ADDRESSING PAIN POINTS OF ANTI-SURGE AND LOAD SHARING CONTROL IN CENTRIFUGAL COMPRESSORS

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Control systems play a critical role in the performance of centrifugal compressors and the efficiency of the processes that they drive. Surge prevention from reversing process flows can result in undesirable outcomes, including damage to the compressor and unscheduled downtime.

A compressor's surge point is dependent on several variables and notoriously difficult to predict with accuracy, particularly in applications with variations in fluid composition and temperature, or where inlet guide vanes (IGV) are used for control. To minimize the risk of surging, many operators are forced to operate compressors conservatively, which results in lower efficiency, higher energy consumption, and increased emissions.

This article discusses Siemens Energy's solution for addressing this problem. The company's Compressor Control anti-surge algorithm is based on a patented Universal Control Map and can accurately predict surge point over a wide range of changing conditions, including in process applications with variable gas composition. The article also discusses the benefits of incorporating load sharing functionality into the anti-surge controller to maintain uniform throughput flow and enable capacity sharing for compressor units operating in parallel.

UNDERSTANDING COMPRESSOR SURGING

Surging occurs when insufficient flow into the compressor and/or increasing pressure across the machine causes a condition in which forward flow cannot be sustained. It can cause serious physical damage to pumps, fittings, valves, pipes, and other ancillary pieces of equipment. Rotor shifting caused by the surge cycle can also destroy thrust bearings and gas seals. In some cases, operating temperatures can exceed allowable limits and cause compressors to overheat. Because of this, it is always important to have effective anti-surge measures in place.

Surge can be prevented either by blow-off or recirculation of flow, which keeps the pressure differential across the compressor at a level in which reversal cannot occur. The moment that either of these actions needs to take place is determined by a controller, which is designed to predict the point at which surging is imminent (i.e., the surge line).

By measuring a function of pressure rise versus flow, the controller is designed to calculate the operating point and take control action to prevent surge. The challenge, however, is being able to accurately define the surge line over a wide range of operating conditions.

ANTI-SURGE CONTROL PAIN POINTS

The surge line (or surge limit) is a complex function which is dependent on several variables, including gas composition, temperature, molecular weight, and compressor speed. Several methods for determining surge limits are in use today, each with its own approximations and consequent inaccuracies.

Operating the compressor safely given these inaccuracies is typically accomplished by establishing the surge controller flow setpoint based on expected worst-case conditions. While effective in preventing surge, this strategy often results in wasted energy and inefficient compressor operation caused by excess recycle and/or blow-off.

The technology that drives many of the anti-surge applications used today is based upon the premise that for any given rotational speed, the compressor surge limit flow will correspond to fixed values of polytropic head and volumetric suction flow. The assumption generally holds true for single-stage compressors, but many multi-stage compressors deviate from this theory.

The methodology also produces surge control maps with coordinate systems that are only partially invariant to inlet gas molecular weight, temperature, and compressibility.

Due to the volume ratio effect, which affects the polytropic head–suction flow relationship, the temperature and molecular weight of incoming gas can significantly change the point at which surge occurs in a multi-stage compressor. As a result, anti-surge algorithms which fail to produce surge control maps with coordinate systems that are completely invariant to changes in the properties of an incoming fluid are subject to a wide margin of error.

INTRODUCING "SE COMPRESSOR CONTROL TECHNOLOGY"

To overcome the limitations of traditional anti-surge control methodologies, Siemens Energy developed a novel anti-surge algorithm, which is based on a patented Universal Control Map. To date, the Compressor Control anti-surge algorithm has been implemented in thousands of centrifugal compressor units across Siemens and Dresser-Rand product lines.

The algorithm enables accurate prediction of surge over a wide range of operating conditions, making it possible to optimize compressor operation without incurring any added risk of equipment damage. Key differentiators of the technology versus conventional anti-surge control methodologies are outlined below.

• **Compensation for molecular weight, temperature, and compressibility of gas:** Most anti-surge controlling algorithms used today feature a coordinate system that's based on the slope of the "reduced" flow variable squared versus reduced polytropic head curve. This makes them only partially invariant to changes in the properties of the incoming gas.

The Compressor Control anti-surge control algorithm uses a coordinate system based on the "corrected" flow variable, which makes surge control completely invariant to changes in molecular weight, temperature, pressure, compressibility, and rotor speed (Figure 1). This method to correct flow for compressor map reference conditions is the most accurate way of determining surge and is recommended by the ASME (American Society of Mechanical Engineers) PTC-10 Performance Test code for compressors.

$$Q_{corrected} = \frac{Q_{actual}}{\sqrt[2]{\frac{RTZ_{actual}}{RTZ_{reference}}}}$$

Q_{actual}: Actual flow measured at the compressor

$Q_{reference}$: Reference conditions are from Compressor Performance Maps

Figure 1. Corrected Flow Equation

• **Adjustment of surge limit flow due to changes in compressor speed:** Many anti-surge algorithms in use today rely on the Fan Law characteristic, which states that flow is proportional to rotative speed. This methodology only allows for accurate prediction of surge under conditions in which surge limit lines do not deviate from the Fan Law. In instances when they do deviate, approximations must be made based upon a speed measurement correction factor.

In most cases, these approximations are subject to a wide margin of error. Siemens Energy's approach for determining surge requires no approximations, which allows for accurate prediction of surge from one compressor speed to the next.

• **Normal control action:** Compressors that use PI controllers as the primary method of preventing surge are highly susceptible to abrupt disturbances that can entirely destabilize a system. Siemens Energy has addressed this with a Floating Proportional Algorithm in addition to the PI algorithm, so that surge can be prevented in the event that flow approaches the surge control set point at a high rate (as is the case during process upsets).

• **Backup control action:** With the use of an easily configurable backup line (the secondary control line located between the surge limit line and the control line seen in Figure 2), the controller provides a useful combination of open and closed loop responses in the event that compressor flow falls below the control line. This allows for fast step openings of the recycle valve to prevent surge and is particularly effective at eliminating overcompensations that frequently cause process destabilization.

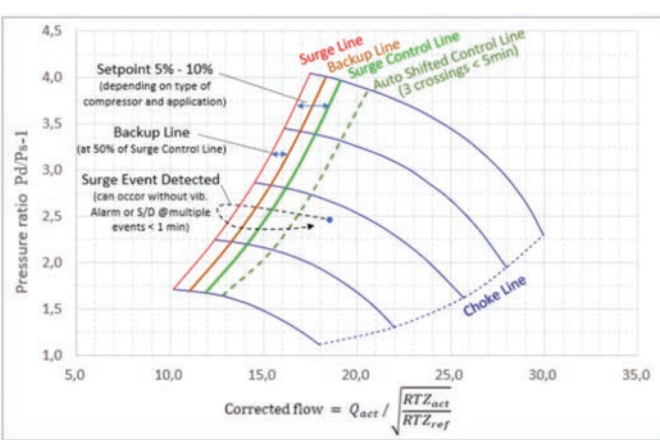

Figure 2. Universal Control Map

• **Automatic tuning of PI gains:** The anti-surge controller automatically adjusts PI gains to optimum values if the default gains set at the time of unit commissioning cannot adequately provide timely control response under changing process conditions.

LOAD SHARING CONTROL

Siemens Energy's anti-surge controllers also feature a load sharing algorithm designed to equalize surge margins and maximize system efficiency by sharing flow among multiple compressors that are connected to common suction and discharge lines. Unique capabilities of the load sharing algorithm include:

• **Coefficient of export flow (CEF):** Conventional load sharing algorithms are based on the relationship between compressor inlet flow (Qin) and the surge control set point (Qsp). In doing so, they limit the load sharing range to the surge control line, at which point Qin becomes meaningless because it does not account for recycled flow (Qrec).

To address this problem, Siemens Energy's load sharing algorithm uses a Coefficient of Export Flow (CEF), which is the distance from the operating point to the surge control line. The CEF value accounts for any flow being recycled and allows for effective load sharing over the entire operating range of the compressor. To ensure consistency across an entire system, each compressor's load sharing controller receives the same CEF set point from a master controller.

• **Decoupling from anti-surge controller:** When the operating point reaches the control line, interaction between anti-surge controllers and load sharing controllers can lead to destabilization, potentially forcing operators to shut the unit(s) down to prevent damage. Siemens Energy's load sharing algorithms prevent such an occurrence, as they are designed to decouple from anti-surge controllers when flow approaches the surge line.

CONCLUSION: *The Advantages of Integrated Control*

Control systems represent an area where companies can realize incremental improvements in compressor reliability, efficiency, costs, and carbon footprint with a relatively low up-front investment.

In the case of greenfield applications, operators can benefit by engaging with OEMs who can manage a large portion of the compressor train supply scope. Doing so allows for the adoption of a holistic control strategy, where different rotating machinery control functions for the compressor, gas or steam turbine, motor, auxiliaries, alarms, and shutdowns are combined in a single integrated PLC or DCS-based control system.

A single supplier approach also makes it easier for technical integration issues to be resolved early in the project timeline, minimizing the risk of late-stage delays. Other benefits include:

- Reduction of system complexity
- Elimination of black box controllers
- Reduction of internal cabinet wiring and communications between disintegrated controllers
- Reduction of control system spare parts
- Faster control interaction between compressor and main driver during process upsets
- Common alarm, trip, and first out indications

REFERENCE: Compressor Control Technology. Siemens Energy