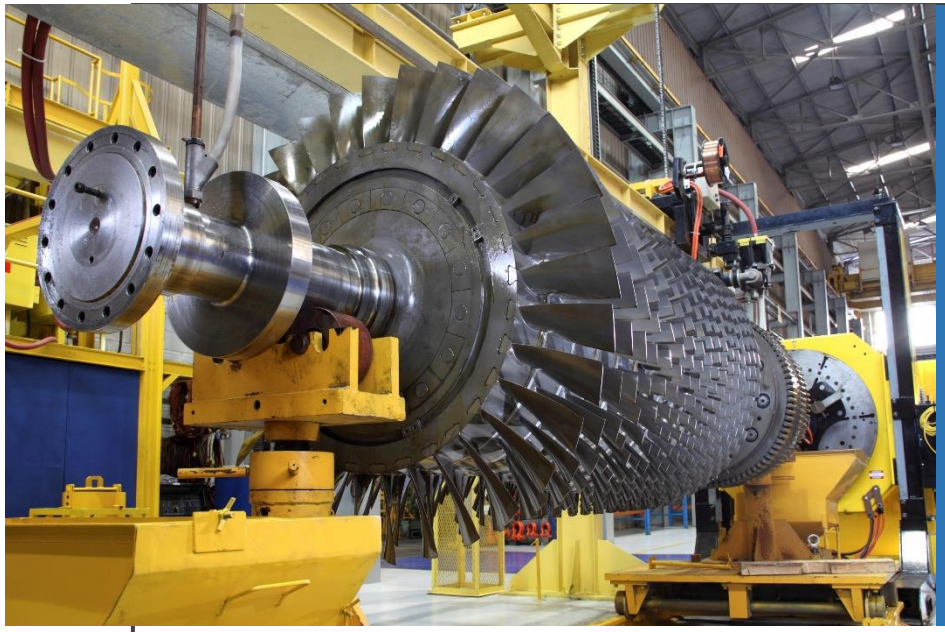


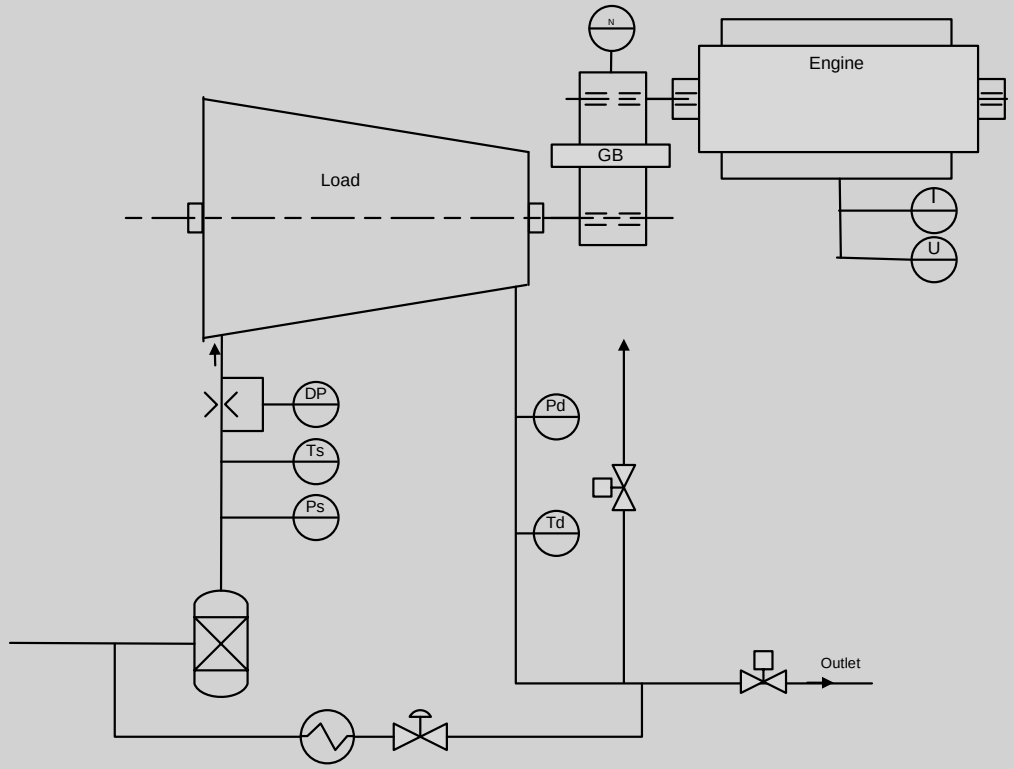
S&C Compressor, Stonewall Control Solution

Turbomachinery Control Solutions Overview

Solutions for all variations of turbomachinery equipment

- Steam Turbine & Extraction Control
- Compressor Control
- Gas Turbine Control
- Reciprocating Unit Control
- Compressor Group Station Control
- Power Generation Unit and Station Control

Solutions for all third-party hardware & software platforms compliant with IEC 61131



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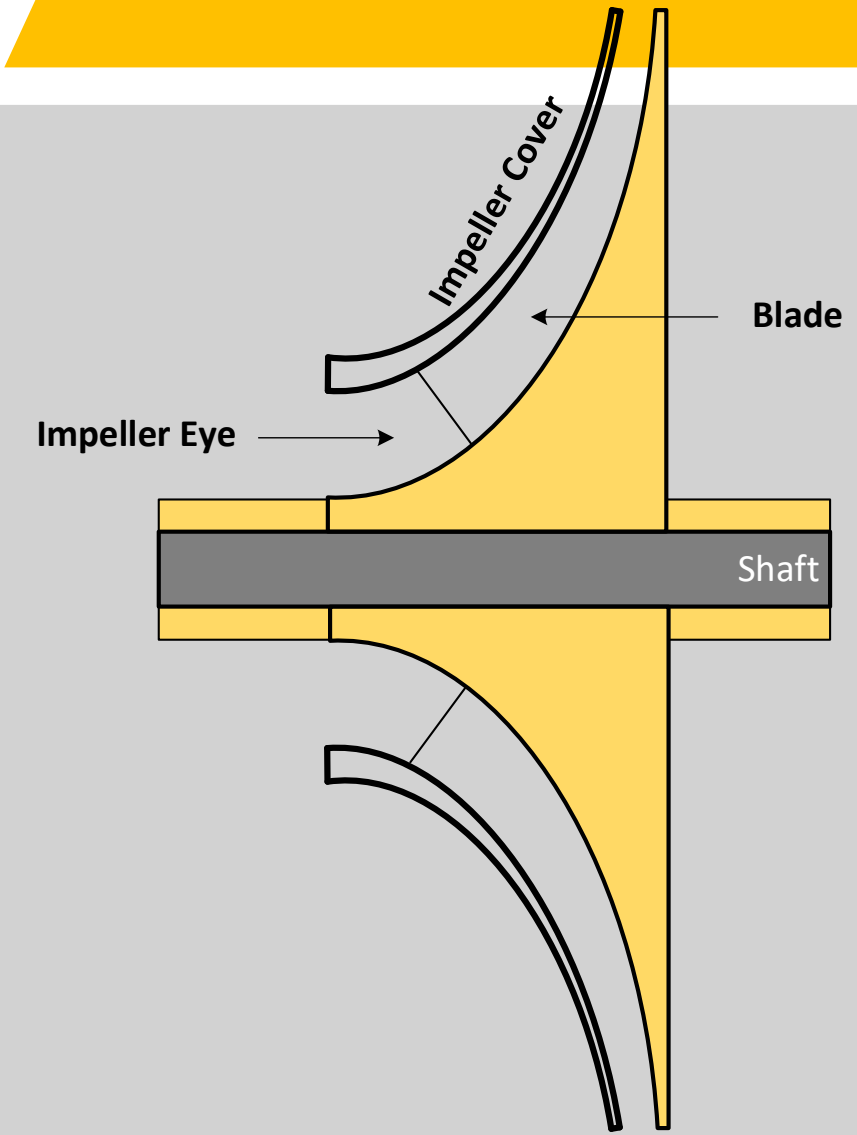
What's Stonewall?

- Stonewall occurs in a centrifugal compressor when the velocity of the gas in at least one stage reaches the speed of sound (Mach 1) at the gas conditions in that part of the machine.
- In a centrifugal compressor, this usually occurs near the *eye of the impeller*. When the velocity of the gas reaches Mach 1, the flow will no longer increase, regardless how much the pressure ratio drops across the stage.
- Compressor Stonewall is an abnormal operating condition for centrifugal compressor. Stonewall of centrifugal compressor occurs when the compressor is operating at low discharge pressure and very high flowrates. These high flowrates at compressor Stonewall point are actually the maximum that the compressor can push through. Any further decrease in the outlet resistance will not lead to increase in compressor output.



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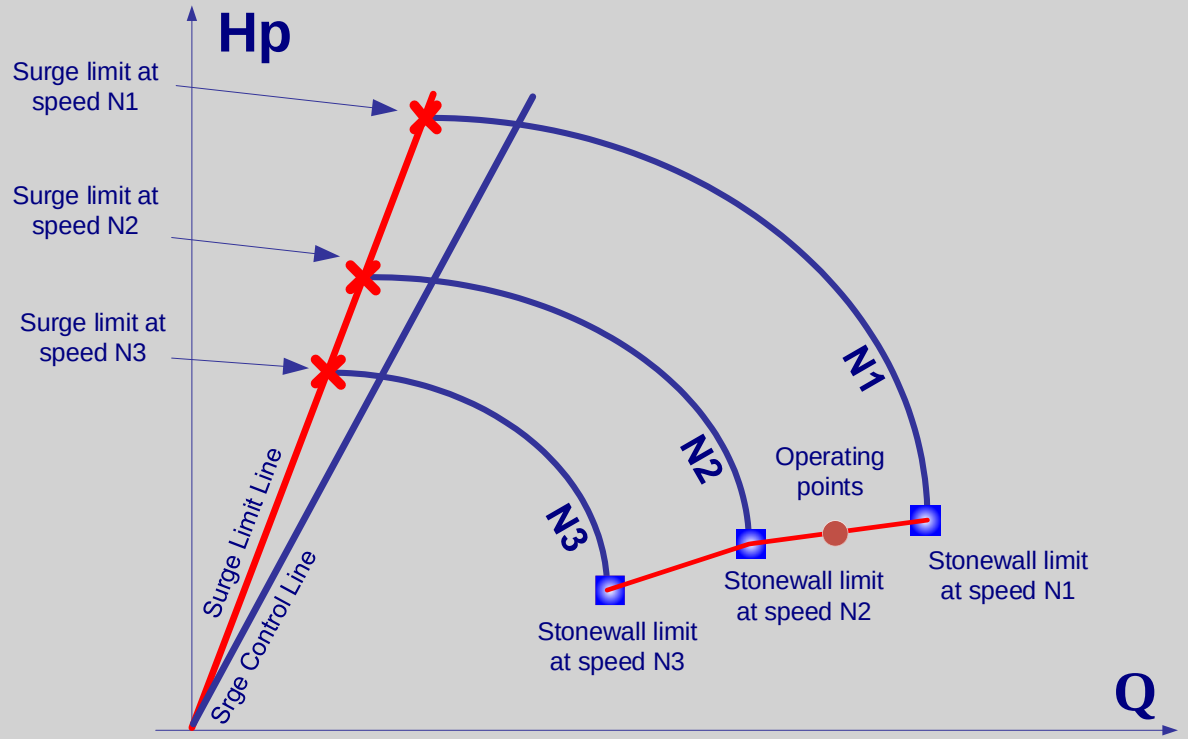
Operation in Stonewall

- Compressor manufacturers have found that prolonged operation of the compressor in stonewall can lead to fatigue failures of the impeller cover and blades. There is also an increase in the compressor discharge temperature due to the increase in entropy across the region of sonic velocity.
- Stonewall can cause serious damage to the rotors and blades of multistage-centrifugal and axial compressors. Prolonged operation in the stonewall region should be avoided, because if nothing else, the efficiency of the compressor is very low.
- In the compressor, stonewall is related to a flow regime at very high flows which means that the flow channels between blade rows may experience blockage effects
- From an aerodynamic standpoint, stonewall refers to a situation where flow passages become blocked either due to the occurrence of compression shocks or due to massive flow separation



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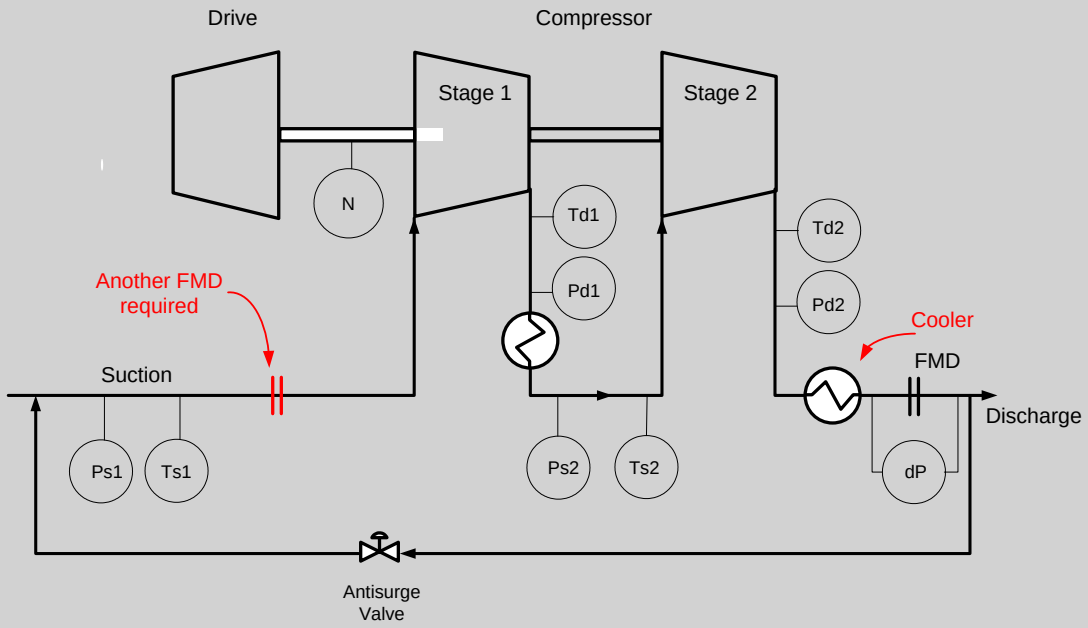
Multistage Compressors

In multistage compressors impellers are in general selected such, that at the design point, all impellers operate at or near their best efficiency point. It tends to yield a good efficiency at the design point as well as a wide operating range. When the compressor moves from the design point to choke it significantly reduces efficiency.

The overall Multistage Compressors may still produce head, when some individual stages are already in stonewall conditions and reducing head, acting as throttles. These impellers will consequently see a lower pressure on their discharge side than on their suction side, which is leading to increased load on the thrust bearings.

Besides the performance penalties, the study indicates that

Operating in choke is often not a problem for the compressor



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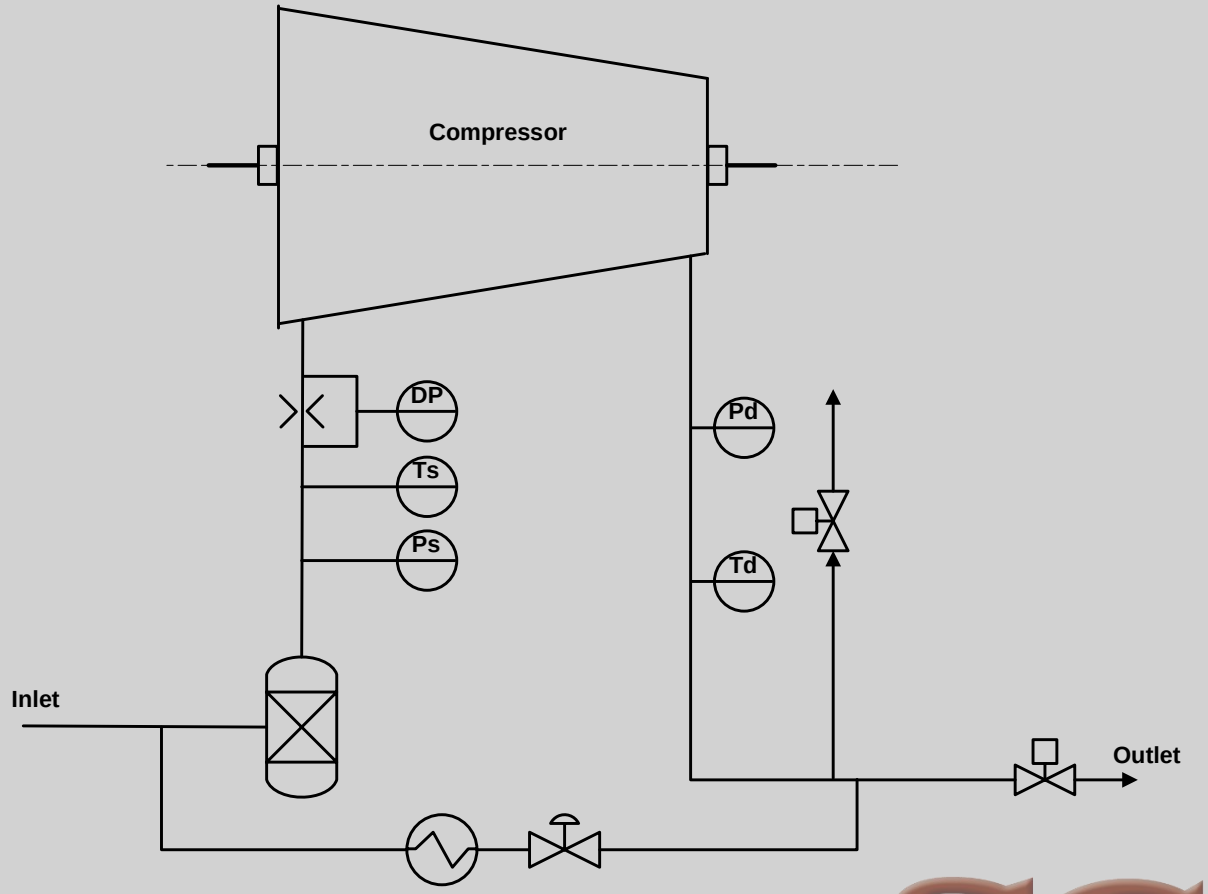
How can Control Module prevent stonewall?

To prevent the compressor's stonewall from happening it is needed to maintain a certain level of flow resistance in the compressor outlet line. Throttle valve can be used for this purpose in the compressor outlet line. Throttle valve closes to restrict the flow to keep compressor from stonewalling. When flow resistance in compressor outlet falls and flow begins to increase, the throttle valve closes to develop resistance to the increasing flow.

Opening of recycle valve also can push compressor towards stonewall conditions. Control system usually opens recycle valve:

- To prevent surge event
- During compressor stopping, ESD, and unloading mode.

To prevent stonewall from happening it is needed to limit recycle flow by keeping recycle valve at certain position.



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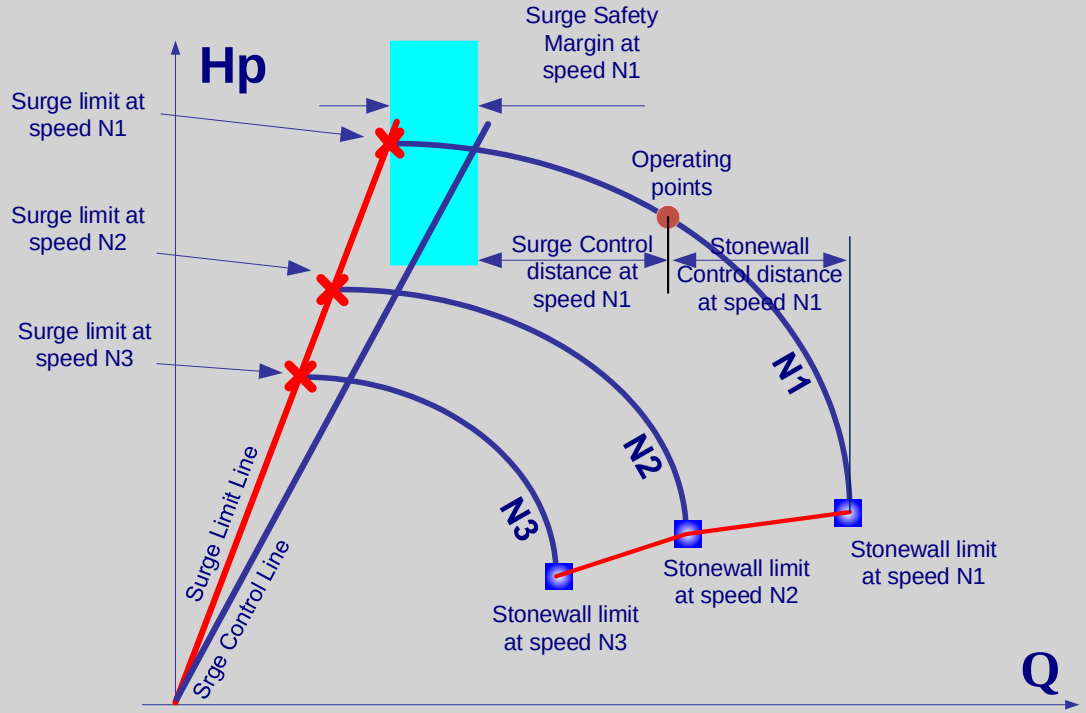
How to map stonewall control line?

Thus, compressor performance is best illustrated by plotting Hp versus Q^2. For a given speed and guide vane angle, this will produce a single performance curve. By allowing either the rotational speed or guide vane angle to take a series of discreet values, we can generate a family of performance curves, which is called a compressor map.

The surge point refers to the minimum flow in the centrifugal compressor, below with momentary reversal of rotor occur. If the compressor operates in this region, it may lead to catastrophic failure. To avoid the compressor surge, an anti-surge system installed in the compressor system. As per the curve, the surge control line considered at 10% higher than the surge flow line.

Like the technique used for preventing surge, a stonewall prediction algorithm is used to calculate the Head at which stone wall will occur for a given flow. A setpoint is established that gives the stonewall controller an operating margin so that it can act in time to prevent excessive flow without acting too aggressively.



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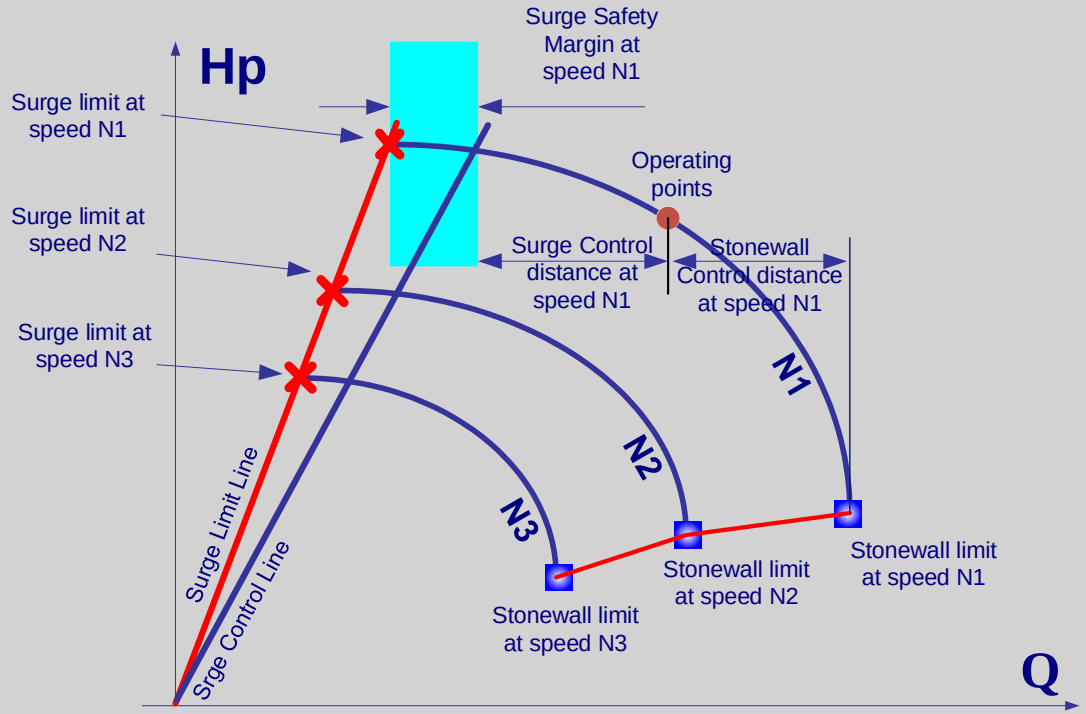
How to map stonewall control line? (2)

Many compressor manufacturers limit the operation of the compressors at high flows by defining a stonewall limit on a compressor map, prohibiting the operation of the compressor at low pressure ratios. Manufacturer provided information can be recomputed and plotted on performance map.

How to recognize stonewall conditions when compressor is tested:

- When the flowrate to the compressor is very high the inlet pressure and outlet pressure almost becomes the same.
- The shock waves themselves tend to be dynamic and fluctuating in nature. The stonewall may lead to high vibration.
- At stonewall point velocity of the impeller reaches a velocity of sound of the gas and velocity cannot go beyond this value. It essentially limits the flow that can pass through the impeller.



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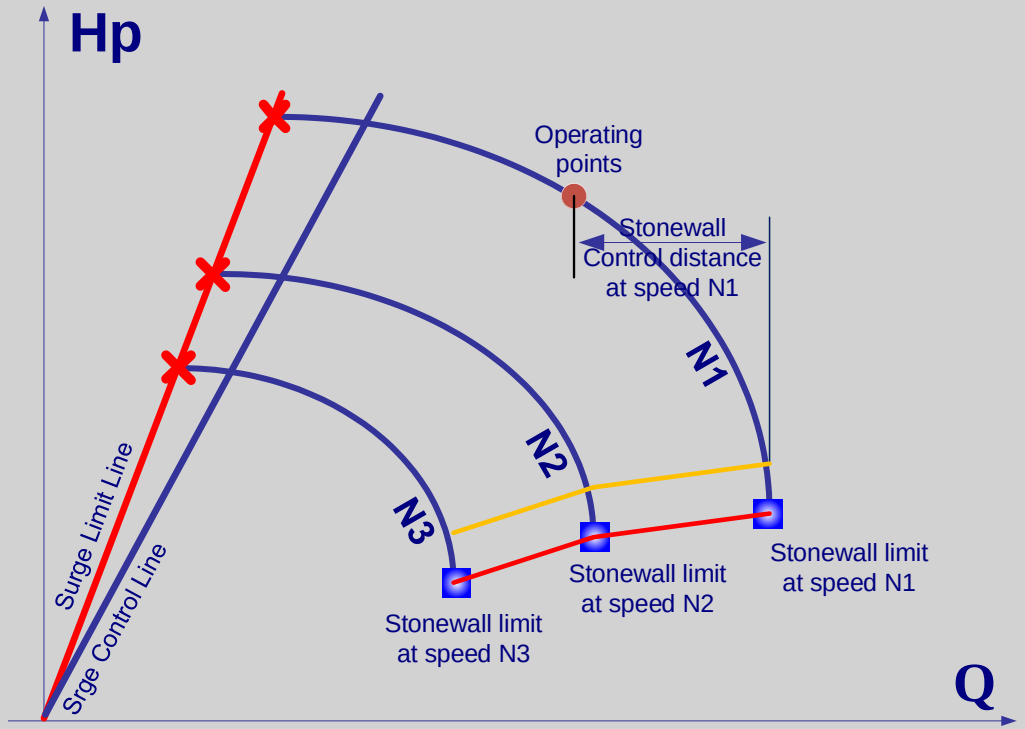
Stonewall control algorithm

Stonewall Prevention Control Application (SPCA)

- Controls gas flow through compressor
- Defines the Stonewall line over a wide range of changing conditions
- Uses PID control to operate recycle control valve
- Calibrated using manufacturer specification and compressor maps or through field testing

Benefits

- Simplify calibration by recording Stonewall events and conditions and by automatically defining parameters
- Balance recycle control valve opening and closing to avoid surge but not waste power
- Use algorithms to determine how the Stonewall limit changes as the process conditions change



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Stonewall control algorithm implementation

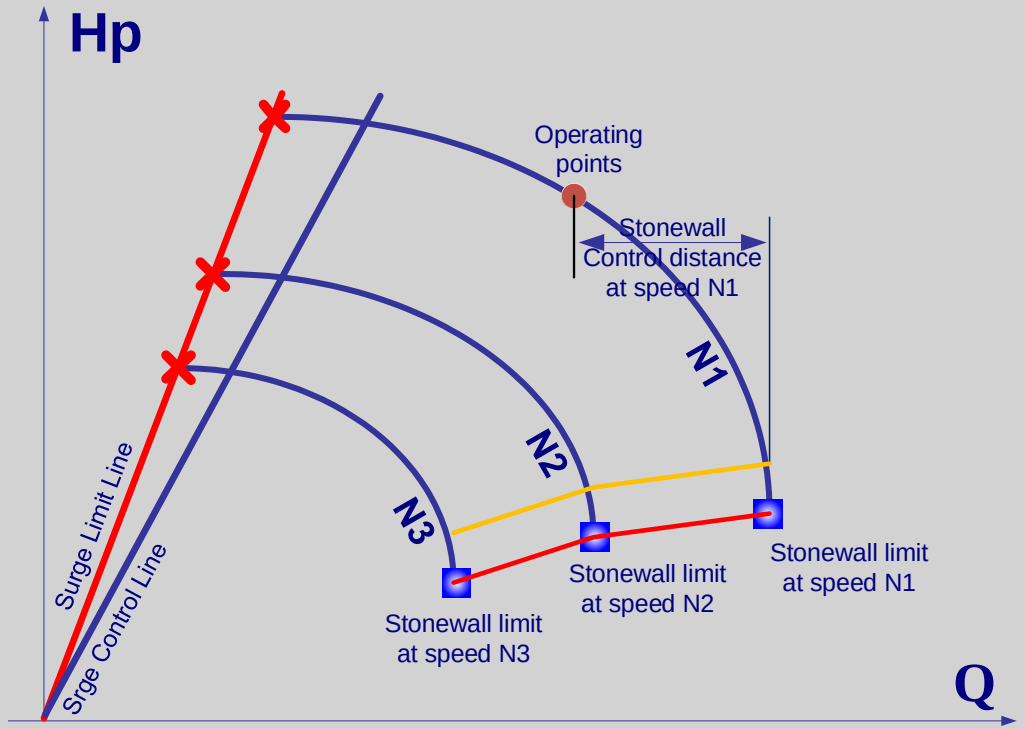
The Stonewall calculation module is the additional SPCA functional block. This module calculates the distance between the compressor operating point and the Stonewall control line. Calculations are continuously made based on operating conditions in the compressor suction, gas composition, etc. At every scan, SPCA calculates the distance between the operating point and the Stonewall line. SPCA keeps the maximal allowable flow through the compressor by limiting opening of the recycle valve.

The Stonewall limit line is determined through tests or is calculated using manufacturer-provided data.

During the surge test, the following parameters are recorded:

Pressure drop across flow measuring device

- Compressor suction pressure
- Compressor discharge pressure
- Compressor suction temperature
- Compressor rotational speed/drive power/guide-vane position



$$k_{su} = \frac{(R_{csu}^{\sigma} - 1)}{\sigma} * \frac{P_{ssu}}{dP_{ssu}}$$

$$SP_{su} = dP_{ssu} * CLM = \frac{(R_c^{\sigma} - 1)}{\sigma} * \frac{Ps}{k_{su}} * CLM$$

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Stonewall control algorithm implementation (2)

The flow coefficient is calculated using the ksu equation

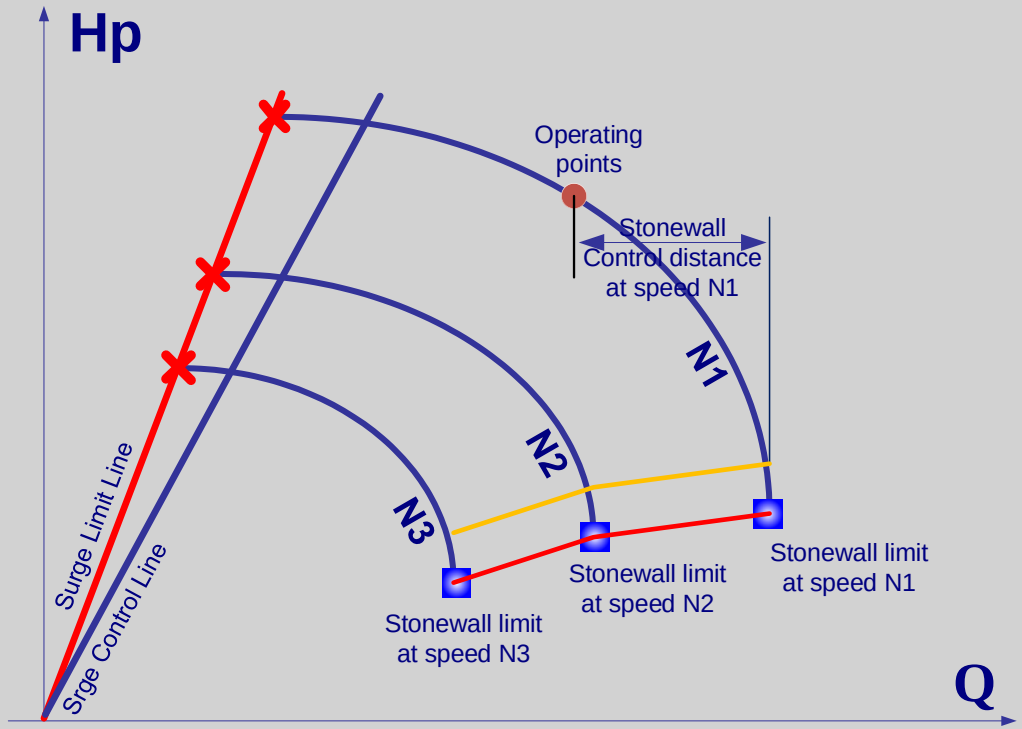
$$k_{su} = \frac{(R_{csu}^{\sigma} - 1)}{\sigma} * \frac{P_{ssu}}{dP_{ssu}}$$

Based on the tests results, the surge point value at current conditions is calculated using equation below and constitutes a pressure drop across the flow measuring device at a stonewall point calculated for the current process conditions. The stonewall control line defines the desired minimum distance between the operating point and stonewall limit line. The stonewall control line is always to the left of the stonewall limit line.

Consequently, the AS PID set point, SP, is calculated using equation

$$SP_{su} = dP_{ssu} * CLM = \frac{(R_c^{\sigma} - 1)}{\sigma} * \frac{Ps}{k_{su}} * CLM$$

The PI Response increases the recycle rate when the operating point is to the left of this line and reduces it when that point is to the right of this line.



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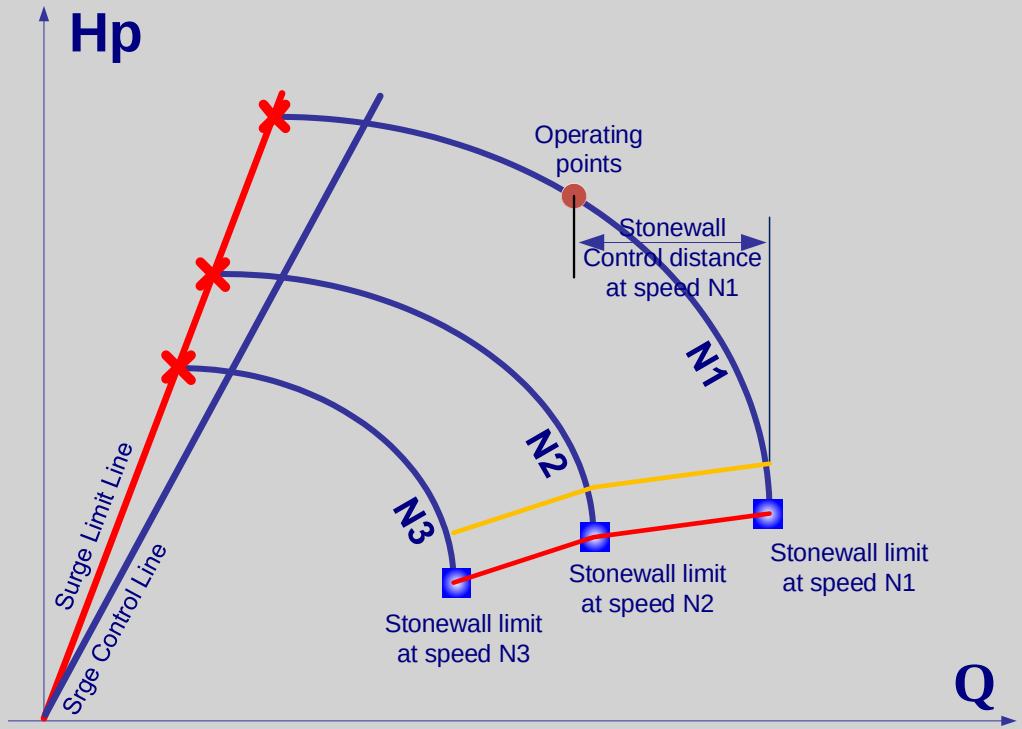
Stonewall control algorithm implementation (3)

While operating in the Stop state, the controller holds the recycle valve fully opened. To protect against Stonewall while operating in Stop state, the controller will keep the operating point to the left of the Stonewall control line.

In addition, manual control cannot be initiated while the Stop state is selected. In this situation Stonewall control is disable.

A normal shutdown ramps the recycle valve to the open position and Stonewall control is disable.

$$k_{su} = \frac{(R_{csu}^{\sigma} - 1)}{\sigma} * \frac{P_{ssu}}{dP_{ssu}}$$



$$SP_{su} = dP_{ssu} * CLM = \frac{(R_c^{\sigma} - 1)}{\sigma} * \frac{Ps}{k_{su}} * CLM$$

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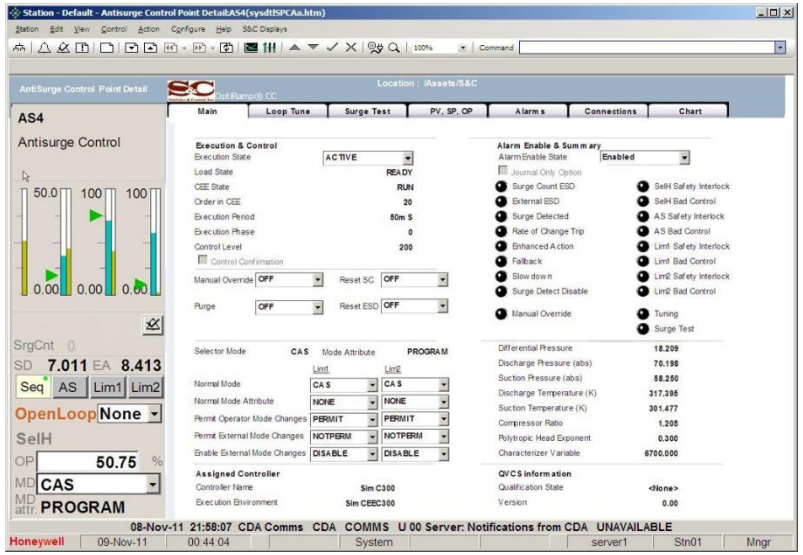
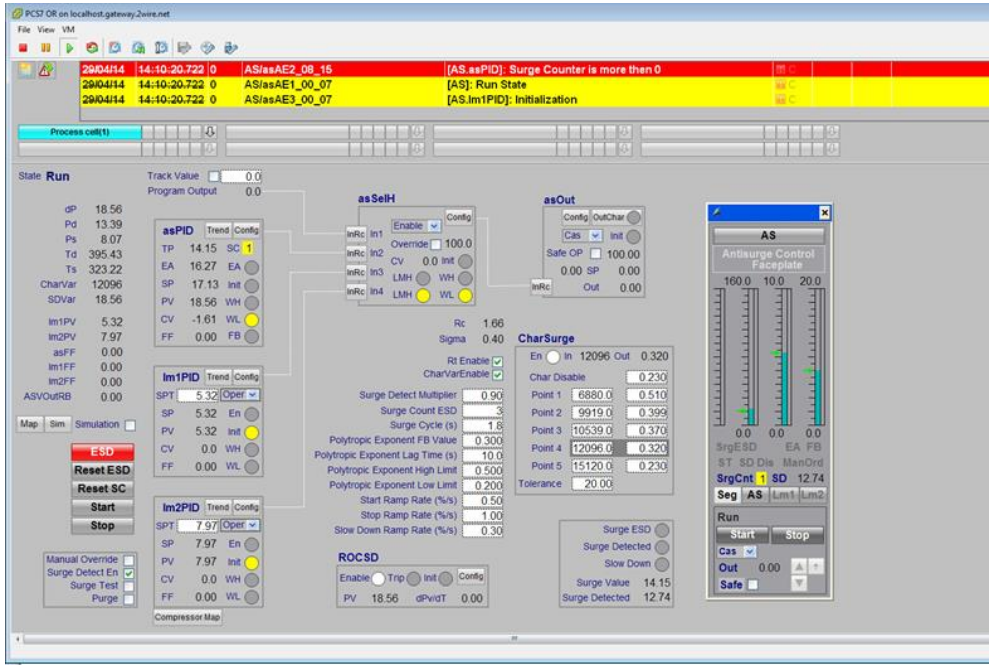
Hardware and Software Independent Control Platform

Now you can control your rotating equipment with the same control platform as the plant with tested, flexible, and competitive solutions and reduce support and maintenance costs





Benefits

Process Control

- Increased process reliability
- Reduced start-up time
- Reduced product waste
- Improved process control
- Reduced energy consumption
- Improved stability
- Reduced maintenance cost
- Reduced capital cost

Unit Control System

- Improved Compressor protection
- Larger operating envelope without recycle
- Optimum control during start-up
- Single supplier solution
- OEM neutral
- Hardware and software independent control platform
- Integrated compressor and turbine control system