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HOW TO ACHIEVE OPTIMAL CONTROL VALVE PERFORMANCE

ADDRESSING CONTROL VALVE PERFORMANCE HAS A DRAMATIC EFFECT ON PROCESS PLANT EFFICIENCY, OVERALL PROFITABILITY AND CONTROL VALVE LIFE-CYCLE COSTS.

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Leaders in the process industries realize that good process control performance is an essential element in achieving world-class reliability as well as optimizing overall process efficiency. Since control valves are the only devices in the process loop that actually "move" to adjust the process, their performance is critical. The best way to achieve excellent performance is to initially select the most appropriate final control valve for the application and then to maintain its performance over time.

Why Bother With Control Valve Performance?

Plant efficiency is the underlying goal of process control. The efficiency of a plant can be looked at as a function of outputs and costs as shown in Figure 1. Outputs, shown here in the numerator, include any factors that directly impact the volume of sellable product from the plant. Here is where factors such as quality, throughput and availability of the process fit into the picture. Increasing any of these factors will improve bottom-line efficiency. Cost inputs, shown in the denominator of this illustration, include raw materials, maintenance, utilities, safety, waste and rework. Increasing any one of these factors will decrease overall efficiency.

Control valve performance has a significant impact on every factor of plant efficiency. As a benchmark,

EnTech Control Engineering examined more than 5,000 control loops and found that nearly 80% of loops failed to reduce process variability to an acceptable degree.[1] This study reported that "the undesirable behavior of control valves is the biggest single contributor to poor loop performance and the destabilization of product uniformity."

A major control valve manufacturer in the hydrocarbon and chemical industries also performed an audit on loop performance and had similar findings. In more than 7,000 loops audited in refining and petrochemical plants, more than half the loops needed valve performance improvements to achieve optimal process performance. Most loops failed to respond to a 2% change in setpoint. Subsequent initiatives to optimize control valve performance resulted in significant efficiency and reliability improvements in the entire process unit. Commonly those unit efficiency improvements were 2 to 5% or greater after control valve performance optimization projects.

The following examples illustrate the impact of valve performance on process efficiency:

- A new, higher activity catalyst was charged into a first-stage hydro-cracking reactor. After commissioning, reactor temperature variations of +/-4° F at the catalyst bed were observed, and the existing hydrogen feed valve could not respond fast enough to process changes demanded by the new catalyst. Changing the main hydrogen control valve reduced the temperature variation to +/- 0.5° F. As a result, unit production was increased by more than 1,000 barrels per day. In addition, the better temperature control has resulted in improved catalyst life and has allowed an extension in the time between turnarounds.
- A naphtha cracker in Brazil added digital instrumentation to 350 control valves to improve the plant's performance. Operational benefits that were realized included a 25% reduction in furnace alignment time, reduced maintenance as a result of more uniform coke formation on furnace tube walls and greater operational stability. The annualized process impact was more than $4 million.[2]
- Because of excessive fuel consumption, the control valves on the fired heaters of a 160,000 BPD crude unit were replaced. Before this optimization, the DT across the passes was +/-9° F. Fuel gas consumption had averaged 18.7 MMSCFD. After the optimization, DT was only +/-2° F, and fuel gas consumption was reduced to 17.5 MMSCFD. In addition to the large fuel gas savings, better control of temperature within the heater resulted in better control of coke formation on the heater tubes and extended the time between heater maintenance requirements.

Figure 1. Efficiency is a function of outputs and costs.

These are just a sample of the evidence showing the profound impact that selection of the right final control equipment can have on the bottom-line performance of process plants. Establishing proper control valve performance is the foundation for establishing process loop performance. The resulting gain in loop performance not only improves process efficiency, it also impacts the overall reliability of the process. Optimum control valve performance is vital for achieving efficient, reliable processes. It is also a sound first step for real improvement in process reliability.

So if the control valve is so critical to plant optimization, how does one go about selecting the right valve?

Traditional Selection

Traditional valve-sizing methods have often been used as a guideline for selecting the "right" valve in each application. Process details are gathered to make sure a control valve is made from the right materials, can handle process temperatures and pressures, and has enough capacity to handle minimum/nominal/maximum flow conditions. ISA (Instrumentation, Systems and Automation Society) and IEC (International Electrotechnical Commission) provide industry standard control valve specification forms that help make procurement of control valves almost as easy as "filling in the blanks" with the pertinent process information. These parameters are very important for many reasons, including process safety, cavitation and/or noise control, and preventing choked flow.

The problem with just filling out the specification sheet is that optimal valve or process performance is not guaranteed, even if the spec sheet is filled out exactly right. Almost all the information gathered deals with the ***static*** performance of the control valve at fixed process conditions. While important, very few parameters are actually

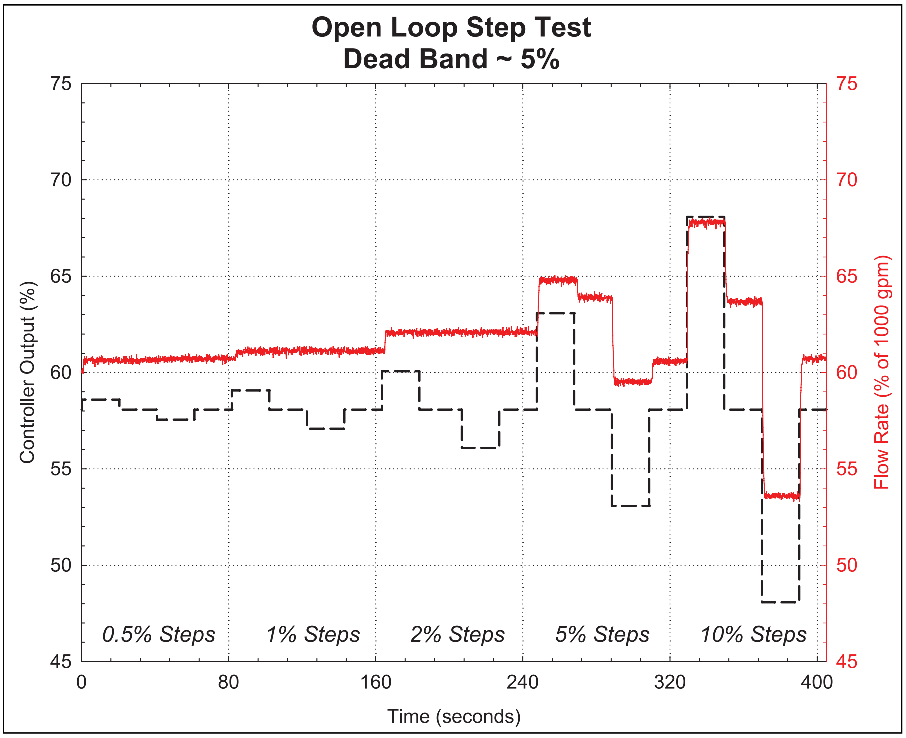

Figure 2. Open-loop step tests results for a rotary valve are shown above. The process dead band for this loop (with this valve) is approximately 5%. Changing to a more appropriate valve design signficantly reduced dead band and gave optimal process control.

focused on the control valve's *dynamic* performance and the impact of that performance on the process. A few static performance parameters addressed—such as flow coefficients, rangeability, linearity and hysteresis—have little bearing on predicting the valve's actual in-service performance.

For Proper Selection, Get Dynamic!

So if dynamic performance is left out of most control valve specifications, what parameters should be considered in this quest for optimum control valve performance? From a dynamic performance standpoint, answering three simple questions can dramatically improve control valve performance.

1) Does the valve move?

This may seem like a silly question, but in reality the dead band of the control valve assembly, including the valve body, actuator and related instrumentation are important here. ISA SP75.25.01-2000 defines the term "dead band" as "the range through which an input signal may be varied, with reversal of direction, without initiating an observable change in output signal." In other words, dead band is the amount the command signal to a control valve can move after signal direction reversal before a noticeable change in the process variable is observed. Dead band is present in any mechanical device. In control valves, dead band comes from factors such as excessive friction, loose or insufficiently rigid drive-train connections and very low process gains.

Rotary valves are the most susceptible to high dead band. High seal torques, multiple mechanical connections and valve shafts that can twist because of high packing/seal loads are all opportunities to lose motion between the trim element and the positioner feedback. This means the positioner, no matter how well it performs, can only position the valve as good as the feedback it receives.

Another important point to mention about dead band measurements is evaluating dead band in a process is absolutely critical. Trying to measure the true dead band of a control valve on a bench or out of service does not paint the whole picture. A process controller only cares about the relationship between the command signal to the control valve and the corresponding changes on the process variable transmitter.

Open-loop step tests with process present provide a good way to evaluate control valve dead band. Any control valve manufacturer should be able to provide flow test data that shows the ability of a particular valve construction with respect to dead band. The manufacturer should be able to provide this data for various product types showing responses to step inputs ranging from 0.25% to 5%. Figure 2 shows an example of process dead band measured with an open-loop step test.

Not all valves will respond to the smallest steps, but the limitations of various valve configurations will be apparent.

It is important to realize that not all control loops require minimal dead band. For process loops requiring good throttling control, the dead band from input signal to process variable should be less than 1%. Many process critical loops may require dead band in the range of 0.25% or less. Ask your control valve supplier to show you what they can do.

2) How fast does the valve move?

Various tests and measurements can be used to determine the response speed for a control valve assembly, but the same open-loop step used above for determining the dead band will work just fine. Obviously, the response time of the whole process is important for controller tuning and loop performance. Control valve design can have a significant impact on process response. High assembly friction (packing loads as well as sealing loads), poorly sized actuators, pneumatic positioner design/configuration/tuning and instrument air supply pressure can all impact significantly the response time of the control valve assembly.

An important parameter when looking at how fast a control valve assembly responds is dead time (T_d), which is how long it takes for a noticeable change in output after a change in command signal to a control valve. This output could be valve travel if you are interested in finding out how fast the valve itself responds, or if you are looking at the entire process response, output could be the process variable. If we look at the process variable, every process would be somewhat different, but since we are looking at control valve responses, the focus will be on travel.

Besides looking at T_d, it is important to look at a time-constant-based parameter for comparing the dynamic portion of a step response. Examples of such parameters include T_{63} or T_{86}, which is the time it takes after the control valve command signal changes for the travel to move to 63.2% or 86.5% respectively. These parameters are roughly equal to T_d plus one or two time constants in a system that is approximately first order. Figure 3 shows response time data from a 2% step change in controller setting. Again, depending on the desired measurement or comparison factor, these response time parameters could look at valve travel responses or at process variable responses.

Several specifications discuss acceptance guidelines for control valve response times. One is the EnTech Control Valve Specification[3]. It is important to note that different processes require different response times. Paying attention to control valve response times allows your process controllers to do a better job rejecting disturbances. Ask your control valve supplier to provide information regarding small- to medium-amplitude response times for assemblies.

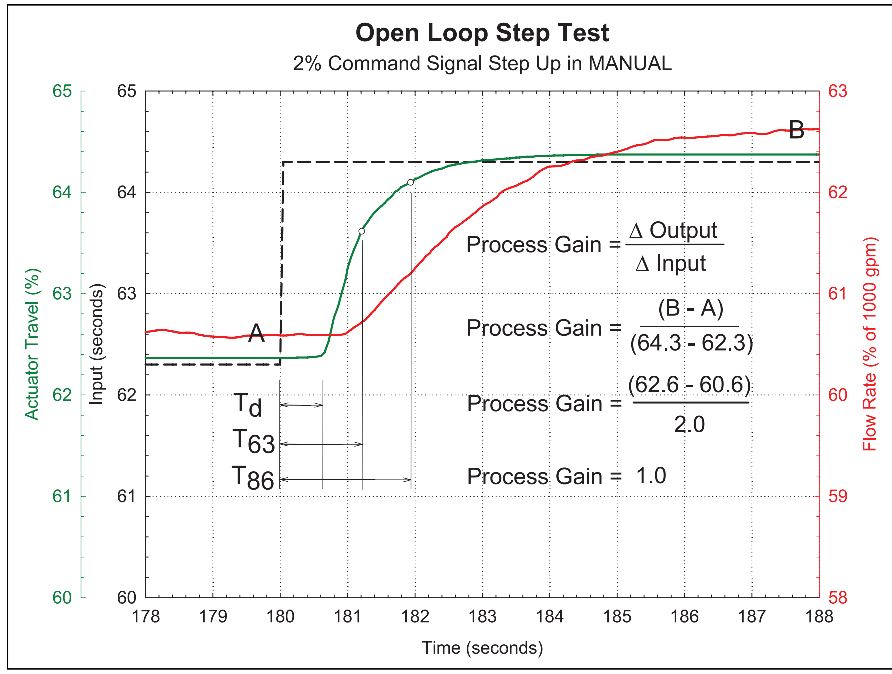

Figure 3. Open-loop step tests results showing T_d, T_{63} and T_{86} response times for a 2% input step change. The process gain (Δ process/Δ input) for this particular loop is 1.0.

3) Does this valve provide the right process gain?

The loop gain or installed process gain is a particularly important parameter to overall controllability of the process. Process gain is typically a value without dimensions that indicates the impact of control valve travel changes on the process. This value is usually determined using an open-loop (manual) bump test, but it can also be estimated by observing controller output changes from trend data. An example of determining the installed process gain is: An operator puts a control loop in manual, bumps the process output 2% and observes the response in the process variable. To determine the installed gain, that operator must determine the process response amplitude in percent of transmitter span, and divide that by the 2% output change. This means that if the PV changed by 4%, the installed process gain is 2, or if the PV changed by 1%, the installed process gain is 0.5.

Based on this example a few important factors to consider include:

- The transmitter span can have a significant impact on the installed process gain. Be careful to set a transmitter span that is reasonable based on expected loop conditions.
- The design of a control valve can have a significant impact on installed process gain. For example, a traditional butterfly valve can have very high gain at one area of travel (usually low travel) and extremely low gain at a different travel (usually high travel). A single operating condition does not describe the installed process gain for the process range, so consider the control valve's entire operating range.

For many processes, the ideal installed process gain is 1.0. This means that when the controller asks for a 2% movement, the PV changes by 2%. However, the real world is full of nonlinearities, and a gain of 1.0 over the entire travel range is very difficult to achieve. Figure 3 also shows a process gain calculation that can be made from an open-loop step test.

It is generally accepted that, when selecting a control valve for most flow and pressure processes, the goal is to size the valve for an installed process gain of 1, but that a 4:1 ratio over the range of the control valve travel is acceptable and manageable. A good rule of thumb is that the installed process gain should be within a range of 0.5 to 2, at least at the control valve's operating travel ranges. However, in such cases, the larger this range of control valve travel, the more flexible the process will be. Ask your control valve supplier for help with installed gain sizing to optimize your control range.

Include Performance in Your Specifications

Selecting a control valve that provides excellent performance based on the parameters above is not difficult. Still, it is not as straightforward as filling out the traditional sizing documents. By combining the traditional sizing methods with dynamic control valve performance requirements, you can develop a very good control valve selection process. Several industry standard specifications now exist, such as ISA SP75.25.01-2000 and the EnTech Control Valve Dynamic Specification (v3.0, 11/98). These give guidelines on testing procedures, definitions and other important aspects of control loop performance related to valve assemblies. The testing procedures mentioned are simple enough for the end user to conduct, and should also be adopted by any control valve manufacturer producing valves for performance-critical applications. The EnTech specification even has the end user determining the level of control required for a given control loop and also gives performance criteria needed to achieve that performance level.

Not all applications require a valve with the highest performance levels. However, using the traditional sizing methods, along with additional performance criteria, will change the thought processes used when purchasing control valves and yield significant improvements in plant or process efficiencies. Discussing terms like dead band, dead time, response times and installed process gain with a control valve manufacturer will give a process a much better chance of control and profitability.

Sustaining Control Valve Performance

After optimal control valve performance is achieved, how can it be maintained? A control valve behaves much like other mechanical devices. Over time, wear gradually decays control performance. If left unchecked, this decay can eventually lead to failure. Often that decay is so subtle, it is not apparent to operators or to maintenance personnel. However, if it's compared to original performance levels, the differences become obvious.

With the advent of digital valve controllers and transmitters, the ability to perform continuous, online diagnostics of critical field instruments became possible.[4,5] With these "smart" devices and the appropriate software, both the health of the equipment and the health of the process can be monitored. Users also can capture the benefits of predictive maintenance practices, which reduce overall maintenance costs while improving process availability and variability. With a loop performance audit, the optimal ***performance*** of the process can be ***sustained*** once the proper loop performance is established.

For example, Figure 4 shows the trending of online friction values, which can reveal subtle changes over time and provide the end user with insight on where the friction level may be headed. This information can give advanced notice of potential control issues, which can then be addressed at a convenient time in the maintenance cycle to prevent serious impact on the performance of the control loop. Ask your control valve manufacturer if its online diagnostics

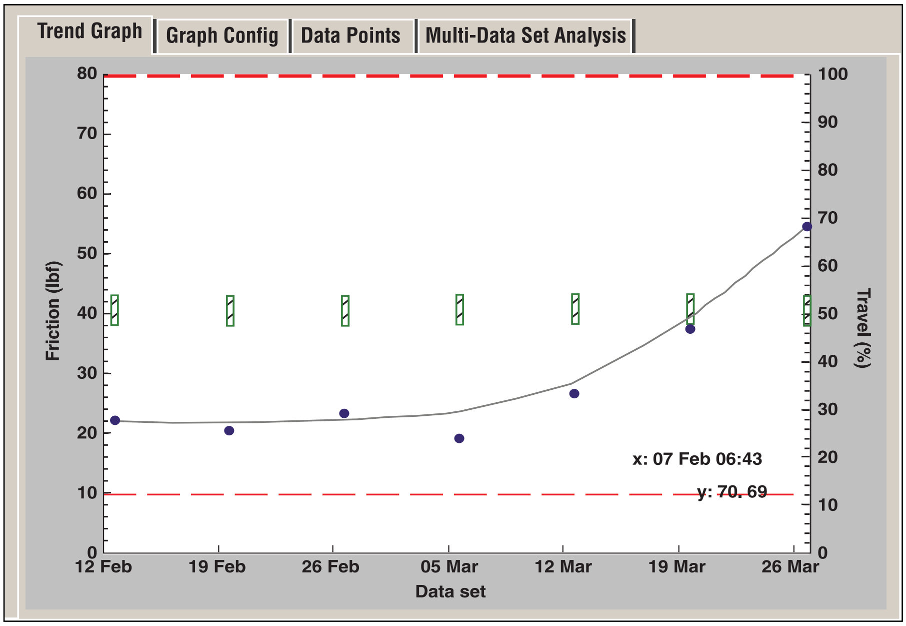

Figure 4. Modern digital control valves permit the use of proactive maintenance practices. In this example, the trending of on-line, in-service friction values in the control valve provides advanced notice of potential process control issues.

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can calculate and trend friction values and provide other online data that can move your organization to a predictive diagnostics approach to control valve maintenance.

Conclusions

Control valves are a highly engineered product and should not be treated simply as a commodity. Addressing control valve performance has a dramatic effect on process plant efficiency, overall profitability and control valve life-cycle costs. While traditional valve specifications certainly play an important role in performance, it is also crucial that valve specifications address dynamic performance characteristics to achieve true process optimization.

The performance of the control loop in the process should be the prime consideration when specifying equipment. Valve manufacturers that understand control performance can share those capabilities and show they can conform to a user's performance specifications. Finally, implementing the best online, in-service diagnostics will optimize maintenance efforts if the information is used properly. Following these steps and adopting work practices to take full advantage of the digital tools available will have a positive impact on all parameters of plant efficiency. **VM**

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