Surge Detection And Surge Control Systems For Centrifugal Compressors -- Part 2

Fundamentals include dynamic centrifugal compressor map, operating envelope, surge cycle

BY NEETIN GHAIAS AND TODD REITSMA

Recycle Piping Considerations

Piping systems around the compressor must be designed to minimize the volume in the compressor discharge - between the compressor discharge flange, the inlet of the anti-surge valve and the non-return (check) valve - as much as possible. Large gas volumes act as energy storage, slowing recycle response times and increasing the risk of damage to the compressor.

Often the degree of damage to the compressor during surge depends on the volume of gas in the compressor discharge. The relationship is pretty straightforward: the higher the volume, the longer it will take to pass back through the compressor and consequently, the greater the risk of damage to the compressor internals. The most effective way to prevent or stop a surge cycle is a fast reduction in discharge pressure. With that in mind, below are some design practices for a recycle piping system.

Minimize the volume in the compressor discharge by locating the recycle takeoff as close to the discharge flange as possible, installing a check valve directly after the recycle takeoff and locating the recycle valve close to the recycle takeoff. If possible, the recycle valve should be located within five pipe diameters from recycle takeoff. Figure 6 highlights the discharge volume that needs to be minimized.

Noise and turbulence of the gas flow at the recycle valve should be assessed before finalizing its location in the recycle loop.

Check valves should be of damped opening type. If check valve is installed upstream of recycle valve take-off, it should be nonslam type. Recycle coolers installed downstream of the anti-surge valve are preferred to minimize the discharge volume. A cooler in the recycle loop allows continuous recycle operation when needed. Compressor discharge coolers are used at some installations to save the cost of a dedicated recycle cooler. This, however, adds significant discharge volume to the system, which compromises surge protection.

Before deciding to install a cooler upstream of the antisurge valve, hydrocarbon and water dew points should be checked to ensure there is no potential for two-phase flow through the valve that can cause erosion of the valve seat.

Liquid condensate must be removed before it enters the compressor suction by installing a suction knockout drum downstream of the recycle cooler and upstream of the compressor suction. The knockout drum should be sized to handle process flow and both cold and hot recycle flows if a hot gas bypass valve (HGBV) is installed.

As shown in Figure 7, an interstage cooler is sometimes used as a recycle cooler for multisection...
compressors to save capital and installation costs. This configuration, however, severely compromises surge protection for the low-pressure case, particularly when the high-pressure case goes into recycle mode and rapidly increases the discharge pressure on the low-pressure case. This arrangement can lead to adverse control interactions. Independent recycle loops should be used for multisection compressors and multicasing compressor trains. Figure 8 shows an improved piping design.

Recycle flow should enter downstream of the suction throttle valve, inside suction block valve, upstream of the inlet flow element and upstream of the suction knockout drum. Recycle flow can be allowed to enter upstream of the suction throttle valve for electric motor-driven compressors to help limit load at start up.

If the throttle valve is located within the recycle loop, a minimum stop should be provided on the suction throttle valve to ensure that adequate recycle flow can pass through the compressor during the recycle operation. Restrictions in the recycle path, such as those shown in Figure 9, can compromise the anti-surge control.

**Anti-Surge Valve Requirements**

To ensure compressor and process safety, the anti-surge valve must be large enough to prevent the compressor from surging even if all other flow paths are blocked. However, the valve must also provide responsive control under less severe conditions. An oversized valve may lead to process instabilities due to the relatively large effect on compressor flow with a relatively small control input. Oversizing the valve should be avoided. An effective anti-surge control system will generally be able to operate with a surge margin of 10% of the surge line flow. The system will also provide smooth control at the surge control line, while also having the additional capacity to step the valve open to prevent compressor surge due to rapid drops in flow caused by upsets in the process.

In summary, the anti-surge valve must be sized to achieve the following objectives:

- Provide protection from surge during the worst possible operating scenarios.
- Provide flow that is greater than steady-state operation on the surge control line.
- Prevent operation of the compressor in the stonewall (choke) region.
- Avoid introducing process stability issues.
- Linear characteristics are preferred for anti-surge valve trim.
- Larger anti-surge valves may provide a better response to equalize pressure faster, but can have poor controllability for throttling purposes during process control operation. If the recycle valve must operate in throttling mode, then it may be necessary to install a small parallel valve to improve the control at low recycle-throttling rates. In parallel valve applications, the antisurge controller can be set up for split-range output.

- Valve overshoot should not exceed roughly 10% of the step change in controller output in both opening and closing directions.
- Anti-surge valve opening time from fully closed to at least 95% open should be two seconds or less. Valve closing time should not be more than two to three times the opening time. Overshoot should not be greater than 10% in either direction and hysteresis should be less than 0.2 seconds on change of direction.
- A "cushioning" feature should be implemented in the actuation system (typically in the last 5% of the full stroke) to prevent the actuator from "slamming" against the mechanical stops at the end of the stroke, which could potentially damage the actuator or the valve.
- Anti-surge valve noise should be limited to 85 dB(A) at 3 ft. (1 m). Noise abatement trim may be required for some valves to achieve noise reduction. Whisper trim requires clean gas to avoid plugging. If process gas is not clean, downstream diffusion and start-up trash trim should be considered.

In addition to having proper sizing, the valve actuation system must be able to make the valve respond quickly and accurately to achieve these objectives.

Experience suggests a properly sized anti-surge valve should be able to provide 100% of the compressor’s minimum flow requirement at roughly 50% open. At maximum opening, it should be able to provide twice the steady-state minimum flow requirement. By applying a 10% tolerance, the result is a valve sizing of $C_{v_{max}} = 1.8$ to $2.2$ times $C_v$, at Surge Flow.
The anti-surge control valve actuation system typically includes such components as:

- A digital positioner that provides for both slow and fast command signals of the anti-surge controller.
- Devices like volume boosters that amplify the action of the motive fluid of the actuator in both the opening and closing directions.
- A quick-dump device (e.g., solenoid valve) that permits the quick opening of the anti-surge valve in response to an emergency shutdown (ESD) signal that may be generated outside of the anti-surge controller.

Valve position feedback is a very important feature to include in the system. Alarms can be generated when there is significant error between the valve position and the controller command. Valve position data, with respect to the controller output, can also be very useful information during critical event troubleshooting.

HGBVs are also commonly used as part of the overall anti-surge control strategy and a secondary objective: to prevent formation of liquids on the compressor suction side due to regular or continuous use of cold recycle. In cases where the HGBV and the cold-recycle valve operate together to prevent surge, the combined $C_{\text{max}}$ of the valves needs to be considered in the individual valve sizing. If the combined valves are oversized, there is a greater risk of operating the compressor in choke flow conditions. The HGBV line should return to enter downstream of the suction throttle valve, inside the suction block valve, upstream inlet flow element, and upstream of the suction knockout vessel (drum).

For initial sizing of the HGBV loop, 100% of recycle flow should be used. Final line size and the HGBV valve sizes are usually not available until after completing a dynamic simulation study. To minimize reconstruction of the compressor-piping layout, the HGBV line should be sized in the early stage of engineering and incorporated in the piping model. Line and valve sizes must be verified after completion of the dynamic simulation study.

HGBVs used for an overall anti-surge control strategy are of modulating type, while HGBVs for an ESD application are only of the quick-acting type (either open or closed).

Figure 10 shows the general arrangement of a cold recycle loop together with a HGBV loop for a centrifugal compressor application.