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Improving control

By K.C. Meyer and Scott Kempf

A precision electric actuator is unaffected by valve stiction and can track closed-loop controller demand almost perfectly, without dead time, lag, or overshoot

FAST FORWARD

- The key performance issue of a final control element is its ability to consistently control the process variable.
- Minimizing the actuator's time-based response dynamics allows the final control element to track demand as closely and quickly as possible.
- No process is linear. However, as process nonlinearities increase, the process model becomes less valid and control performance degrades.

A natural response to the increasing economic, environmental, and competitive pressures facing industry is to improve process control performance, and many companies are investing in powerful, state-of-the-art control instrumentation as a result.

Unfortunately, these efforts often suffer from the performance of the final control element, or FCE (defined as the control valve/actuator or damper/actuator assembly).

The positioning performance of the FCE and its importance on process control is often misunderstood, underestimated, or simply ignored.

Updating control instrumentation and design is a wise, but costly, investment. Maximizing the return on the investment is possible, only if the proper actuator couples to a properly applied valve/damper.

Here are the actuation performance issues critical to control. We'll look at why electric actuators designed for precise positioning and continuous modulation duty eliminate a major source of performance limitations and control loop non-linearity.

Of course, this makes the return on a control system investment look good.

The performance issue

The key performance issue of an FCE is its ability to control consistently the process variable in response to the closedloop controller demand, without inducing dead time, lag, or gain variations over the expected control range.

The FCE gain is a function of the valve/damper itself (hereafter referred to as the valve only), while the time-based dynamics (dead time, lag) are largely a function of the actuator performance.

An ideal FCE includes a valve with a constant gain throughout the control range and an actuator that responds to the controller demand perfectly with no effect on the overall process dynamics.

In reality, no FCE can provide this perfect performance, but by minimizing actuator dead time, lag, dead band, and performance inconsistencies, while appropriately selecting and sizing the valve, one can minimize a major source of control performance limitations and nonlinearity.

Minimizing the actuator's time-based response dynamics allows the FCE to track demand as closely and quickly as possible. Insuring these dynamics are constant over time and changing process conditions reduces nonlinearities and makes it easier to tune a controller aggressively without worry of instability.

Key players in the cast

Traditional PID control theory rests on the premise that the process to be controlled is linear within the control range. To better understand this premise, first define the terms "process," "dynamics," "gain," and "linear."

For this discussion, a "process" is a particular system or variable, acted upon and maintained by a controller. The time-based response of a process (i.e. dead time and lag) is the process "dynamics," while the proportional, non-time-dependent response is the process "gain."

It is important to note the overall process response (i.e. dynamics and gain) is the cumulative sum of the dynamics and gain of each individual device or element within the process control loop, except for the controller itself.

Consider a flow control loop for example. The overall process dynamics and gain not only include the flow response itself—as determined by the flowing medium, the pressure, the temperature, volume, etc—but also the response dynamics of the actuator, the valve, the primary element, and the transmitter.

The definition of "linear" in the context of process control is not always intuitive. Process control principles assume one can describe a process using a mathematical model.

Since these models are based on linear differential equations (in time), linearity is not defined in the traditional algebraic sense. Take, for example, the most common of process models, the first order plus dead time response. The differential equation for this model is as follows:

$$\tau\frac{dy}{dt}+y(t)=K_p m(t-T_d)$$

Where:

- $y(t)$ = Process output as a continuous function of time
- $m(t)$ = Controller output (process input) as a continuous function of time
- K_p = Process gain
- τ = Process time constant (lag)
- T_d = Process dead time

When using this model to describe a process, linearity is a measure of the model's validity under all the expected control conditions. Non-linearities are the actual process response characteristics that tend to invalidate the model.

Non-linearities, therefore, cause the process dynamics and gain, represented by the constant terms in the model equation, to vary over the control range or with changing conditions. In this model, the constants are the time constant (τ), the process gain (K_p) and the dead time (T_d).

Simply defined then, a process is "linear" if the dynamics and gain remain constant for all inputs throughout the entire control range. If these terms vary, the process has non-linearities.

No process is linear; however, as process non-linearities increase, the process model becomes less valid and control performance degrades.

Role of FCE non-linearity

Just as the response of each device in a control loop (FCE, measurement device, the process itself) contributes to the overall loop dynamics and gain, each device also contributes to the non-linearities present in the loop. FCE non-linearity is anything that causes the response dynamics or gain of the FCE to vary. For simplicity, FCE non-linearities break out into two groups:

1. Non-linearity characteristic of the valve itself and not the actuator
2. Non-linearity that results from the actuator positioning ability

Non-linear valve characteristics result from using a valve that is the wrong size or that has wrong flow characteristic. This results in process gains that vary with valve position, which makes optimal loop tuning over the entire control range impossible.

However, the good news is one can minimize, even eliminate, this valve non-linearity by carefully selecting the correct valve for the application.

A far more insidious non-linearity is one that is a function of the actuator. Actuator related non-linearities tend to affect the time-based loop dynamics, adding inconsistently variable dead time and lag.

Actuator non-linearities are a function of many variables including valve friction and load as well as control loop activity. Some degree of actuator non-linearity is always present, but often it becomes significant.

What compounds the problem of actuator non-linearity is actuator non-linearity, especially in pneumatic actuators, can develop and change over time and with changing conditions making it inconsistent and unpredictable.

Known non-linearities negatively affect control but can be compensated for at the expense of optimum control performance; however, inconsistent and unpredictable actuator non-linearity cannot be effectively handled.

The normal response is to severely detune the loop or simply put it in manual. Engineers often overlook this common situation in spite of the significant control penalties that result.

Actuator dynamics on control

The many cause and effect relationships associated with control performance are vastly complicated, but it is a certainty that adding dead time and lag to a process limits control performance. Although lag is not as detrimental as dead time, multiple or higher-order lags effectively add more dead time to the loop.

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The negative impact of dead time on control, which is especially apparent in processes with inherent fast dynamics like pressure and flow, is like the difficulty one would experience driving a car if there was dead time between seeing the road and taking action to steer.

Predictive control algorithms intended to compensate for dead time exist but are more effective for set point changes than they are for load disturbances. Dead time kills control performance, and valve actuators are often a leading source.

Every effort to reduce process dead time is important; this makes the potential for better control performance and optimal loop tuning possible.

Since one can do little to reduce the physical process dead time, eliminating dead time from control devices like the actuator is important.

Actuator dead time leads to poor positioning resolution and limit cycling of the valve that tuning or other compensation techniques cannot solve. Both pneumatic and electric actuators can create problems.

A common source of significant pneumatic actuator dead time is sticking due to friction (stiction). This causes stick-slip response, and that occurs as a pneumatic actuator builds air pressure to overcome the static frictional valve load to initiate motion.

Once the pressure builds to a level sufficient to overcome friction, the valve begins to move, and the coefficient of friction drops. This causes the valve to overshoot its target and initiate correction in the opposite direction.

The end result is a limit cycle around the desired valve position.

Electric actuators not well suited for continuous modulation will create similar dead time, resulting from the wide dead bands necessary to protect against thermal trips or motor coast.

In this situation, the reset action of the controller constantly integrates back and forth through the dead band in an effort to position the valve, and a limit cycle with a magnitude equal to the dead band results.

Ultimately, whether dead time results from a pneumatic actuator sticking or an electric actuator with a wide dead band, the result is poor positioning resolution, limit cycling, and the inability of the FCE to track closely the closed-loop demand signal from the controller.

Detuning does not eliminate the cycle, rather only changes the frequency.

Actuator closed-loop tracking

A precision electric actuator designed for continuous modulating control service can minimize the actuator's contribution to closed-loop dynamics.

In addition, it can eliminate dead time and lag non-linearity caused by stiction problems in pneumatic actuators and duty-cycle and dead band limitations of typical electric actuators.

Select an appropriate electric actuator with the following design characteristics:

- Capable of continuous modulation without thermal duty cycle limitations
- Ability to start instantaneously at full rated torque/thrust
- Ability to stop instantaneously

without coast or overshoot
- High degree of positioning precision and accuracy (0.1% or better)
- Performance unaffected by frictional or dynamic load
- Repeatable performance that remains consistent over time, over the valve operating range, and with varying process conditions

An electric actuator with these characteristics provides a large process-control performance advantage. The closed-loop field response of an electric actuator, equipped with integral position control electronics, shows close tracking.

The electronics monitor the controller demand and instantly position the valve in very small precise movements (as small as .075%) to balance the position with the demand.

The actuator performance is accurate, repeatable, and virtually eliminates actuator-induced dead time and lag common with pneumatic actuators and accessories, as well as typical electric actuators.

Furthermore, since the performance of this actuator is unaffected by changing conditions, friction, and load, it remains constant over time and throughout the valve range, thus eliminating non-linearities.

The actuator produces near perfect closed-loop demand tracking thanks to its ability to start/stop instantaneously and make quick, precise position adjustments.

Normal closed-loop control requires quick, precise valve position changes, but seldom if ever requires extremely large and fast adjustments.

In rare circumstances, the full-stroke timing of an electric actuator may be a concern. These circumstances normally are associated with emergency or other unusual operating conditions and handled using emergency shutoff valves or similar equipment.

In most circumstances, the electric actuator full-stroke timing is actually several orders of magnitude faster than the speed at which the demand signal from the controller is changing.

Utilizing an electric actuator with the described capabilities results in near perfect closed-loop tracking of the controller demand that is consistent over time and changing conditions.

> **Actuator non-linearities cause variable dead time, overshoot, sluggish response, and limit cycling. They are inconsistent, unpredictable, and easily overlooked.**

This minimizes the actuators contribution to closed-loop process dynamics and eliminates actuator-induced non-linearity in the form of variable dead time and lag.

Therefore, tuning can be faster and geared to the actual process response rather than the actuator response. Also, the loop tuning remains consistent over time and with changing conditions.

Every element of a process control loop contributes to the overall dynamics and loop non-linearities, and FCEs are a leading contribution of both.

Valves have a significant effect on loop gain and can add gain non-linearity due to the valve size and flow characteristic; but these effects can be smaller, and we can eliminate them with proper valve selection.

Actuators, however, are more problematic.

They are a leading source of control loop dead time and lag, both of which limit control performance. Worse yet, actuator dynamics are often non-linear resulting from pneumatic actuator susceptibility to stiction, or electric actuators not capable of continuous modulation.

Actuator non-linearities cause variable dead time, overshoot, sluggish response, and limit cycling. They are inconsistent, unpredictable, and easily overlooked.

They develop over time and with changing conditions and limit overall control loop performance. These problems prevent the FCE from tracking the closed-loop controller demand and control the process.

A precision electric actuator designed for modulating control service provides an enormous control advantage because it is completely unaffected by valve stiction and can track closed-loop controller demand almost perfectly, without dead time, lag, or overshoot.

The performance remains consistent over time and with changing conditions. When coupled to a properly selected and sized control valve, the electric actuator ensures the FCE's ability to position the valve never limits the control performance.

This makes it possible to maximize the return on a control system investment.

ABOUT THE AUTHORS

K.C. Meyer (kc.meyer@alcoa.com) is registered professional engineer. He is a project engineer with Fluor Global Service – Fluor/Alcoa Alliance. **Scott Kempf** (sek@haroldbeck.com) is an applications engineer at Harold Beck & Sons, Inc.

RESOURCES

Final Test: Safety valve testing goes digital.
www.isa.org/link/FinalTest

Speed manages streams: The case for variable frequency drives as a final control element spreads.
www.isa.org/link/Speedstreams

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