Solution For Compressor Anti-Surge Control
The Triconex® methodology

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1. Introduction - Compressor Surge

Turbine-driven compressors are pervasive in refining, petrochemical and power plants, and their continuous, stable operation is critical to the processes they support. Compressor surge, or cycling, can be a significant problem in process plants by degrading product quality, lowering equipment integrity, and reducing efficiencies. Precipitated by insufficient flow, surge most often occurs when a downstream valve closes, causing the discharge pressure to increase. The condition occurs when the internal pressure (head) produced by the compressor is less than the pressure (head) produced by the process. If flow reverses (back through the compressor), the load is suddenly lost and the compressor can be damaged; conversely, stress to the axis and bearings returns rapidly upon forward flow. Outlining the process of surging, the key events are as follows:

1. Pressure ratio rising due to the loss of load
2. Flow Reversal – load is immediately lost causing a thrust
3. Pressure ratio decreases as flow reverses
4. Forward flow resumes - load immediately returns again causing a thrust
5. Cycle repeats if corrective action is not taken

If the instantaneous force is sufficient, it can cause an axial shift of the rotor wiping seals. At minimum, continuous surging will certainly cause the compressor to overheat; at worst, equipment can be damaged and the process experiences a major upset. Figure 1 displays the major parts of a centrifugal compressor. The compressor consists of impellers mounted on a rotor. The gas is drawn into the impellers and exits at a high velocity into the diffuser section where the gas then makes a return bend and enters the next impeller. It is in the diffuser section where velocity is converted to a rise in pressure.

Figure 2 describes the various states of a typical compressor with the surge line providing the defining difference between stable and unstable operations. The surge line lies on the maximum point of each characteristic curve. The region to the left of this line is unstable and where surge occurs; while the region to the right is the desired area of stable compressor operation. Figure 3 depicts the dynamic instability of a surge condition using the four states of surge referenced above. Under the right circumstances, the compressor can go from stable operation to surge in less than 50 milliseconds. A complete surge cycle will run from 1.5 to 3 seconds depending on the size of the compressor and piping volumes (1).
Compressors experience surge because the compressor performance control strategy, valve failure, loss of steam speed), and instrumentation are not properly configured and/or positioned. An effective anti-surge control project will consider all these elements and, potentially, apply an array of technologies, including dynamic modeling and fast-acting, redundant control hardware. The Invensys Turbomachinery consultants have extensive experience in anti-surge control projects, highlights of which are shared in the following sections.

2. The keys to effective surge control

A surge controller must accurately predict when and at what conditions a surge will occur. There are key operational requirements that must be met for an anti-surge control package to be effective. In general, the solution must be stable and reliable, keep energy costs to a minimum, and compliment the overall performance objectives of the compressor. A project to upgrade the compressor and associated process control system(s) will have the following general objectives:

- Protect Compressor from Surge
- Maintain Stable Process Control
- Minimize Energy Cost
- Reliable Operation

Control of the performance of the compressor and anti-surge control strategies interact, which must be accounted for in implementing the anti-surge controller. If, for instance, the anti-surge value is sticky, step-changes will occur in the process flow that will degrade performance control. Likewise, the stability of the performance control affects the surge controller. Invensys applies a set of rigorous criteria to ensure success of an anti-surge project, including the following:

- Performance control must be smooth and stable while the recycle valve is open
- Compressor must be able to start and shut down without surging
Control valves must be fast-acting, yet able to move in small increments
Transmitters must report the correct process conditions over the full range of startup and running
Flow meter sensing lines must be impervious to condensation resulting from temperature changes
Recycling or venting must be kept to a minimum where applicable

When met, the above criteria will maintain process stability while maximizing reliability.

3. Methodology for anti-surge control

Most of the current surge controllers utilize a reduction in compressor head as a function of the volume flow through the compressor, as depicted in Figure 4. The three most common methods of controlling against surge conditions are provided in Table 5. Each of these traditional methods is relatively simple to implement but each has disadvantages, as shown below.

<table>
<thead>
<tr>
<th>Traditional Method</th>
<th>Control Strategy</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum flow control</td>
<td>A simple flow controller is used with a setpoint fixed at a minimum value to recycle or vent flow to maintain compressor flow</td>
<td>Inexpensive and easy to understand</td>
<td>May not prevent surge at abnormal conditions. The operating point may be distant from the surge line resulting in unnecessary recycle and lower efficiencies</td>
</tr>
<tr>
<td>Maximum pressure control</td>
<td>A simple pressure controller is used with a setpoint fixed at a maximum value to recycle or vent flow to relieve high pressure</td>
<td>Inexpensive and easy to understand</td>
<td>May not prevent surge at low flow. Also has the same inefficiency problems of the minimum flow method</td>
</tr>
<tr>
<td>Pressure rise method</td>
<td>Uses the $\Delta P$ across the compressor (discharge pressure - suction pressure) against the $\Delta P$ across the orifice</td>
<td>Works well when the surge line is linear or the suction pressure is reasonably constant</td>
<td>Should not be used if suction pressure is not constant</td>
</tr>
</tbody>
</table>

Table 5 - Traditional methods for anti-surge control
In contrast to these methods, the Triconex surge control strategy uses a compressor Pressure Ratio relationship \( \frac{P_{d}}{P_{s}} \) against the dp across the orifice, which compensates for changes in suction pressure. Using a head-producing flow meter (orifice or venturi) avoids having to calculate molecular weight and compressibility of the fluid. The Universal Surge Line, shown in Figure 6, does not change with molecular weight or compressibility of the fluid. The method enables the curve for any compressor to be accurately followed with a prescribed safety margin. Using this approach, surge is prevented for all possible positions of the operating point of the compressor while energy is saved by reducing recycle or vent, thereby increasing operating efficiency.

The Triconex algorithm uses either the predicted/tested surge curves supplied by the turbine manufacturer or derived through testing the compressor in the field. Shown in Figure 6, \( \frac{P_{d}}{P_{s}} \) is directly determined from pressure transmitters at the compressor suction and discharge.

The anti-surge controller, critical for stable performance control, is typically tuned for slow response when the operating point is close to the control line. More aggressive action becomes necessary to prevent a surge as the operating point approaches the surge line. When it is necessary to operate near the surge line, it is better to have a conservative surge line, which means the control system will apply aggressive action earlier. Some control strategies will employ high gain, while others will setpoint the control valve to a safe operating position. The anti-surge controller will also likely employ a Maximum Valve Closing Rate and Adaptive PID Tuning.

When designing the anti-surge controller, the Invensys implementation team will seek to know...

- Is the recycle valve needed to assist the performance controller for turndown?
- Is the recycle value required to protect a section from over pressure to avoid lifting a relief valve?
- Will the recycle value be used to protect the compressor from low suction pressure?
- Are performance controller limits required to avoid surge?

If the answer to the last question is yes, it may be necessary to decouple anti-surge and performance controls. As downstream units, such as furnaces, are taken offline the performance controller will lower the speed setpoint to maintain suction or discharge pressure. Decoupling is accomplished by the performance controller assuming control of the recycle valve to maintain suction pressure such that speed can be slowly reduced toward the control line.

Figure 6 - Universal line map coordinates
4. Modeling compressor and controls for surge control

Process conditions can fall outside allowable operational limits either during the compressor startup sequence or during upsets occurring in the process. Several factors contribute to compressors working below optimum: incorrect design criteria, improper calibration/commissioning or overly conservative set points (due to poor control schemes) to name a few. In some cases, driver or coupling torque levels can exceed specified limits. Low or high pressure conditions may also result from transients in the pressure profile during startup or during upsets. A dynamic, high-fidelity model of the compressor and the associated process control system reveals insights into the compressor and associated controls strategy. A model, therefore, enables the system to be optimized, increasing efficiency, reliability and overall compressor safety.

Invensys Operations Management offers a dynamic simulator comprised of DYNSIM™ and TRISIM Plus™, the later emulating Triconex control applications. DYNSIM is a leading dynamic simulator used for design, assessment and training. Once a model of the compressor/process is built in DYNSIM, the Dynamic Simulation Suite (DSS) then effectively and accurately replicates the actions of the Triconex control system. Once implemented, the integrated dynamic simulator will demonstrate how the control system can...

- Prevent the compressor from operating within surge regions,
- Maintain compressor torque within acceptable limits at all stages, and
- Enable the overall controls to be tuned to prevent any of the pressures within the compressor train from exceeding design limits.

Figure 7 is a typical process flow sheet in DYNSIM and Figure 8 provides the output of the simulation, depicting the conditions which will induce surge. Note that compressor surge is predicted to occur below actual volumetric flow of about 7,500 m$^3$/hr, based on the existing process conditions.
In the case shown in Figure 8, the effectiveness of the startup sequence in keeping the compressor out of surge was based on the observation of the DYNSIM model. The red line, representing the low pressure stage, is the surge line based upon the surge point defined for the normal operating speed of 4490 rpm and the origin. The startup trajectory is the wavy grey line tracing the head/flow process values as the compressor speed is increased during the startup. This curve is superimposed upon the operating curves for the stage. In this example the compressor entered surge at a low speed as the trajectory drifted to the left of the surge line and essentially stayed in surge until the clutch closed and operation shifted to the right of the surge curve.

5. Triconex controller hardware

While the distributed control system (DCS) can support the Triconex algorithm, a fast-acting, fully-redundant control platform is recommended due to the high-speed process conditions existing within the compressor. The frequency of the dynamic instability during surge conditions also requires an open-loop override, anticipatory control and adaptive tuned feedback control. The process application of the particular compressor is also important in determining the choice of control platform. Tricon is a state-of-the-art fault tolerant controller based on a Triple-Modular Redundant (TMR) architecture.

Invensys has developed a comprehensive set of control strategies within the Triconex control algorithm to effectively fit many different applications and process configurations.

6. Conclusion

Compressor surge conditions are rapid, dynamic instabilities that can damage the compressor and reduce process efficiencies. While simplified, inexpensive control strategies exist to limit surge, these will not prohibit surge under specific, frequently occurring conditions, such as extremes in pressures. Effective, robust anti-surge strategies are available; however their implementation requires a solid understanding of compressor control methods and dynamics. Applying domain-specific process control knowledge, dynamic modeling tools, such as DYNSIM, and the Triconex algorithm results in a high-reliability anti-surge solution that protects equipment while improving overall process efficiencies. The Tricon fast-acting, triple modular redundant (TMR) hardware is also recommended as the best hardware platform when the compressor is critical to plant operations.
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