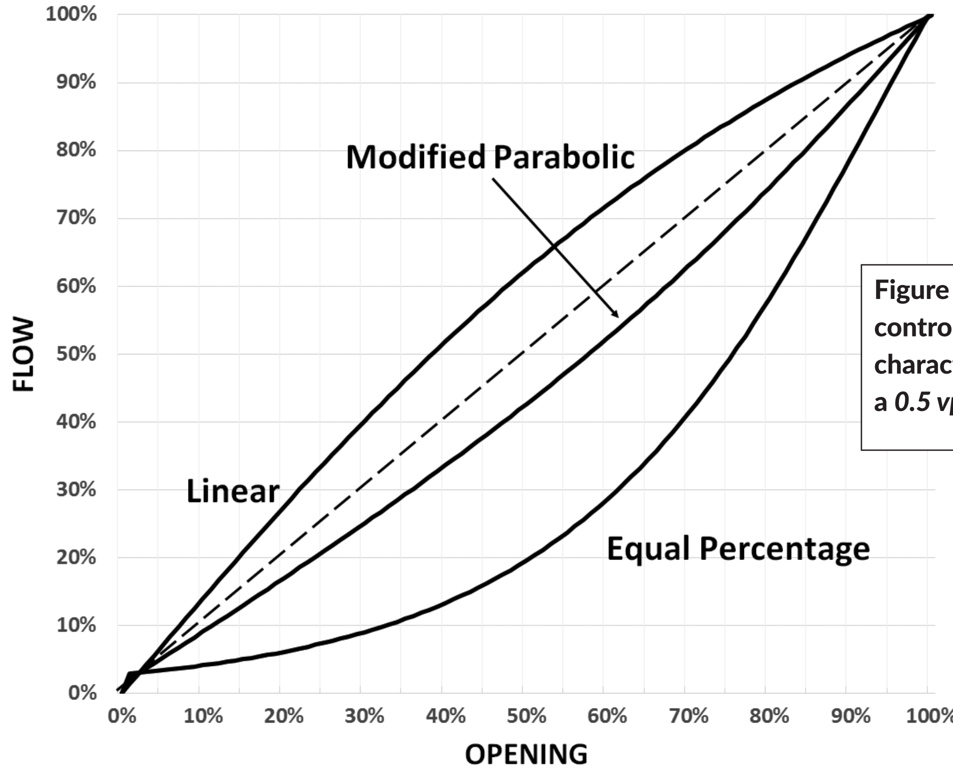


Figure 4. Installed control valve characteristic for a *0.5 vpdd*.

pressure drop decay (*vpdd*), then the "installed control valve characteristic" will be different, changing the proportion from controller signal output to the control valve flow.

Some modern digital control systems have self-tuning/ auto-tuning functionality that can reduce or minimize the inconvenience of loop tuning.

A simple way to choose among the inherent control valve flow characteristics is to calculate the *vpdd*. The ratio between the high flow and low flow valve pressure drop *Δp* can yield an indication of how to choose a valve flow characteristic for a given application.

$$vpdd = \frac{\Delta p(qmax)}{\Delta p(qmin)}$$

where:
vpdd=valve pressure drop decay
Δp(qmax)=valve pressure drop at maximun flow
Δp(qmin)=valve pressure drop at minimun flow

Using the *vpdd* calculation, the control valve characteristic can be chosen according to the following:

- For linear valve characteristics, *vpdd* is between *0.60* and *1.0*.
- For modified parabolic valve characteristics, *vpdd* is between *0.35* and *0.60*.
- For equal percentage valve characteristics, *vpdd* is between *0.20* and *0.35*.

If *vpdd* is less than *0.20*, review the pipe or other specs. There should be a minimum of *0.20 vpdd* to reach a reasonably linear control loop.

It is also possible to manage control valve characteristic requirements through the valve positioner. Control valve positioners can typically transform a linear control valve flow characteristic to a modified parabolic or equal percentage characteristic, or vice-versa. However, it is better to have the correct control valve in place.

ABOUT THE AUTHOR

Joao Bassa, MSc, senior consultant, MAHAM Serviços de Engenharia Consultiva, Brazil, has 40 years of international industrial experience in automation and process controls. He is a professor at Mauá Technology Institute and a member of ISA District 4 (Brazil).

Remote-Site Data in Real Time: A Case Study

Wireless devices reduce road trips for pulp and paper mill workers.

By Jack Smith

State regulations require pulp and paper companies to monitor and record daily effluent water rates. An employee from the main control site of a leading pulp and paper company in the Pacific Northwest went to a remotely located pond three times a day to manually record water levels to fulfill this requirement. This process was inefficient and time-consuming, and it didn't provide operators of the pulp and paper facility with real-time data. By installing digital and wireless technology, the company implemented a system that is scalable for future installations while reducing employee workload and maintaining state regulatory compliance.

Problem details

The pulp and paper company needed to monitor effluent water flow as it drains into a remote pond at its facility. Because of a new government regulation, personnel had to drive a truck three times a day to the remote site, log the height of the water along with the date and time, and return to the office. The company realized this was not an efficient use of time and wanted to automate the process.

This was done by calculating changes in water level in a V-neck weir entering the pond and using this data to calculate flow rate.

In addition to automating flow data collection, the company also wanted this data to be displayed on an Ethernet-based human machine interface (HMI) panel in its boiler room. Since the data was required by the state, it needed to implement a historical collection and archiving system that allowed operators to easily view historical data and produce reports when required. Seeking a quick and efficient solution, the company turned to Autoline Controls, a full-service process instrumentation manufacturer's representative with expertise in the pulp and paper industry.

Solution

Dale Stepper at Autoline Controls first suggested implementing a system at the pond site that uses a HART radar level transmitter (Figure 1) with precise measurement capabilities and a HART concentrator system (HCS). The HCS is a HART-to-MODBUS RTU converter that serves as a HART master and polls the HART radar level transmitter to obtain its primary variable (PV) data—in this case, water flow level. In addition, the HCS receives and converts the level transmitter's secondary variable (SV), tertiary variable (TV), and fourth variable (FV) to MODBUS RTU along with diagnostic data.

There were two main reasons why Autoline Controls chose an HCS for this solution. First, the HCS accurately gathers the digital level data from the transmitter along with giving the pulp and paper managers access to additional process variable data and critical diagnostic data about the transmitter's health and performance. The HCS also converts this HART data directly to an industry standard MODBUS RTU format, a serial communication standard that almost all industrial radios support.

The HART radar level transmitter has a front panel display for local viewing and connects to the HCS's input via a two-wire twisted pair cable. The radar gauge sensor measures the water height in the weir and publishes this data along with other process variable and diagnostic data to its internal HART memory location. This HART data is then polled by the HCS two to three times per second. The data is then mapped to a MODBUS memory map that resides in the HCS. This constant polling process ensures that data is continually updated on both the HART and MODBUS sides of the HCS.

Using the HART radar transmitter connected to the HCS solved the problem of measuring the water level; the next step was transmitting this data to site operators. In this case, the data needed to go to an

Figure 1. The HART radar level transmitter is connected to a HART concentrator system (HCS) to send weir flow level and diagnostic information to the boiler control room.

Ethernet-based host HMI panel and a historical collection system. There were no Ethernet networks, fiber lines, or twisted pair wires available from the pond site to the control room, so installing a local wireless network was chosen as the best method for acquiring these signals.

An initial wireless site survey done using photos of the site showed potential problems in establishing a direct line of communications from the field site to the host system due to either tree growth in the forest or accumulated snow on tree branches that may diminish the wireless radio's signal strength. Since there was potential for future RF signal path attenuation, Autoline Controls recommended the following wireless components:

- Wireless network module (WNM) radios from Moore Industries were used. Frequency hopping spread spectrum (FHSS) 900 MHz radios were used instead of 2.4 GHz models as their longer signal wavelength tends to better penetrate foliage.
- Ethernet versions of WNM radios were installed to meet the customer's existing preference to use Ethernet communications throughout the facility. While the remote pond site previously had no communications links, using Ethernet communications at the pond site is a desirable forward step in extending the ability to add future assets with minimum added investment.
- The 900 MHz Yagi antennas were installed at both the boiler site (Figure 2) and at the pond site (Figure 3) with the narrow RF beams directed toward each other. After

Figure 2. The omnidirectional antenna situated on the boiler room rooftop offers complete radio signal coverage for the entire site.

Figure 3. The Yagi-directional antenna was used at the pond site to transmit level signals from the HART level transmitter to the boiler room.

this was proven to be successful, the boiler site antenna was changed to an omnidirectional antenna to enable expansion of the boiler site to communicate via wireless Ethernet with all locations of the facility.

- Low-loss coax antenna cables with lightning arrestors were used.

The last piece of the solution involved delivering the level transmitter's signals to their host system in a manner that met their total requirements. The site operators expressed a desire for the level transmitter's data to be represented by both digital and analog signals.

While this could get quite expensive with traditional programmable logic controller (PLC) or distributed control system (DCS) solutions, Autoline Controls recommended adding a small net concentrator system (NCS) to the host site. The NCS is a dynamic input/output (I/O) system that can act as an expandable I/O system, MODBUS RTU master, MODBUS RTU slave, or MODBUS/TCP slave. The NCS also provides myriad math and logic solutions through its embedded control and logic program.

The heart of the NCS system is the Ethernet/MODBUS module (EMM), which is the NCS's CPU and communications center (Figure 4). The EMM takes on various roles in this application. It first acts as the MODBUS RTU master and polls the HCS at the pond site through the serial port of the WNM radio. The MODBUS RTU data collected from the HCS contains the HART data from the level transmitter and is then placed into the EMM's local memory map. Here it is stored as MODBUS RTU and MODBUS/TCP compliant registers.

The EMM is polled as a MODBUS/TCP slave by the Ethernet-based HMI at the boiler room so that site operations can view the level and diagnostic data. The EMM is then programmed with ISaGRAF logic to assign process variables to the NCS's analog output module

Figure 4. The wireless receiving panel installed at the boiler room of the pulp and paper mill. An Ethernet/MODBUS interface module (EMM) of the NCS serves as a MODBUS master to retrieve HART data from the HCS at the pond site.

(AOM). The AOM provides up to four 4-20 mA or voltage signals (ranging from 0 to 10 V) that can be taken to any analog receiving device, such as a historical data collection system.

Site operations also requested that a full-time communication link with the pond site be established and verified. A simple communication watchdog routine residing in the EMM was written to monitor the wireless connection and instruct the MODBUS RTU, MODBUS/TCP, and 4-20 mA values from the AOM to go to predefined limits if there is a wireless link failure to the EMM. This allows site operations at the boiler room to immediately tell when the wireless communication link has failed. Once the link is re-established, the system automatically picks up where it left off, transmitting and making available real-time process variable and diagnostic data from the level transmitter.

End results

Autoline Controls expedited the installation. Moore Industries application engineers preconfigured the electronics and bench tested the solution using a similar radar level transmitter kept at its headquarters for such customer applications. This allowed Autoline Controls to install the system quickly and have confidence that it would work with minimal adjustments needed. The system is now enabling the pulp and paper company to efficiently get accurate and required readings on the levels of their effluent water system (Figure 5).

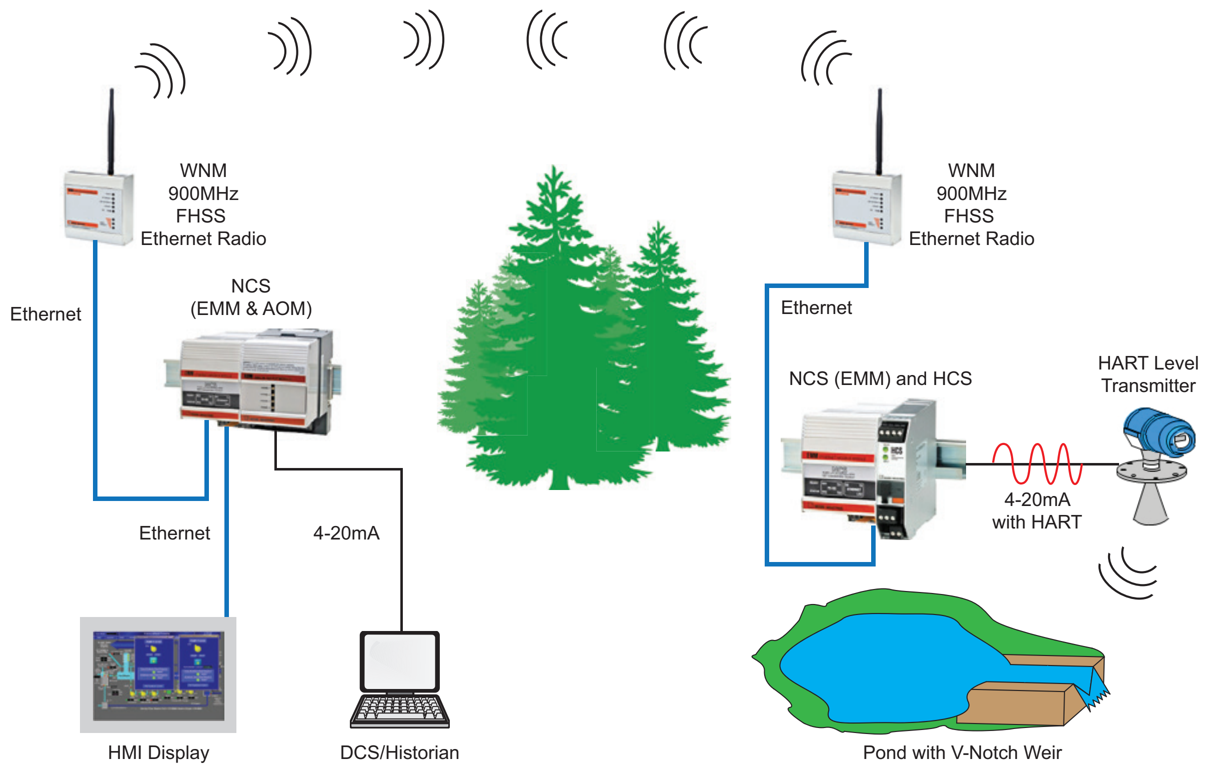


Figure 5. HART flow level measurements at the pond site are converted to MODBUS RTU by an HCS and sent from a WNM at the pond to a receiver radio at the boiler control room. The information is relayed from the wireless radio to an HMI display and DCS/historian by the NCS.

Frequency hopping spread spectrum (FHSS) 900 MHz radios were used instead of 2.4 GHz models as their longer signal wavelength tends to better penetrate foliage.

"Part of their license with the state required them to send an employee to the site to write down numbers three times a day, seven days a week," Stepper said. "That's essentially one-half of the work of a full-time employee—including having to work weekends. This system automates their formal measurement and documentation requirement process, and lets their employees focus on other critical aspects of their operation."

NOTE: This article is compiled from information provided by Moore Industries.
Images courtesy of Moore Industries

ABOUT THE AUTHOR

Jack Smith is senior contributing editor for Automation.com and ISA's *InTech* magazine. He spent more than 20 years working in industry—from electrical power generation to instrumentation and control, to automation, and from electronic communications to computers—and has been a trade journalist for more than 25 years.

Industrial Computers: Robust and Ready

Possibly more similarities than differences exist between consumer/commercial computers and industrial computers. Industrial PCs (IPCs) leverage many of the advances that come from the consumer tech world but add the software, programming, determinism, and connectivity essential to industrial applications.

Industrial PCs differ from consumer PCs in ways that are vital to industrial automation applications.

By Jack Smith

"From increased memory to the exponential growth of processing power described by Moore's Law, industrial controls only stand to

benefit from the evolution of PC technology. But IPCs must be hardened to withstand harsh production environments," said Eric Reiner, IPC product manager, Beckhoff Automation LLC.

"Commercial computers are often far more powerful and cheap, easier for POC [proof of concept], and AI [artificial intelligence] applications," added Oliver Wang, product marketing manager, Computing Division at Moxa Americas Inc. "But they are problematic when deploying to scale in industrial environments [due to] reliability in supply and hardware, or additional support for industrial use cases, industrial voltage/certs, and the like."

IPC characteristics

IPCs are similar to commercial PCs in terms of receiving, storing, and processing information to perform operation sequences based on software instructions. Hardware components such as motherboard, CPU, RAM, expansion slots, and storage media are also similar. However, IPCs differ from consumer PCs in terms of ruggedness, reliability, performance, compatibility, expandability, and long-term availability. Perhaps the biggest differentiator from commercial PCs is that IPCs have industrially hardened exteriors (Figure 1) and, therefore, offer an advantage over personal computers in industrial environments because they enable equipment that can withstand temperature fluctuations, noise, vibration, and other industrial harshness.

IPCs must operate in harsh, aggressive, and dirty environments. Operating in tough conditions, industrial PCs can withstand such factors as shock and vibration, which can be detrimental to commercial PCs; thermal extremes, which can affect performance and hardware lifespan; dirt and humidity; IP rating; and electromagnetic interference (EMI), which is common in industrial environments.

IPC-based control systems increase connectivity capabilities for industrial applications. They also provide powerful, flexible, and cost-effective control. IPCs typically operate in real time and are deterministic. For example, highly accurate and deterministic cyclical updates enable increased accuracy for coordinated motion control and data samples at precise time intervals. In contrast, programmable logic controllers (PLCs) typically offer scan rates in milliseconds, as opposed to the IPC's microsecond level.

"IPCs are definitely not direct replacements for PLCs, but the younger generation

Figure 1. Components are selected for ruggedized IPCs based on performance, long-term availability, and then price.

Image courtesy of Beckhoff

seems to be taking to the PC approach and are finding lower barriers to entry," said Wang. "Consider this: It's clunky and unresponsive and expensive to use an app on your iPhone to change the channel of your TV versus using the purpose-built remote control. Purpose-built controllers and devices are often superior because they are designed to do that specific thing."

IPC benefits

IPC-based control systems provide benefits for industrial applications, including performance, decreased costs, and an increased system lifecycle. IPC-based control systems can integrate faster, with more powerful processors than a hardware PLC. Many machines and equipment benefit from centralized control, while there are cases where decentralized control is advantageous. In general, it is most beneficial to access all software and data from one central location and use one central communication method for all devices on the control system.

When a PLC becomes obsolete, the software may also require upgrading. In an IPC-based control system, the end of a processor's lifecycle does not mean the system architecture or software becomes obsolete. By incorporating more functionality into the software and running that on an IPC, users can replace the aging IPC with a new one without any changes to the rest of the control system—including the software. Automation programs and fieldbus configurations can be downloaded to a software system on the new IPC with no need for code changes.

The evolution of industrial control technology has sometimes accentuated differences between PLCs, programmable automation controllers (PACs), and IPCs. Other times, it has blurred them. But there are some general differences.

IPCs enable equipment that can withstand temperature fluctuations, noise, vibration, and other industrial harshness.

"PLCs are designed with a single processor to execute machine control logic deterministically," said Reiner. "They were the evolutionary step immediately following hardwired relays. Ladder logic is the prevailing programming language for traditional PLCs. They typically communicate just one protocol, with any additional fieldbuses or protocols requiring an additional piece of hardware. PACs can use multiple processors per rack for higher performance. They accommodate more programming languages and even some third-party software for increased functionality. However, the system is still fairly closed compared to true PC-based control.

IPC applications

More industrial users are taking greater control over software. "They are looking for ways to use Linux, cloud, and PCs to hedge against reliance on traditional specialized, purpose-built HMIs [human-machine interfaces] and

Figure 2. Flasheye is using rugged IPCs to create LiDAR-based monitoring solutions for the mining industry to prevent dangerous conditions and downtime.

Image courtesy of OnLogic via Flasheye

proprietary technology to stay competitive and flexible," Wang said.

He adds that many of these applications are in the power and transportation sectors. There are also applications in edge computing for Modbus data acquisition and aggregation in renewable energy and energy storage, as well as those that exist for "onboard rail and bus for fare collection, GPS-based fleet tracking, onboard video surveillance, and machine-learning-based visual track inspection."

"PC-based control was foundational for Beckhoff," said Reiner. "We've been successfully executing applications with IPCs since the early 1980s. The first OEM [original equipment manufacturer] to integrate Beckhoff controls was a woodworking machine builder, but we have decades of experience using PC-based control in just about every industry: packaging, fabrication, assembly, logistics, test and research, etc. Now, a single CPU can handle machine control logic, vision, safety, HMI, and much more, compared to the many single-purpose black boxes required in legacy architectures."

"Automation in a factory setting is definitely a key use case for industrial computers, but our clients are using our hardware for a nearly limitless number of applications," said Darek Fanton, communications manager at OnLogic. "Industries we're seeing on the rise now include energy management, smart cities and buildings, smart agriculture, mining (Figure 2), autonomous vehicles—from self-guided warehousing robots to autonomous tractors and concierge robots that move items around a hotel, hospital, or mail room—and medical devices. And, in addition to SCADA applications, our systems are used for IoT [Internet of Things] gateway applications, digital twin setup, and model building, which is essentially edge to cloud communication, data logging, edge servers, and the like."

Fanton added that industries having high regulatory requirements and standards are turning to IPCs that can often be standardized and made available with longer lifecycle commitments "to avoid costly and time-consuming recertification that can crop up when consumer PCs go through a generational revision."

Software and operating systems

According to Wang, the continued trend is to enable industrial users to build their own tailored solution on a "host device" or IPC-based platform. "The impact of supply chain and cybersecurity concerns is still developing. Best practices for secure supply chain, secure boot, and OS [operating systems] are new challenges for both manufacturers and users," he said.

Reiner echoes this sentiment. "IPCs provide deterministic control for industrial equipment, and the use of wide-ranging multi-core processors enables extreme scalability," he said. "Programming of Beckhoff IPCs takes place in TwinCAT 3 automation software, an end-to-end engineering and runtime platform that supports programming in IEC 61131-3 languages and their object-oriented extensions, predefined or custom function blocks, and computer science standards like C, C++, JavaScript, Python, and more. Other third-party software—for everything from HMI to historians—can run alongside the machine control logic on the same controller hardware.

"In the past, many believed PLCs were more secure and deterministic, but this has not stood the test of time," continued Reiner. "PLCs, PACs, and IPCs all use a modified version of commercially available OS and BIOS rather than the proprietary firmware of yesteryear. The key differentiator is that IPCs provide greater openness to best fit [users'] requirements for flexibility in programming, connectivity, and integration with devices from other vendors."

IIoT-ready IPCs

Implementing IIoT and Industry 4.0 functionality with IPCs is the logical next step to establishing more connected enterprises. PC-based control provides the most logical control platform with an unobstructed migration path to add higher levels of connectivity today or at any time in the future, even if users are not ready to embrace IIoT and Industry 4.0.

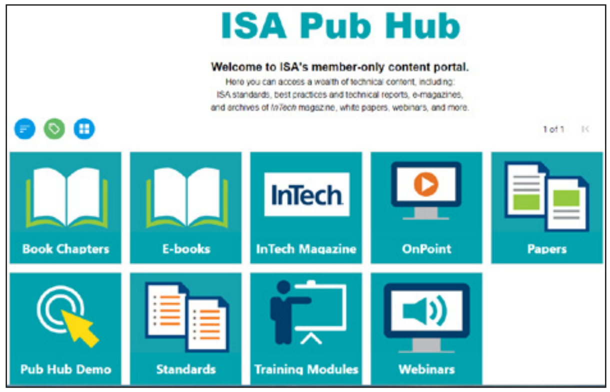
Historically, adding IoT communication with PLCs has become increasingly difficult. Doing so typically entails adding third-party IT hardware and software to make it work. However, this type of connectivity has been possible with PC-based control, even before many modern buzzwords emerged. Internet and Ethernet connectivity has been built into PC-based control platforms for decades, which has enabled connectivity with little or no additional hardware.

"More companies are adding IoT capabilities out of the box as a standard feature for machines and systems," said Reiner. "With the inherent open connectivity of IPCs, this is no problem. Our controllers can connect to the cloud or enterprise level securely and without the need for an additional IoT gateway."

ABOUT THE AUTHOR

Jack Smith is senior contributing editor for Automation.com and ISA's *InTech* magazine. He spent more than 20 years working in industry—from electrical power generation to instrumentation and control, to automation, and from electronic communications to computers—and has been a trade journalist for more than 25 years.

ISA Pub Hub: Member Access to a Wealth of Technical Content



ISA has introduced the ISA Pub Hub, a new ISA Member benefit. Pub Hub provides access to valuable technical information including ISA standards, best practices and technical reports, InTech magazine archives, white papers, webinars, e-books, e-magazines and more.

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OT Cybersecurity Summit Successfully Debuts

ISA chose Aberdeen, Scotland, as the launch venue for its Operational Technology (OT) Cybersecurity Summit given the city's strategic position in the energy sector. The Summit brought together in-person and online attendees to discuss where vulnerabilities lie and to gain insight into better protection for themselves and their companies.

After two days of cybersecurity training, the conference welcomed Aberdeen Lord Provost Dr. David Cameron as well as keynote speakers Cheri Caddy, deputy director at the US Office of the National Cyber Director, and Megan Samford, VP and chief product security officer–Energy Management from Schneider Electric. They were joined by subject matter experts from the US and UK who presented real-world applications of ISA/IEC 62443, the world's only consensus-based automation and control systems cybersecurity standards.

Commenting on the success of the event, Claire Fallon, ISA Executive Director, said: "Attracting more than 120 in-person and online delegates to our first-ever UK event of this kind is a clear demonstration of the appetite which exists for learning and networking opportunities focused on cybersecurity in operational technology environments."

From left to right: Steve Mustard, ISA Treasurer and ISA OT Cybersecurity Summit conference committee chair; Cheri Caddy, Deputy Assistant National Cyber Director, The White House; Megan Samford, Vice President and Chief Product Security Officer for energy management at Schneider Electric; and Dr. David Cameron, Lord Provost of Aberdeen.

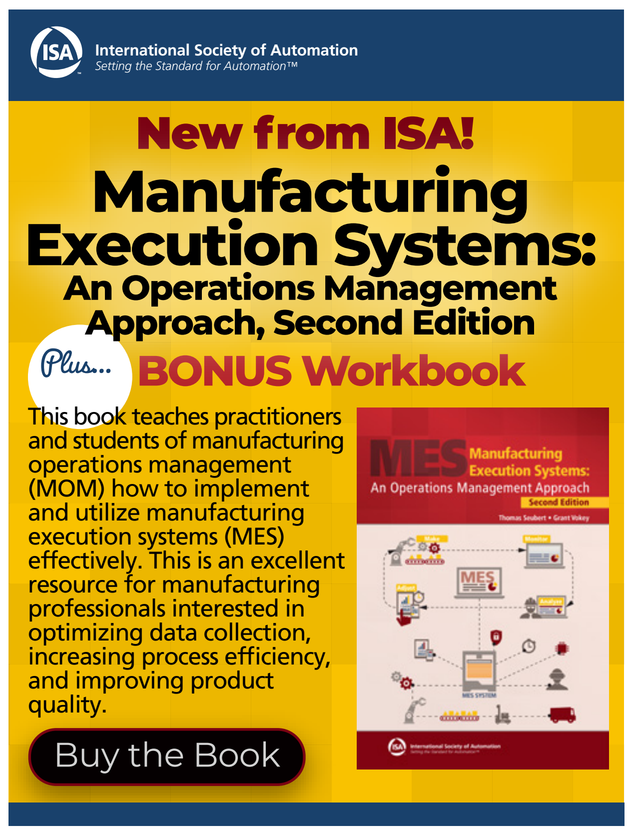
ISA Connect Wins Award for Best Community Design

ISA is proud to announce that its member community and discussion platform—ISA Connect—has won the prestigious Best Community Design Award from platform vendor Higher Logic. Launched in 2020 and updated in July 2022, ISA Connect is built upon the Higher Logic Thrive platform, used by many different associations across industry sectors. What makes the ISA Connect design and implementation stand out is its visual and experiential integration with other ISA web properties.

ISA has created an experience that earns continuous positive feedback from its members on ease and usability. "If you need to find an answer to a technical problem at your work, the right place to go is the Technical Discussion Forum on ISA Connect," says ISA Past President Carlos Mandolesi.

With an international membership base of nearly 14,000 automation professionals, ISA needed a platform that could bring its diverse community together for high-quality and engaging technical discussions. "ISA Connect is a trusted resource I can count on to provide reliable, unbiased answers and views on any automation-related topic, including control, safety, cybersecurity, and digital transformation," says ISA Treasurer Steve Mustard.

"The member home page is a great one-stop shop for all of my ISA involvements," says Mary'beth Ramey, an Automation and Process Control Engineer at Celanese Engineered Materials. "The feed brings together updates from all the communities I am in and makes it easy to navigate wherever I need to go."



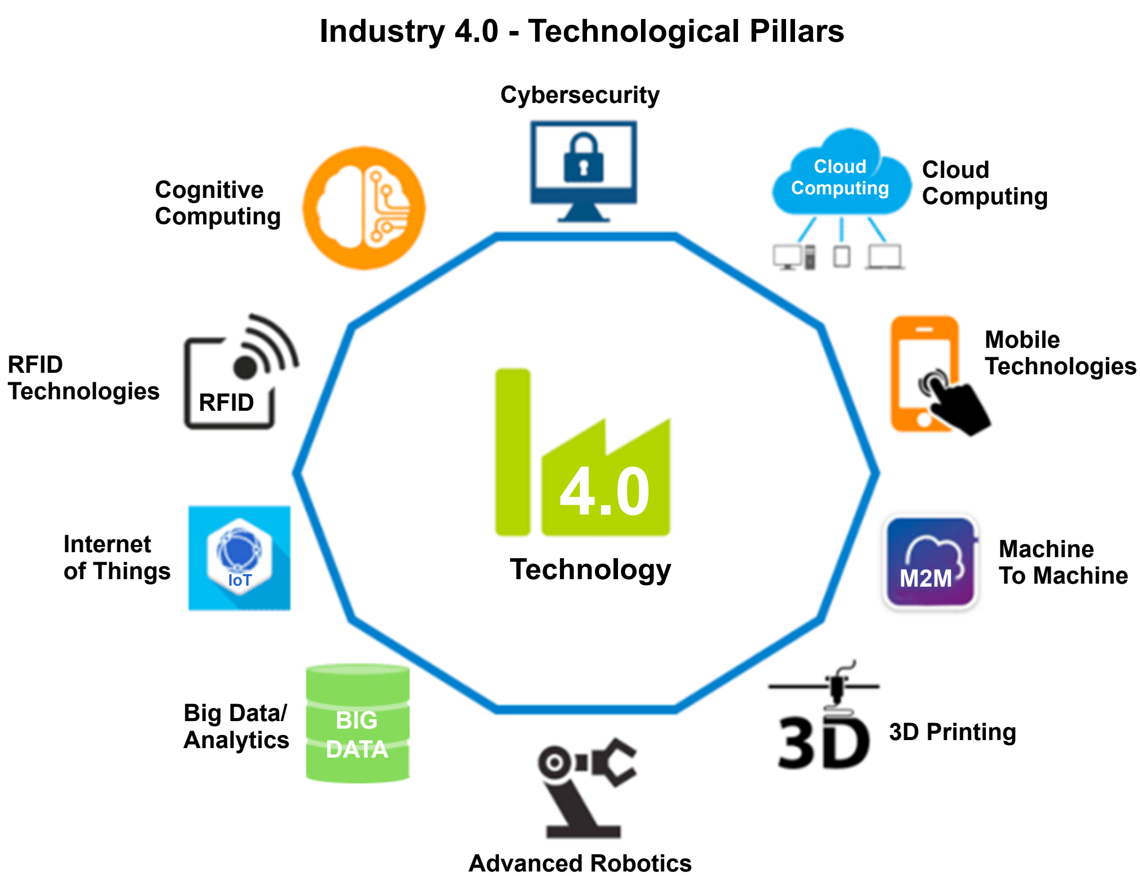
The Future of Workforce Automation Competency

By Steve Mustard

In the early days, automation professionals would need to understand a world of analog computers, pneumatic control, and relay logic. Today's automation professional needs to have a broad range of skills and knowledge—from more conventional aspects such as PLC programming and instrumentation to networking protocols, databases, and virtualization.

If this were not enough, Industry 4.0 assumes the use of newer technologies and concepts such as augmented reality (AR), the industrial Internet of Things (IIoT), and digital twin. Various organizations are attempting to understand what the future workforce will need to look like to embrace all the benefits of Industry 4.0, also called "smart manufacturing."

An article by Deloitte, *The Future of Work in Manufacturing*, examines "what future manufacturing jobs will be like in the digital era." To help explain their predictions, they created 10 personas, each describing a future job in manufacturing. Four of the personas are conventional manufacturing jobs (e.g., "Quality Assurance (QA) manager") with the word "smart" added. The remainder are a mixture of new job titles for existing roles that use new technology in that role (e.g., "digital twin" engineer) and very narrowly defined



jobs that may exist or be part of another role (e.g., "drone data coordinator”).

Digital twin and augmented reality systems are no more core business for manufacturing organizations than are manufacturing execution and enterprise resource planning systems. Roles cannot be so specialized that they only support one technology.

MxD (Manufacturing x Digital) is a non-profit organization where major manufacturers, in partnership with the U.S. Department of Defense, are identifying the tools and expertise they need to enhance their capabilities. Its report *The Digital Workforce, Succession In Manufacturing*, identifies 165 roles, although each role is narrowly defined, and the skills and knowledge overlap with several others. For example, there are eight roles with IT/OT in the title (application developer, systems analyst, systems architect, systems technician, etc.). In reality, there are probably two roles here (technician, engineer), and a variety of company-specific names or activity-specific roles (e.g., during a project).

A more likely reality

The approaches by Deloitte and MxD can certainly stimulate good discussion, but manufacturing organizations are unlikely to change so dramatically. The real benefit of Industry 4.0 technologies is that organizations can achieve their core mission more efficiently and deliver better quality output. As a result, the skills and knowledge requirements for existing roles will need to change and personnel in those roles will need additional training.

A simple example is the QA engineer. Today’s QA engineer’s toolkit includes 2D drawings, manufacturers data books, and a tape measure. The role has developed over the years and has moved further away from hardcopy toward electronic documents, including 3D models. Future QA engineers will continue to develop and be able to utilize:

- A digital twin that combines an accurate 3D model of equipment with the manufacturer’s data fully integrated
- Smart glass technology to allow the overlay of a 3D model on the actual equipment, simplifying the process of tie-in point validation and dimensional control

This is the Deloitte Smart QA Manager role—although it would be more helpful to focus on the new skills and knowledge the QA manager needs, rather than dwell on the name of the role. This is a minor issue. The more significant concern is that Deloitte and MxD both foresee manufacturing organizations creating roles such as digital twin engineer and virtual reality/augmented reality software engineer. Digital twin and augmented reality systems are no more core business for manufacturing organizations than are manufacturing execution and enterprise resource planning systems.

Of course, manufacturing organizations will employ personnel who can support the business with technology, most likely in their IT departments. But even then, these roles cannot be so specialized that they only support one technology. As technology inevitably evolves, the role needs to be one that can keep up (or ahead) and continue to evolve. Therefore, organizations should update the skills and knowledge requirements for their relevant roles to include the new technologies that need supporting.

Automation competency model

ISA, representing the automation profession, has been working with the U.S. Department of Labor since 2008 on the development and ongoing maintenance of an automation competency model (ACM). The model identifies the knowledge and skills needed in the automation profession. The ACM defines the totality of skills and knowledge needed in the automation profession. To identify a specific profile for a role, users are able to employ the needs analysis matrix. This can be used to screen applicants for roles, as well as to assess gaps in skills and knowledge in the existing workforce.

With the ACM skills and knowledge descriptions, it is possible to define a training curriculum. ISA's existing training portfolio covers a significant portion of the ACM skills and knowledge, and work is underway to review the gaps. This will also include identifying the gaps in new skills and knowledge areas, such as Industry 4.0, and identifying a strategy for closing those gaps.

This may involve the development of a new training (or certification) program or partnering with other like-minded organizations that are better suited to a particular set of skills and knowledge. Either way, ISA will be able to offer all the relevant training and certification needed for the future automation professional and help manufacturing organizations achieve their ambitions to deliver better-quality output more efficiently through the use of Industry 4.0 technologies.

A version of this column originally appeared on the ISA Interchange blog.

ABOUT THE AUTHOR

Steve Mustard is an independent automation consultant and a subject matter expert of the International Society of Automation (ISA). Backed by more than 30 years of engineering experience, Mustard specializes in the development and management of real-time embedded equipment and automation systems. He serves as president of National Automation, Inc., and served as the 2021 president of ISA. Mustard is a licensed Professional Engineer in Texas and Kansas, a UK registered Chartered Engineer, a European registered Eur Ing, an ISA Certified Automation Professional (CAP), a certified Global Industrial Cybersecurity Professional (GICSP), and a Certified Mission Critical Professional. He also is a Fellow in the Institution of Engineering and Technology (IET), a Senior Member of ISA, a member of the Safety and Security Committee of the Water Environment Federation (WEF), and a member of the American Water Works Association (AWWA).