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Design innovations offered in compressor surge-relief valves

Examining recycle-valve options may help achieve a flexible control system without increasing costs

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Continuing advances in surge-relief valve design for gas-transmission centrifugal compressors raise the prospect that a wise valve choice can help engineers pay for the rest of an advanced surge-control system without exceeding budget.

Avoiding and escaping surge events without upsets or chronic inefficiency is a major aspect of compressor-control system design, procurement and operation. However, most discussions of the subject are limited to the control strategy and controller hardware. Too often, other elements of the surge-control system are taken for granted—especially the recycle or surge-relief valve, which is the final control element.

Ironically, for large gas-transmission compressors, the valve is by far the most expensive item in the surge-control system, possibly costing well into six figures. Historically, these valves have been globe style, often with noise-attenuating trim. Today, there are high-performance rotary valves available.

Basic surge concepts. First, a fresh look at basic concepts is in order. The surge problem is inherent in dynamic compressors—centrifugal and axial, as distinguished from positive-displacement types. The usual explanation is based on a compressor's performance curve of differential pressure head vs. inlet flow at a fixed speed for the given gas composition and inlet temperature.

Here, imagine a gas-turbine-powered pipe line compressor running at a speed which is controlled to maintain constant downstream pressure. There is a different curve for each speed, altogether forming the compressor's "wheel map." However, speed changes of such a heavy rotating mass require a substantial lag time which may be as long as several minutes. Therefore, on a shorter term, speed may be considered constant. The head imposed on the compressor varies independently as a result of rapidly changing downstream demand, so that flow is a function of head.

Suppose there is a steady state at Point A and there comes a sudden decrease in gas demand, experienced by the compressor as a head increase (Fig. 1). At constant speed, the compressor cannot keep up as much flow against a higher pressure, so flow goes down toward Point B as reflected in the curve.

To visualize the physical mechanism at this point, imagine the compressor as a single centrifugal stage. The coupling of the impeller to the load, meaning the gas being compressed against the pressure head, depends on maintaining flow through the impeller. As long as there is appreciable forward flow, the impeller keeps its grip on the gas, so to speak. That is, energy is transferred from the impeller to the gas in the form of increased velocity—which is converted to pressure head as the gas slows down again in the diffuser passage. This coupling depends on maintaining some minimal amount of forward flow.

Now suppose downstream demand is progressively reduced. The head increases to the maximum achievable by the compressor at that speed, shown as Point B. This is called the surge point. The locus of the surge point for all compressor speeds, above and below the characteristic curve in question, is called the surge line. The flow here has

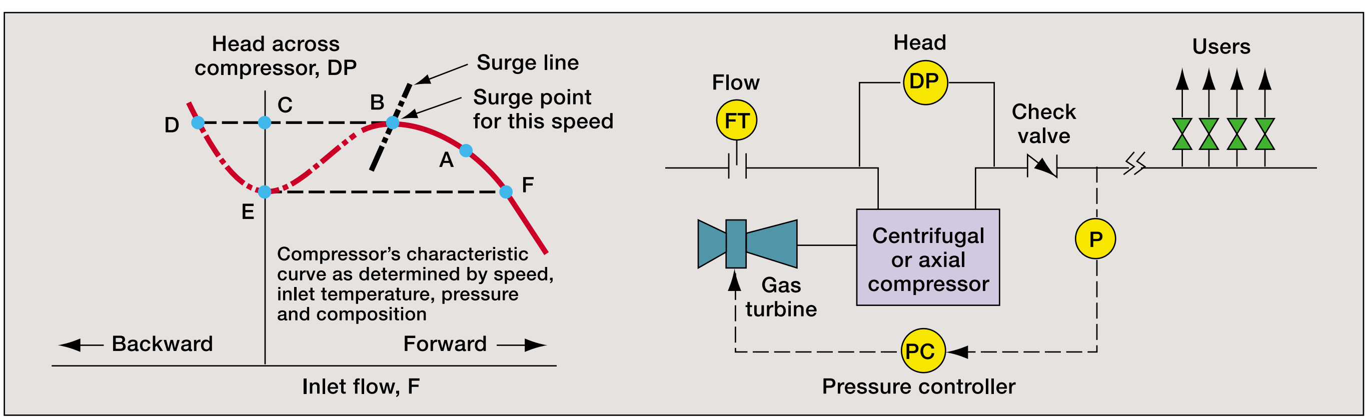

Fig. 1. Centrifugal-compressor performance curve showing key points in surge event and a simplified piping and instrument diagram of a compressor installation.

fallen to the least that the impeller can handle without losing its grip on the gas. A further decrease in downstream demand no longer results in increased head. Instead, the impeller suddenly loses its effectiveness as a motive element and becomes decoupled from the load. Perhaps in as quickly as a fraction of a second, gas within the impeller quits being impelled forward and begins simply spinning around with the impeller. The effect is like an automobile tire skidding, or an airplane wing stalling. The impeller is no longer functioning as an impeller. As the pipe line gas rapidly coasts to a stop, the operating point falls to zero flow at Point C.

But it doesn't pause there. Gas previously compressed in the volume behind the downstream check valve begins leaking backward through the interstices around the impeller—even through the impeller itself, because the head it can create by centrifugal force alone is considerably lower than it had built up by velocity. On the graph, the beginning of this brief flow reversal is shown as a continuation of the jump past Point C to Point D, lying on a theoretical extension of the normal characteristic curve into negative flow. The extension is shown as a broken line.

Then, within a short time—which may be a second or so—the head bleeds down to the minimum that the decoupled impeller can maintain purely by centrifugal force, at Point E. There, the impeller suddenly picks up the load again, throwing gas forward until the operating point hits Point F on the normal characteristic curve. If line flow is still restricted below the surge point for the given speed, the cycle repeats at regular intervals, typically on the order of one second.

Preventing surge. Unrelieved, repeated surging of a large compressor is a fearsome thing which ends in catastrophic damage. Because of surge controls and emergency shutdown systems, few operators today have witnessed it. Even one cycle can have undesirable consequences in terms of upsetting operations, altering internal clearances and overstressing seals. The cost of replacing seals in a 3,000-hp compressor can easily exceed $20,000. It is far better to take action before the compressor reaches the surge point, because—by then—nothing can prevent one cycle. That preventive action is provided by a dedicated surge-control system, separate from the compressor's other controls because of response-speed requirements (Fig. 2).

Of course, those other controls attempt to stay reasonably clear of the surge line, but only on a relatively long time horizon. Surge events tend to be transient disturbances. It would be both impractical and inefficient to slow and then accelerate a large turbine-driven compressor as every potential surge comes and goes. If the compressor has variable inlet vanes, the control system typically manipulates them to optimize fuel efficiency, not to dodge every threat of a surge.

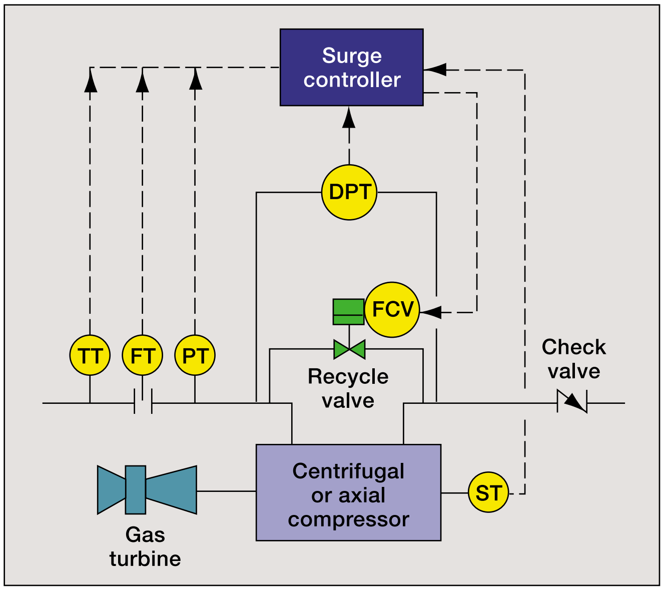

Fig. 2. Simplified piping and instrument (P&I) diagram of compressor installation with surge-control system.

Instead, the action provided by the surge-control system is to open the recycle valve to an appropriate degree. In the past, when the most sophisticated systems were based on analog PI (proportional and integral action) ratio controllers, the dominant strategy was to begin cracking the recycle valve well before the operating point reached the surge line. This led to prolonged periods of operation with appreciable recycling and attendant waste of compressor fuel as well as capacity.

Today's philosophy is to avoid opening the recycle valve until absolutely necessary, move away from surge as quickly as possible, and then shut the valve again.

The dedicated digital controller which is the heart of an advanced surge-control system, receives inputs:

- Inlet pressure
- Temperature
- Flow
- Head across the compressor
- Compressor speed.

If gas composition is subject to appreciable change, an indication of that variable, such as density, may be included. Characteristic curves for various temperatures—and, if applicable, various inlet pressures and compositions—are available to the control algorithm as equations or look-up tables.

The advanced controller's reaction time may be well under 50 milliseconds. The algorithm attempts to duplicate the action of an experienced human operator having an eye on the instruments, a hand on the manual valve control and a wish to minimize energy waste resulting from prolonged recycling. This requires a combination of closed-loop (feedback) and open-loop (prearranged) control. The system keeps the recycle valve closed as long as the operating point is well away from the known surge line. As the operating point approaches the surge line, the control algorithm becomes more sensitive to its motion. Getting too close or moving too suddenly toward the line causes the valve to open by an appropriate amount to halt progress toward surge smoothly without triggering control oscillations. Should extraneous circumstances continue to force the operating point toward the surge line, the recycle valve opens all the way. If a load reduction persists, then after a relatively long time (perhaps a few minutes), speed typically is reduced by the compressor control system.

Consequently, unless the reduced flow is beneath the capability of the compressor, the operating point and the surge point move away from each other, and the surge controller gradually shuts the recycle valve. The compressor has kept a firm grip on the gas.

Valve requirements. The main requirements of a compressor recycle valve are listed in Table 1. These requirements are also more than adequate for the valve's other employment, which is unloading the compressor during startup and shutdown.

First and most obviously, the valve must be able to stroke wide open very quickly, typically within three seconds or less. The faster it can open, the more likely that it will catch and prevent an impending surge in time. For a valve as big as 24-in. or more, this is no small feat. One implication is low friction in the valve seals and stem or shaft. Another is plenty of force in the actuator—which is assumed to be either a fail-open, spring-opposed pneumatic diaphragm, or a double-acting pneumatic piston.

Required actuator accessories could include a large, solenoid-operated vent valve to speed the unloading of the "closing" side of the actuator and, in the case of a piston actuator, a volume-booster relay on the "opening" side. In addition, many users favor quick closing as well as quick opening. That requires a booster on a spring-and-diaphragm actuator or a second booster on the "closing" side of a piston actuator.

Second and equally obvious, the valve should have large capacity. In some cases, the valve's nominal size will be as large as the pipe line itself. Some surge-control experts size the valve for about twice the minimum flow capacity required simply for stable operation under full recycle condition, as in startup and shutdown. That minimum size typically corresponds to the flow coefficient for a point on the compressor's maximum performance curve which is comfortably distant from the surge line. This is big enough to prevent a rapidly impending surge when, for instance, line flow is suddenly blocked entirely at the same time that compressor speed is falling. It not only can halt the motion of the operating point toward the surge line, but also move it quickly away.

On the other hand, if the valve's capacity is too large, it will be susceptible to unstable control in throttling conditions. Furthermore, it may allow the compressor to reach the choke or stonewall region when wide open, leading to shutdown and possible damage.

A third requirement is noise reduction. Because of high flowrates through large pressure drops—up to 500 psi—noise levels inside compressor bypass valves are potentially the highest encountered by a control valve. At its peak, when the valve is throttling part-way open to stay away from the surge line, noise intensity can reach damaging levels above 110 decibels unless attenuation measures are provided. These provisions may include source treatment, in terms of special valve features, and path treatment, such as acoustic insulation and silencers. Although insulation helps reduce personnel noise exposure, it does not prevent acoustic damage to the valve, pipe and compressor. An appropriate silencer (resembling an automobile exhaust muffler) is a large, expensive item. Therefore it is far better to select a valve having inherent low-noise characteristics.

Table 1. Typical requirements of a surge-relief valve

1. Extremely fast stroking speed when opening (typically under 3 seconds)
2. High capacity (double the minimum for startup and shutdown)
3. Extreme noise abatement provisions (up to 30 decibels)
4. Very stable throttling control.

Finally, on top of all the foregoing rigorous requirements, the recycle valve must be capable of accurate throttling control. In most surge events, the necessity for full opening is avoided by sophisticated controller action. Typically, the valve is required to stroke open quickly and accurately to a position that will arrest the impending surge, then throttle gradually back toward the closed position. There are few applications where throttling control-valve accuracy and stability are more crucial. Position overshoot or delay in valve movement can tip the compressor over into surge. This critical factor is often overlooked in valve selection and is even more frequently not thoroughly understood.

The throttling control valve must be viewed as an integral assembly comprised of several components. These components are the valve itself, the actuator, a positioner and (typically) a transducer. These components, when properly matched and applied, should form a high-performance assembly capable of providing the required accurate throttling control.

The best measurement of the valve assembly's capabilities is the change in flow resulting from a change in input signal. Consider three rotary products (Valves A, B and C) with spring-and-diaphragm actuators, positioners and transducers. Valves B and C do not respond to input step changes of less than 2%, while Valve A responds to 0.5% changes in the input signal.

A surge-control system using a valve with the responsiveness of Valve A could move its operating point closer to the surge line. This could have significant economic impact. Improved surge protection, of which the valve is a critical component, has been reported to result in annual energy savings of more than $250,000 for a 4,500-hp compressor. Of course, actual realized savings depend on numerous variables involved in the compressor's operation.

Another critical factor in throttling control is the valve characteristic. Historically, it has been generally agreed that linear is the preferred characteristic versus quick-opening or equal-percentage. Today's digital controllers can easily compensate for variations from the linear characteristic.

Another consideration is the amount of overall pressure drop that is taken by the piping system relative to the control valve. If the piping system takes too large a percentage of the pressure drop (typically more than 30%), the system characteristic can become quick opening. A quick-opening characteristic can result in poor throttling control. The goal is to have the valve determine the system characteristic. The use of some form of equal-percentage characteristic, coupled with the piping-system pressure drop, results in a system that can provide accurate throttling control.

Sliding stem, rotary. For years, the typical recycle valve for a large compressor was a cage-guided type with fabricated angle body which provided desirable long plug travel. While well-suited for large flows and noise-attenuating features, these valves in 24-in. size stand 12 to 14 ft tall, and the angle bodies can lead to some convoluted piping arrangements.

For applications with smaller flow requirements, typically up to 16 in., certain cage-guided globe bodies—cast rather than fabricated—have proved effective. These valves can be versatile since some can be left in the line while servicing trim or replacing it to change flow characteristic, capacity, or noise-reduction capability.

In today's applications, noise con-

Fig. 3. A new design in large ball valves for surge relief, the Fisher Design V260, incorporates a noise-attenuating device for up to a 25-decibel reduction.

trol is the most challenging technical or design concern. Noise generation in a control valve depends on several variables such as inlet pressure, pressure drop, flowrate, outlet pressure and pipe-wall attenuation. It is highly sensitive to flow-path geometry.

Noise can be reduced by using numerous small flow restrictions rather than one or a few large ones. The prevailing approach in sliding-stem valves is to use a cage-guided design with numerous small holes drilled through the wall of the cylindrical cage. At higher pressure drops, the holes are spaced farther apart to reduce interaction between jets from adjacent holes. A baffle resembling the cage may be mounted concentrically around it to weaken jet interactions and stage the pressure drop. In extreme cases, a second concentric perforated baffle may be used, providing a third stage of pressure drop that helps achieve an overall noise attenuation—as much as 30 decibels.

Noise-control trim of this general type also meets the other three main requirements of a compressor recycle valve. The cylindrical plug sliding inside the cage is pressure-balanced by one or more passages next to the stem, so that relatively little actuator force is required to overcome the differential pressure across the valve. Throttling is achieved by moving the plug to uncover more or fewer holes, an inherently stable process which is not susceptible to chattering or buffeting. Fisher Controls can address the capacity challenge by special patterns of hole spacing and diameters through the cage. The result is a potential reduction of required body size.

While the control-valve industry has achieved steady improvements in sliding-stem valves for compressor recycle applications, these innovations have mainly consisted of incremental refinements. Rotary valves have changed more dramatically. Improvements in ball and disk valve technologies over the past 20 years have propelled these devices into more applications. Until recently, difficulties with noise abatement and stable throttling have kept rotaries out of large, high-pressure compressor recycle applications. However, a method now has been found to apply high-performance, full-bore ball valves in this difficult service, represented by Fisher's Design V260, first of its type (Fig. 3).

In essence, these new devices apply the concept of the specially drilled noise-abatement cage to a compact, heavy-duty ball valve of proven quality and performance. A perforated dome, spanning the entire valve passage and contoured to fit the ball very closely, is mounted against the downstream side of the ball. As the ball is rotated through 90 degrees, from fully closed to fully open, its cylindrical passage uncovers more and more of the holes in the dome. For compressor recycle service, these openings are sized and spaced to provide the desired stable flow characteristic, coupled with much higher capacity than same-size sliding-stem valves. Noise reductions up to about 25 decibels are achievable by this method. Stroking speed is enhanced by low-friction seals and shaft packing. Stable throttling control is further promoted by tight mechanical linkages, including splined attachment of the shaft to the ball and crank.

The final selection of a recycle valve for a large compressor depends on many details of the particular application—especially the line pressure, the pressure drop across the valve and the capacity required. A sliding-stem type may be favored if the head is higher, while a rotary type may be more attractive if the capacity requirement is larger. The lowest bid may not be the optimum choice due to uncertainties such as controllability and noise. Innovations make the decision more challenging, but the results, in terms of economy and performance, are definitely improving year by year. ■

The author

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