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Matching antisurge control valve performance with integrated turbomachinery control systems

Optimize plant performance by improving compressor efficiency, availability and protection

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In refineries, petrochemical and gas processing plants, such as olefins, liquefied natural gas (LNG) and gas-to-liquids plants, compressors are some of the most critical and costly pieces of equipment. For example, capital costs of a single refrigerant compressor in an LNG facility can be on the order of $50 million, and the cost of energy required to run the compressor can easily exceed the initial capital cost over the lifetime of the compressor. In addition to capital and operating costs, compressor surge, which is a fast, high-energy flow instability, can damage internal components and can lead to downtime and expensive repair bills.

Compressors represent a sizeable investment and ongoing expense. However, recent advances in digital technologies at the controller and control valve levels have led to significant improvements in compressor operation. These advances have been used to automate startup and improve running efficiencies, while reducing the risk of surge.

Surge prevention control systems. Surge is characterized by fast flow reversals through a compressor and is caused by a large-scale breakdown of flow patterns within the compressor. Surge happens at low flowrates, often when the downstream demand decreases. When flow decreases beyond a certain minimum point, flow patterns in the compressor become unstable and fluid can move back through the compressor from the high-pressure side to the low-pressure side. Flow reversals are only temporary, and forward flow is quickly re-established once the compressor discharge pressure drops.

The pattern starts over again, setting up a large-scale flow oscillation in the system. The set of operating conditions under which surge begins, at a given rotational speed, is referred to as the surge point. Because surge is a fast, high-energy phenomenon, it can introduce excessive dynamic loads on internal components, such as thrust bearings, seals and blades, as well as introduce unwanted piping vibrations. Over time, surge can introduce fatigue failures that can damage the entire compressor.

To prevent surge, a compressor can be operated in a region far removed from its surge line, although this approach is not always completely successful at eliminating surge. However, operating a compressor in this fashion means that the full capabilities of the compressor go unrealized and that a larger compressor than necessary needs to be purchased to meet throughput requirements. Compressor operations can be improved substantially, and surge protection assured, with a properly designed and well-implemented compressor control system. Such systems allow the compressor to operate more efficiently and can expand the operating conditions over which the compressor can run.

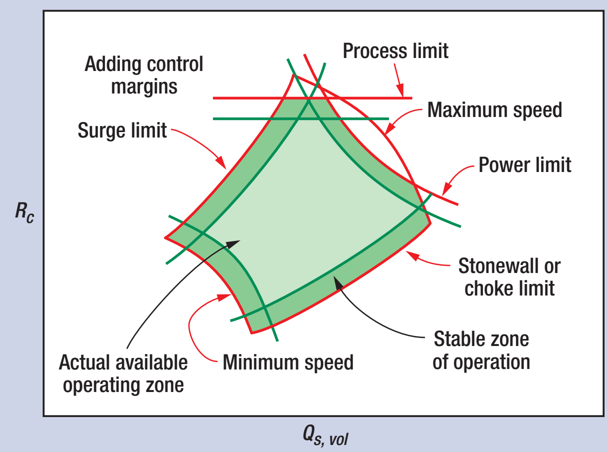

FIG. 1 Compressor map with defined operating boundaries.

Integrated turbine and compressor control. The goal of any compressor controller is to operate turbomachinery within a safe operating envelope. A typical compressor map, showing operating limitations, is illustrated in Fig. 1.

Aside from surge limits, compressor controllers must be designed to handle a number of physical limitations including choke, power, process and rotational speed limits. The task of operating a compressor within this region becomes particularly complex on multistaged compressors or when multiple compressors are operated in parallel, series or a combination.

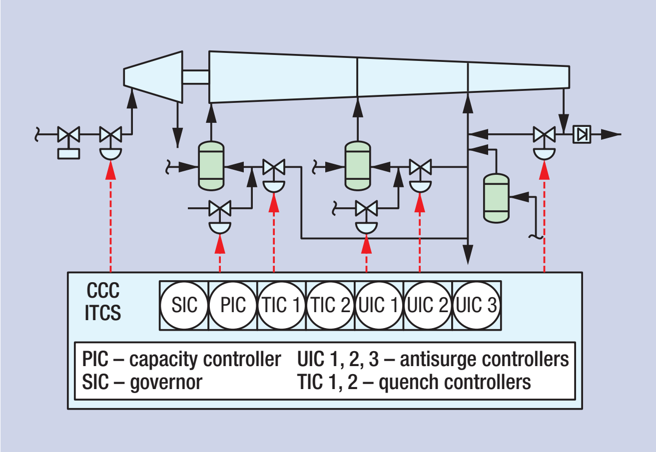

FIG. 2 Antisurge and capacity controllers have been integrated to decouple interacting loop dynamics.

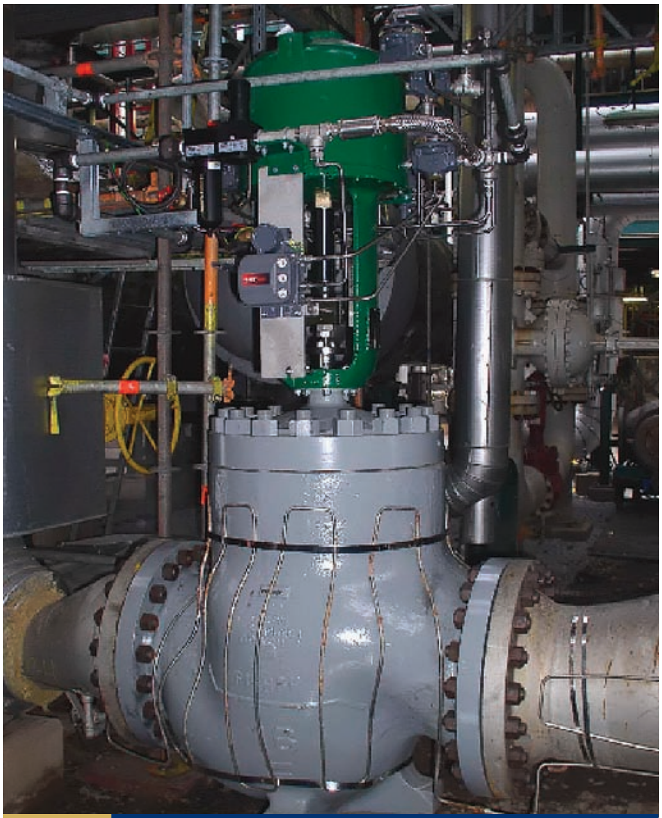

FIG. 3 This antisurge valve has been configured to meet the new performance criteria.

Integrated turbomachinery control systems (ITCSs) provide antisurge control and capacity/throughput control for compressors and governor control for turbines or other drivers. Integrating these functions reduces controllability problems, especially during reduced or part-load conditions. For example, when a plant is operating at part load, loop interactions can make the compressor difficult to control. Under these conditions, plant operators will generally put the compressor into manual control until base-load conditions are met.

To maximize operating efficiency while preventing compressor surge, an ITCS employs advanced control algorithms using adaptive open- and closed-loop techniques. Advanced constraint-control schemes (such as predictive setpoint and feed-forward, rate-of-change calculations) are important in maximizing control system performance. The ITCS must also be versatile enough to adapt to diverse turbomachinery train configurations (parallel, series or both), different driver types (fixed versus variable speed), and factors such as condensers, sidestream loads, and stage designs for various compressor types.

Fig. 2 shows an ITCS implemented for a propylene compressor in an ethylene plant. In this system, antisurge and capacity controllers have been integrated to decouple interacting loop dynamics. Without decoupling at low-flow conditions, the control actions taken by the antisurge controller can conflict with those taken by the capacity controller, causing unstable control. This, in turn, can increase the possibility of surge. This instability will generally continue until the loop is put into manual or the gains in the capacity and antisurge controllers are reduced. However, gain reduction (loop detun-

TABLE 1. Recommended antisurge control valve performance specification

Item	Criteria	Specification
1	Flow capacity	Flow of 1.8 to 2.2 times the maximum surge point flowrate
2	Full opening by positioner control in response to a step change from 20 mA to 4 mA	≤2 seconds (including dead time)
3	Full closing by positioner control in response to a step change from 4 mA to 20 mA	≤3 seconds
4	Full opening by solenoid valve trip	1 second preferred, <1.5 seconds maximum
5	Opening dead time	≤0.4 seconds
6	Large amplitude response with 10%, 20%, ..., 80% step changes from a baseline of 10%	Maximum of one overshoot per step in the opening direction ≤3% of calibrated span. Minimal overshoot in the closing direction
7	Valve movement in response to a 20% per minute ramp signal from 4 mA to 20 mA and from 20 mA to 4 mA	No stick/slip motion
8	Valve movement in response to 1% amplitude blocked sinusoid from baselines of 5% and 50% of calibrated travel	Valve stem shall respond bi-directionally
9	Terminal based linearity	≤±1%
10	Maximum control signal to initial movement off the valve seat	≤2%
11	Frequency response with a 20% peak-to-peak input signal centered around 50% of calibrated span	Gain and phase plots to be continuous with no resonant peaks. Magnitude to be <0 dB at –180° phase shift

ing) results in loss of tight control, affecting compressor output and efficiency. An ITCS alleviates this problem without having to reduce the system gains.

In multistage compressors, dynamic decoupling between the series compressor stages is important for smooth operation. For multistage compressors, opening an antisurge valve on the low-pressure stage will reduce flow to the high-pressure stages, pushing them toward surge. To protect the high-pressure stages from surge, antisurge valves around each stage must be opened in a coordinated manner to stabilize the interacting antisurge control loops.

With an ITCS combining capacity and antisurge control along with intricate loop decoupling, the role of the antisurge control valve becomes critical. Fast-acting, accurate control is required to ensure that the capacity and antisurge control functions can be properly integrated. Integrating all of these control functions requires the antisurge control valve to operate outside of the areas where traditionally intended.

Traditional criteria for antisurge valves. Antisurge control valves have been used on compressors for decades. Most antisurge valves recycle flow from the compressor outlet back to the inlet to keep a minimum amount of flow going through the compressor. Less common, but equally effective, antisurge valves can be implemented as vent valves to reduce pressure on the discharge side of the compressor. Because surge involves fast transients, antisurge valves are required to open quickly. As a result, performance specifications for antisurge valves have focused on stroking time, which is the time it takes for the control valve to move from a fully closed to a fully open position.

Stroking time is a relevant criterion for quantifying the speed of response of a valve under extreme conditions. However, antisurge valves are rarely used in this fashion, especially when antisurge controllers are in place. Fully opening an antisurge valve causes excessive flow to be recycled or vented, significantly reducing compressor efficiency. Moreover, this type of operation often protects the compressor at the expense of introducing large upsets throughout the entire process. Recent advances in antisurge controllers have meant that antisurge valves are used predominantly as throttling devices.

Although exceptions exist, antisurge valves are typically required to open in less than two seconds. Occasionally, stroking time will be specified in the closing direction, although the requirement is generally very loose and varies considerably from project to project. It would not be uncommon, for example, to see a requirement to have the valve stroke closed in less than 10 seconds.

Clearly, stroking time is an important factor when specifying antisurge valve performance. However, when stroking time is the only performance criterion, actuator accessories are often selected and adjusted to meet those requirements, usually at the expense of controllability and overall robustness. The faster the valve is required to move, the more apparent this tradeoff becomes. In turn, this impacts the ability of the ITCS to react quickly to rapidly changing operating conditions. To fully realize the advances in compressor controls that have been made at the systems level, other factors at the valve level need to be considered.

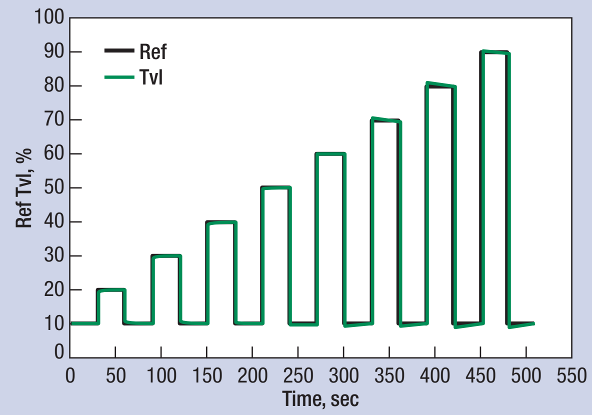

FIG. 4 Typical large-step response of an antisurge valve with robust dynamic performance.

New dynamic performance criteria. Realistic guidelines have been developed in the past few years to ensure that antisurge valves meet static, dynamic, and servo robustness requirements necessary for smooth startup and reliable operation. These criteria are summarized in Table 1. Note that certain applications may have additional requirements or tighter constraints.

Most of the criteria listed, such as stroking time in the opening direction, are straightforward, if not traditional. A few items, though, need additional explanation. Perhaps the first item to take note of is stroking time in the closing direction, item 3, which has been specified to be approximately equal to that in the opening direction. This specification has been put in place to prevent the control valve from being configured with widely asymmetric dynamics. If the control valve dynamics vary considerably with respect to the direction of valve travel, tuning the valve positioner and getting the overall desired response can be difficult. For the same reasons, asymmetric dynamics can present tuning problems at the loop level. By configuring the accessories so that the dynamics are roughly symmetric, performance improvements are possible both at the valve and loop levels.

Large amplitude step response, as defined by item 6, is a criterion that has not traditionally been applied to antisurge valves. When a compressor's operating point approaches surge, open-loop control algorithms in the ITCS open the valve quickly and move the compressor to a more stable operating point. This test, which starts from a baseline of 10%, is used to ensure that the response is fast and precise in both directions, and that there will be no surprises or unexpected transients if the valve is called on to move quickly.

Frequency response testing, item 11, is a traditional method of evaluating positioner performance and is often done during product development. Once a product has been released to manufacturing, additional frequency response testing is generally not required. However, many antisurge valves, especially large ones, are built with custom pneumatics and configured with an array of accessories—such as volume boosters—that introduce unique dynamics into the system. Frequency response testing, which uses a swept sinusoid test signal, is particularly helpful in quantifying robust dynamics and identifying "bright spots" in the response that would not otherwise be picked up with a step test. To help identify problems, the test signal amplitude must be carefully chosen to make sure that actuator accessories are fully engaged during the test.

Factory acceptance tests (FATs) based on the criteria listed in Table 1 have proven to be useful in ensuring the antisurge valve responds well and that the dynamic performance is very good. Fig. 3 shows an antisurge valve that was designed to meet these criteria and Fig. 4 shows a sample response to large amplitude steps. When antisurge valves are designed and tested to these criteria, dynamic response and robustness are generally very good, making field adjustments unnecessary. **HP**

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