The Unstable Nature of Conventional Anti-Surge Controllers

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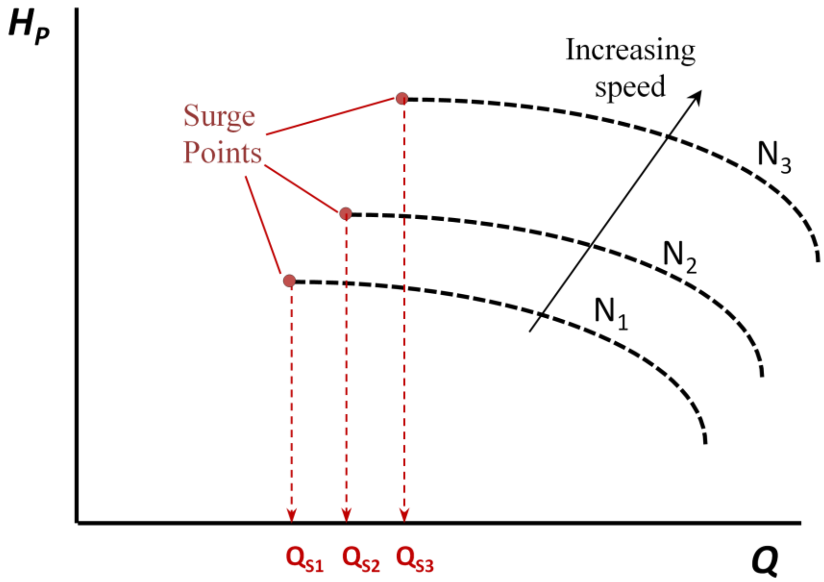
This article examines the unstable nature of conventional Antisurge controllers. The source of instability is their dependence on ***reduced performance curves***. The behavior of these controllers can actually create some of the worst aspects of surge and surge avoidance. These controllers are difficult to tune, can create unnecessary disturbances, and increase the severity of surge when it does occur.

Volumetric anti-surge controllers are inherently stable because they are based on ***fundamental performance curves***. Volumetric anti-surge controllers are easier to tune, more stable, and reduce the severity of surge [1].

Volumetric Anti-Surge - Design [1]

Volumetric antisurge is based on the fundamental compressor performance. The compressor manufacturer will provide a set of performance curves for each stage of compression. These curves describe the behavior of the compressor independent of the gas being compressed . Fig-1 illustrates a typical manufacturer's performance curve that relates polytropic head (Hp) to inlet volumetric flow rate (Q) at several compressor speeds (N).



Volumetric anti-surge controller uses inlet volumetric flow rate (Q) as the measurement of distance from surge. The minimum inlet volumetric flow rate necessary to avoid surge (Qsurge) is dependent only on compressor speed (N). A curve fit of the performance curve surge points provides a calculation of Qsurge that is independent of gas conditions.

$$Q_{surge} = K * N$$

The inlet volumetric flow controller setpoint is calculated to maintain a sufficient margin of safety above surge. In the example below uses a 10% safety margin.

$$Q_{SP} = 1.1 * Q_{surge}$$

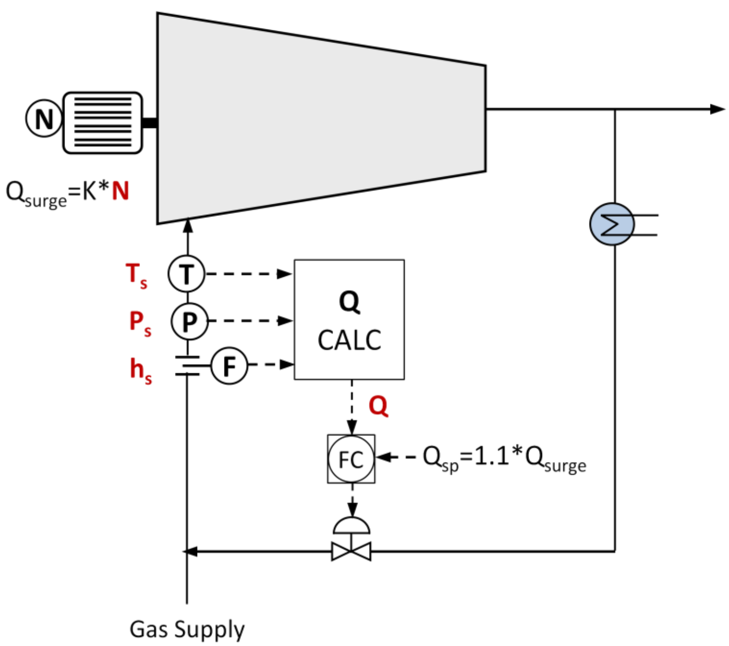
The controller feedback term, actual inlet volumetric flow rate, can be calculated from the inlet instrumentation and the ratio of gas molecular weight to compressibity. [1]

$$\rho = \frac{1}{R}\frac{mw}{Z_S}\frac{P_S}{T_S} \qquad Q = K^{Q}_{meter}\sqrt{h_s}\frac{\sqrt{\rho_K}}{\sqrt{\rho}}$$

Where

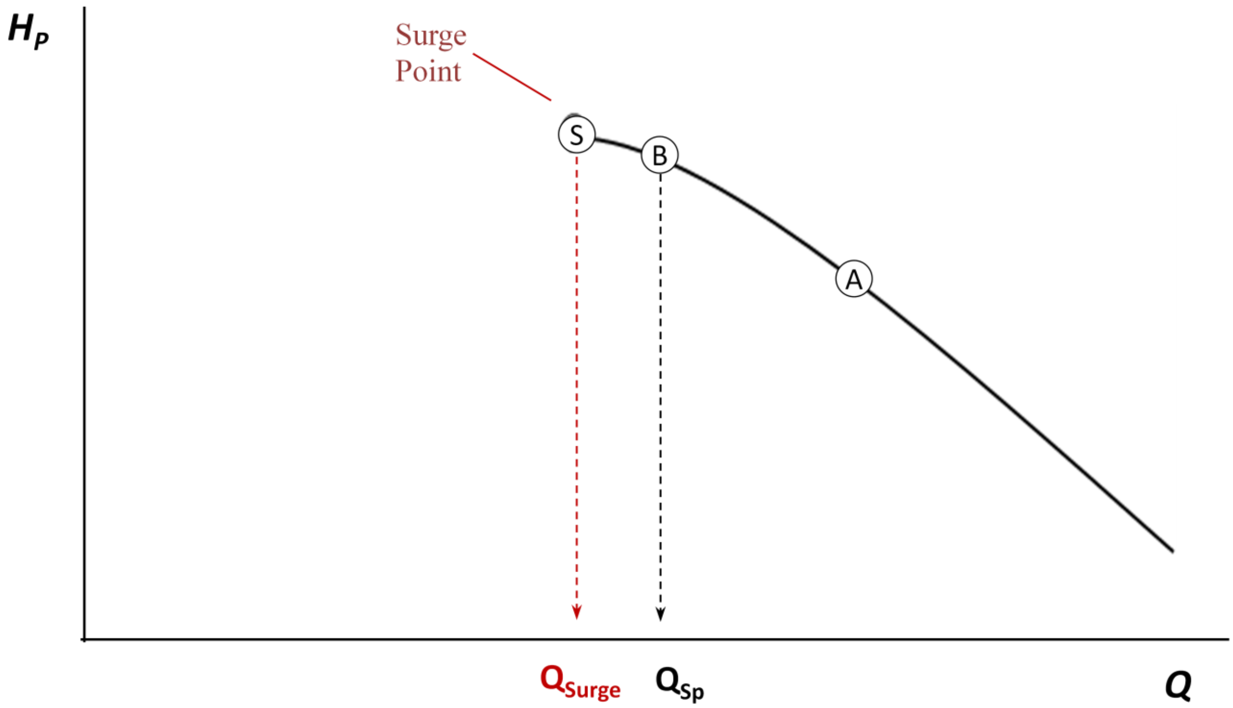
ρ	Gas density
R	Ideal gas constant
mw	Gas molecular weight
Z_S	Gas compressibility at inlet (suction) conditions
P_S	Suction Pressure (absolute)
T_S	Suction Temperature (absolute)
Q	Inlet volumetric flow rate
K^{Q}_{meter}	Volumetric flow meter constant value
h_s	Inlet flow meter differential pressure
ρ_K	Gas density value used to calculate the meter constant

This figure illustrates the functional design of a volumetric controller.



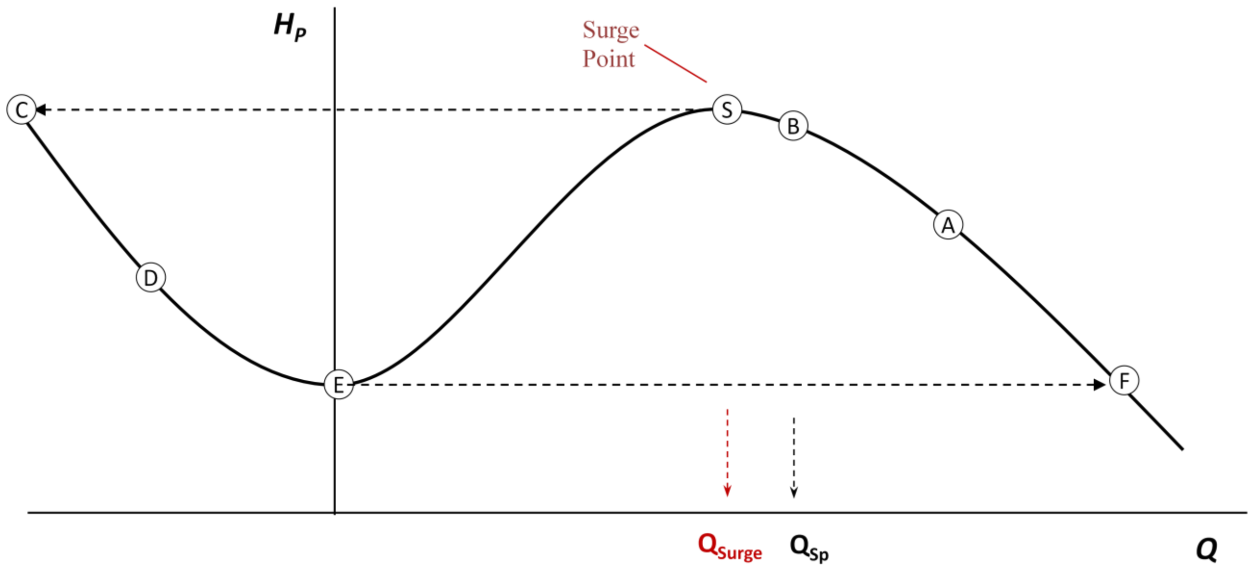
Volumetric Anti-Surge - Normal Response

Let's examine a volumetric controller's response to a normal disturbance. Assume the compressor speed is held constant. Our experiment starts at point **A** with the surge valve closed. Now imagine a complete gradual reduction in compressor gas supply. As flow drops to **B** the flow controller will open the surge valve as necessary to maintain the desired minimum inlet flow. As gas supply returns, the surge valve will close maintaining a minimum false load. Note that the antisurge controller setpoint does not change.



Volumetric Anti-Surge - Response to Surge

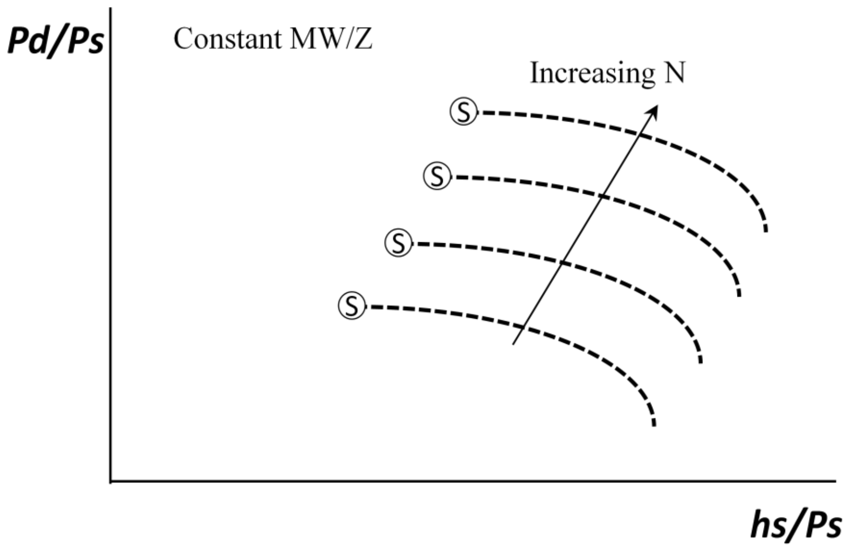
Lets repeat the experiment starting at **A** with sudden complete loss of gas supply [3]. Let's assume that the flow controller isn't tuned for such a disturbance and is unable to open the valve quickly enough to prevent surge. Flow drops to **S** triggering surge and a flow reversal to **C**. As suction and discharge pressures equalize performance moves through **D** and to a point **E** where stage flow recovers. Recovery is toward a high flow low head point **F**. As head increases performance returns to point **A**. A Limit on how quickly the valve can close will prevent the cycle from repeating. Note that the volumetric flow setpoint remains constant which results in the correct control action throughout the surge cycle.



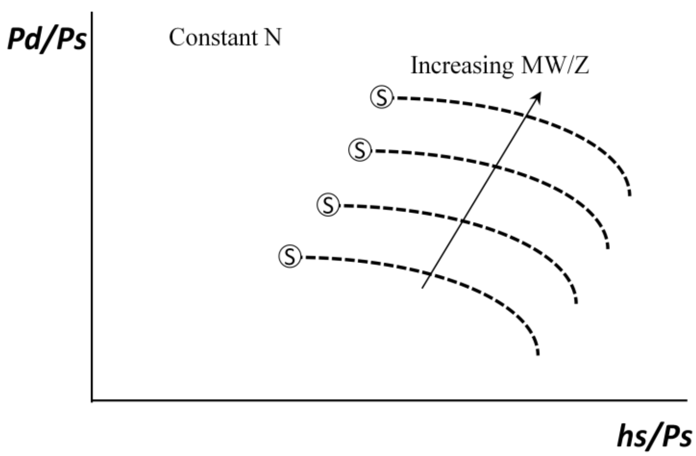
Conventional Anti-Surge - Design

Conventional anti-surge controllers are based on reduced performance curves. Performance reduction is accomplished by replacing the axis of the fundamental performance curve with terms that don't require molecular weight to evaluate. While the method of reduction and the resulting calculations vary between specific controllers they all share an inherent instability. [2]

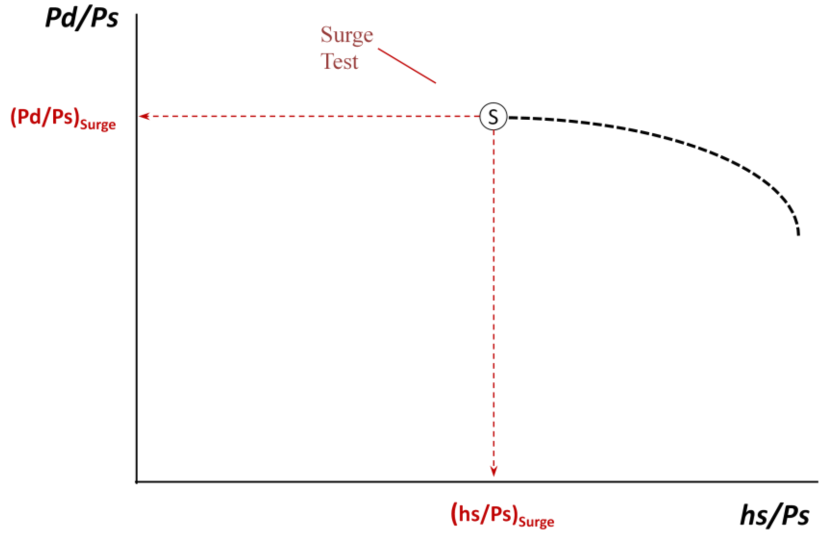
The instability of all conventional antisurge controllers can be illustrated with a controller that is a reduced curve that relates compression ratio and the differential pressure across the inlet flow meter. Similar to the fundamental relationship the location of the curve is affected by compressor speed.



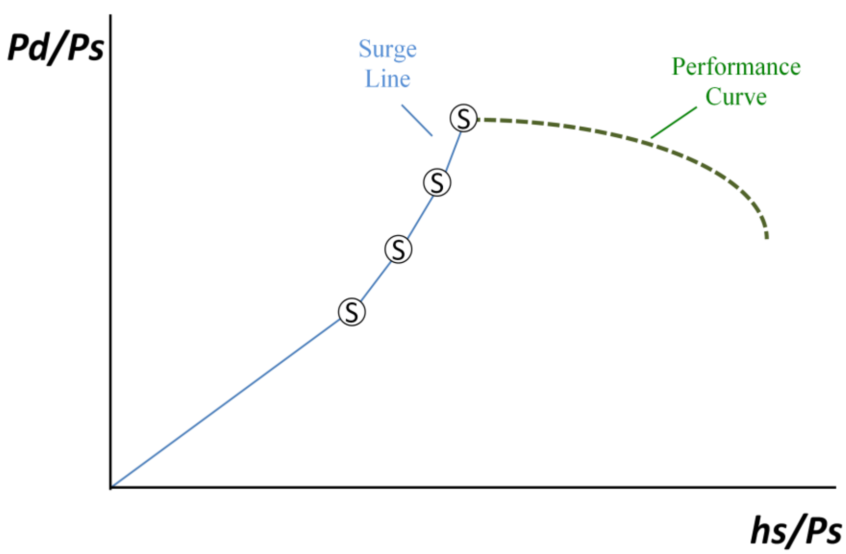
However, unlike the manufacturer's curve reduced performance curves are not independent of the gas being compressed. Increasing gas MW/Z (molecular weight /compressibility) moves the curve toward higher compression ratios and flow meter differentials.



This controller uses hs/Ps as the measure of distance from surge. All we need from the curve is the value of hs/Ps at surge. That presents a challenge since without more information about the gas and flow meter we know neither the shape nor location of the reduced performance curve. We can however find the current location of the curve by surging the compressor and noting value values of Pd/Ps and hs/Ps.

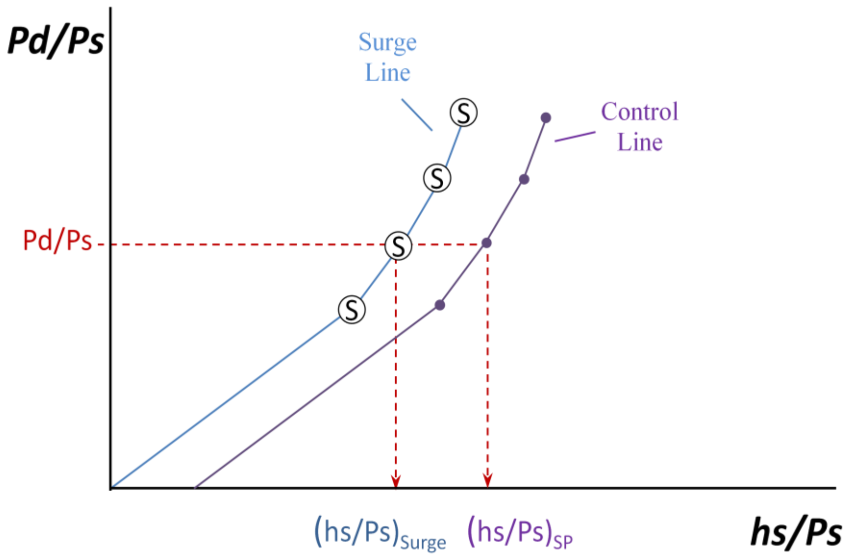


Surge tests at different conditions should be conducted if changes in compressor speed or gas composition are expected. The results of the surge test are used to construct the Surge Line that relates the values of Pd/Ps at surge to the values of hs/Ps at surge.

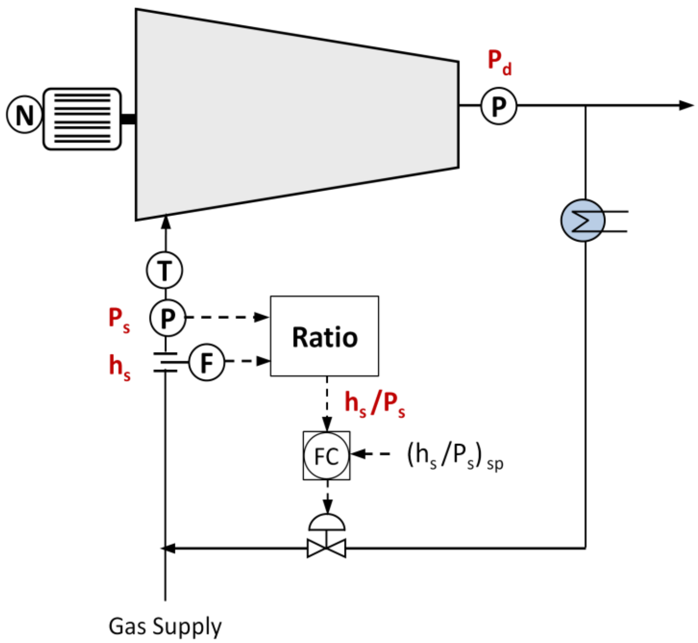


It is important to keep in mind that the performance curve describes the relationship between Pd/Ps and hs/Pd. **The Surge Line is valid at surge only**.

The Control Line constructed at a safe margin from the Surge Line is used to calculate the controller setpoint from the current value of Pd/Ps.



This figure illustrates the functional design of a conventional controller.



Conventional Anti-Surge - Normal Response

Let's examine the controller's response to a normal disturbance. Assume the gas composition and compressor speed is constant which results in a "fixed" curve. Our experiment starts at point **A** with the surge valve closed. The flow at **A** produces a compression ratio (Pd/Ps) below its value at surge. This results in a controller setpoint (hs/Ps)sp that is lower than value of hs/Ps at surge. Note that in spite of the Control Line safety margin our experiment starts with the controller calling for a flow that would result in surge!

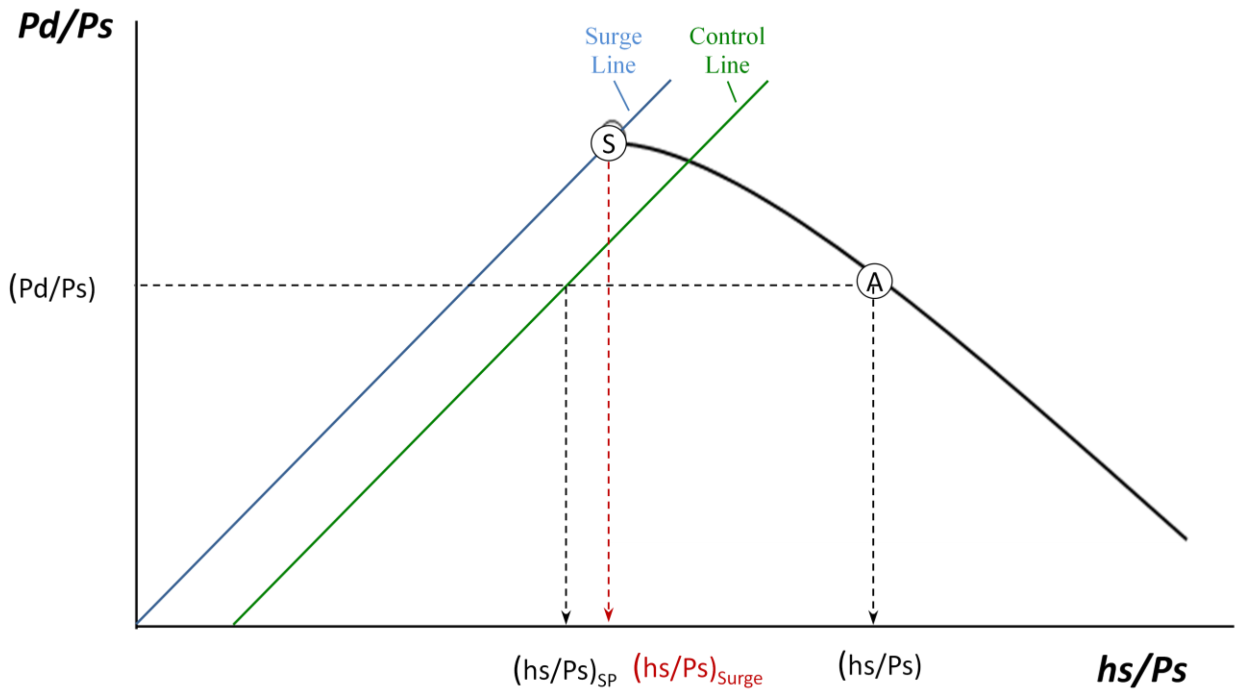
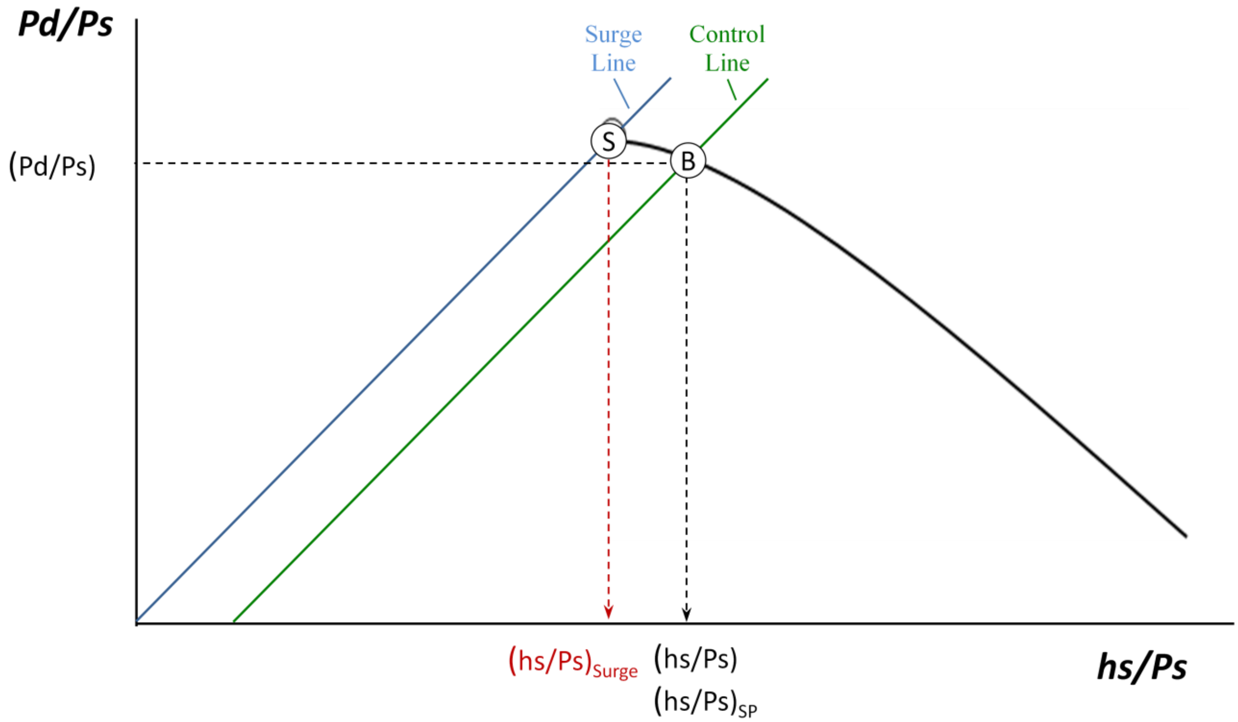


Fig 11

Now imagine a complete gradual reduction in compressor gas supply. Fortunately as flow through the compressor drops, the compression ratio (Pd/Ps) rises which results in an increasing controller setpoint (hs/Ps)sp. The surge valve will open and the controller settle at B and a flow rate somewhat below our intended safety margin.



The unnecessary changes in the calculated setpoint exaggerates the controller error and makes tuning more difficult.

Conventional Anti-Surge - Response to Surge

Lets repeat the experiment starting at **A** with sudden complete loss of gas supply. Let's assume that the flow controller isn't tuned for such a disturbance and is unable to open the valve quickly enough to prevent surge. Flow drops to **S** triggering surge and a flow reversal to **C.** At the instant surge starts the correct controller setpoint is calculated.

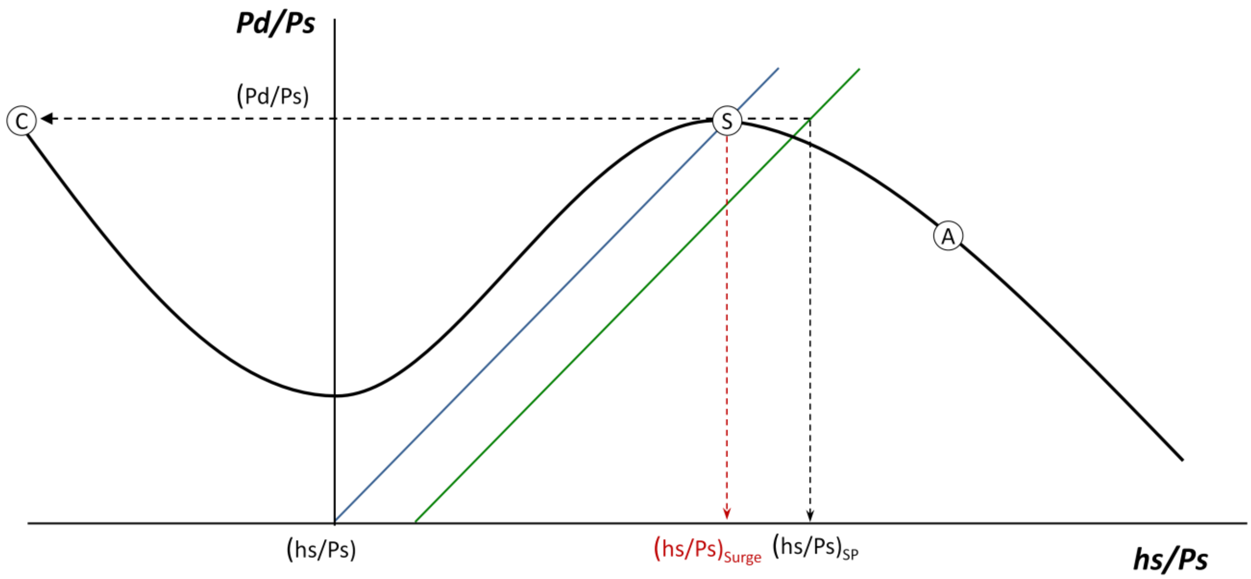


Fig 13

As suction and discharge pressures equalize the performance moves to **D.** Unfortunately, the drop in compression ratio results in a decreasing controller setpoint which slows recovery from surge.

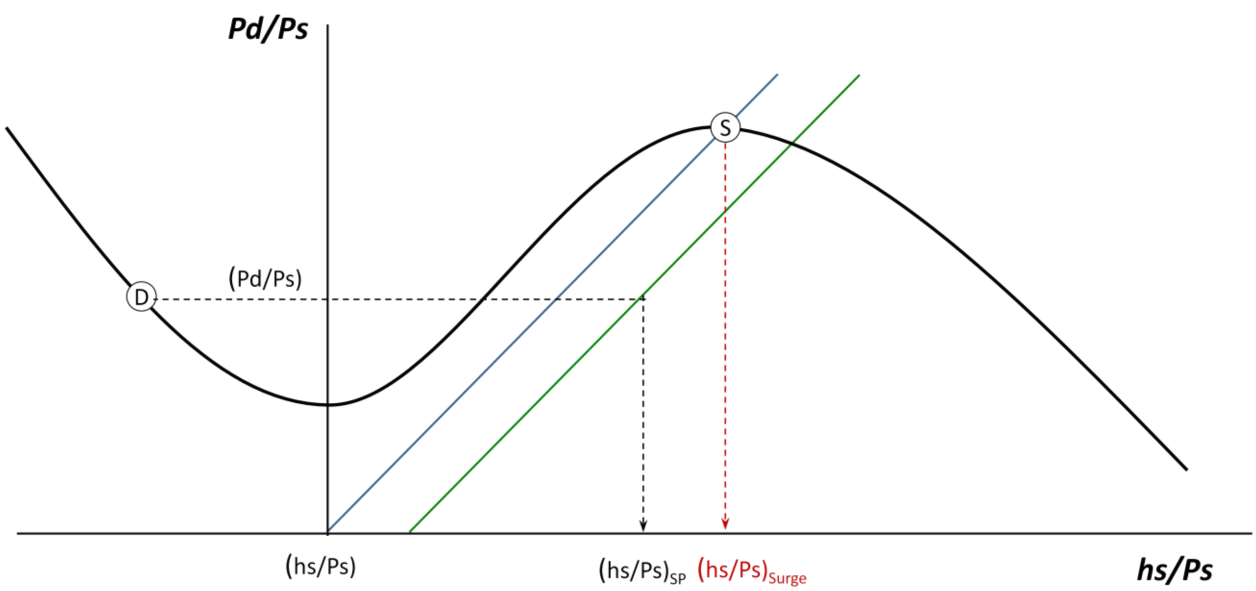


Fig 14

The controllers "fight" against recovery continues as the compression ratio drops. If the controller isn't "tuned" properly it can win that "fight" and drive the compressor into sustained surge.

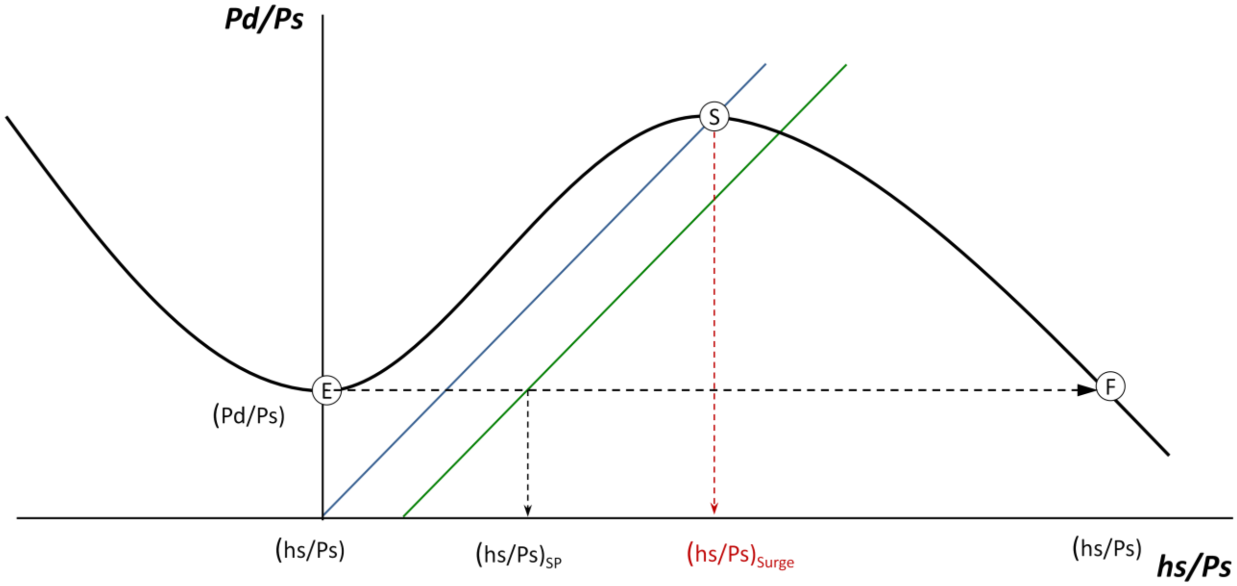


Fig 15

Conventional anti-surge controllers respond purely to surge. Rather than help the compressor recover from surge, conventional controllers tend to "push the compressor off the cliff " if surge starts. The result is the need to avoid surge at all costs! Implementation requires (expensive) fast acting valves, high frequency calculations, emergency controller override actions and great care with controller settings and instrument filtering.

Volumetric anti-surge controllers are boring in comparison, becoming just another control loop in the plant that handles disturbances in a stable simple manner.

Volumetric Anti-Surge - Update

Reference 1 describes the benefits and methods of implementing volumetric anti-surge control. Since posting that document, a new method for implementing volumetric control has been developed. The method allows volumetric control, using conventional instrumentation without a require for constant or even know gas composition. I plan to post a future article describing this new method.

References

1. Moore, R. (2015). *Compressor Anti-surge with Volumetric Flow Control*. Retrieved from https://simsready.com/posts/Compressor-Anti-surge-with-Volumetric-Flow-Control.pdf

2. Moore, R. (2015). *Surge Line Calculator*. Retrieved from https://simsready.com/posts/Surge-Line-Calculator.pdf

3. Dynamic Simulation of Compressor Control Systems. Retrieved from https://projekter.aau.dk/projekter/files/14589708/dynamic_simulation_of_compressor_control_systems.pdf