Understanding Centrifugal Compressor Capacity Controls:

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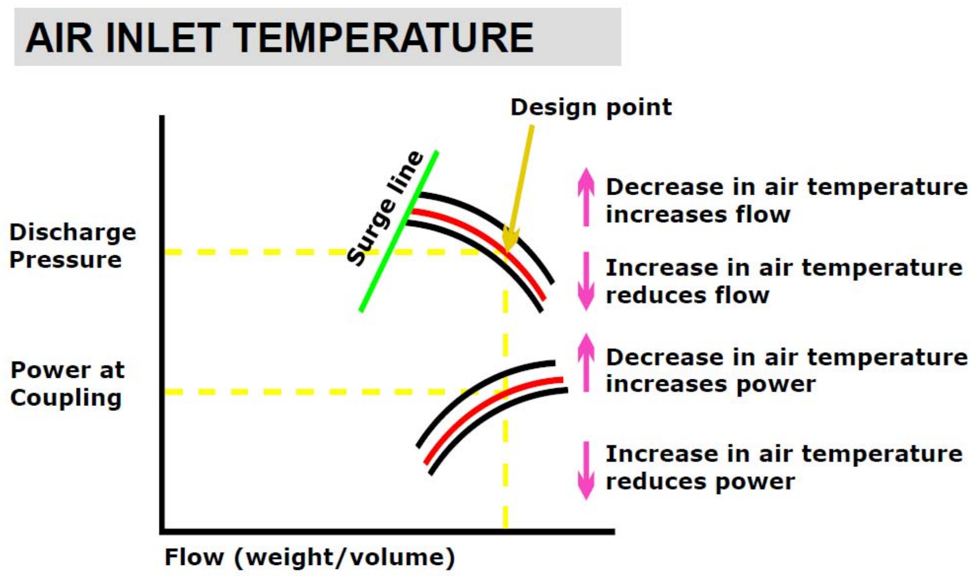
CAGI and our centrifugal customers all share a common interest and goal - to maximize the compressor system efficiency and optimize the system energy usage. Since the capacity controls on a centrifugal compressor are a bit more complex than positive displacement types of compressors, consulting a factory-trained technician is always recommended. The members of the Centrifugal Compressor Section of CAGI can provide that assistance.

Centrifugal compressors are dynamic and each has a characteristic curve of rising pressure as capacity decreases. Without any control system, the compressor would operate along this natural curve. A centrifugal compressor's flow and pressure are typically controlled by a combination of an inlet control device and unloading valve (UV).

Solutions for Inlet Regulation

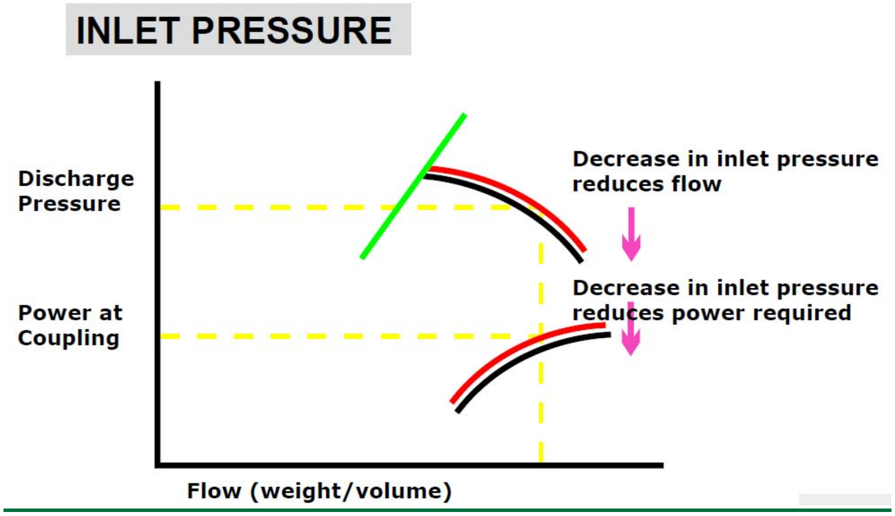
The inlet can be throttled on a dynamic compressor to continuously reduce the capacity of the compressor. The minimum flow is determined when the pressure ratio reaches the pump limit and the machine reaches maximum pressure. The regulation range, or turndown, is determined by the design of the machine. For example, turndown is affected by the number of stages and the impeller design. Regulation range is also affected by external factors, such as inlet air conditions (temperature, pressure, and humidity), and coolant temperature.



Inlet Control Devices

The following are two methods for throttling the inlet:

Inlet Butterfly Valve (IBV):
The Inlet Butterfly Valve may be driven electronically or pneumatically, and as it closes it creates a pressure drop across the valve, effectively reducing the inlet pressure into the compressor and throttling the compressor's ability to make pressure and subsequently flow.



Inlet Guide Vanes or (IGV's):
The Inlet Guide Vanes may also be driven electronically or pneumatically, and are a series of radial blades arranged in the intake. These vanes, in the wide-open position, are parallel to the airflow, and at fully closed are at 90 degrees to air flow. As the guide vanes are rotated from full open to partially closed they cause the drawn-in gas to rotate in the same direction as the impeller. These pre-swirl changes the incidence angle of the incoming air as it approaches the inducer section of the impeller, effectively reducing the energy required to produce pressure and flow. The use of IGV's can effectively throttle the compressor with the added benefit of being more efficient. Depending on where you are operating on the compressor curve, a user may see up to a 9% efficiency gain over standard IBV throttling.

The load set point of a centrifugal compressor is typically at a given pressure so when the system pressure falls below a given level the compressor will load.

CONTROL AND REGULATING SYSTEM FOR CENTRIFUGAL COMPRESSORS

Auto-Dual Control (See Figure 1)

- The standard regulation is achieved by means of inlet butterfly valve (IBV), or inlet guide vanes (IGVs) and controller.
- The compressor discharge pressure set point will be set at the desired level and the IBV or IGVs will modulate the compressor inlet to maintain constant discharge pressure over the control (B→C) range.
- At the minimum throttle point (C), the IBV or IGV valve stops closing, allowing the discharge pressure to rise to the unload set point. At this moment the compressor will unload, IBV or IGV will close and an unloading valve fully opens.
- The compressor remains in the unloaded condition until the compressor resumes load at full flow and the cycle is repeated.
- Re-loading time varies in this control method and depending on the system's storage capacities relative to the demand swings it may be advisable to install measures (additional compressed air storage) to protect the process and the compressor against short cycling.

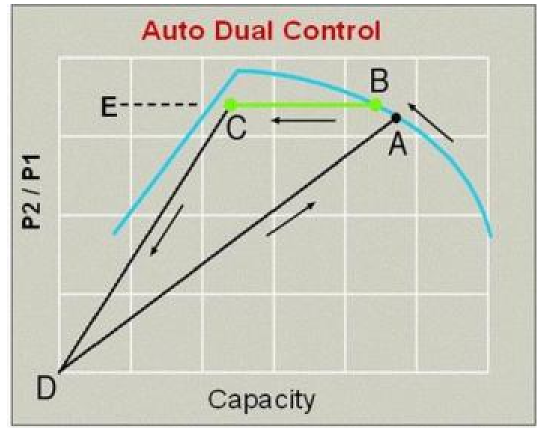


Fig. 1

If the compressor does not need to reload within a fixed time period, the unit may be configured to power down and stop. The controller will automatically restart and load in response to the system pressure falling to the load set point (A).

Constant Pressure Control with Modulating Unloading Regulation (UV) (See Figure 2)

- This control method uses the IBV or IGV, modulating UV and a controller.
- The compressor discharge pressure set point will be set at the desired level and the IBV or IGV will modulate the compressor inlet to maintain constant discharge pressure over the control (A→B) range.
- At the minimum throttle point (B), the position of the IBV/IGV is maintained as fixed, and the unloading valve (UV) starts to modulate open.
- In this way, a constant discharge pressure is maintained over the full operating range of the compressor (A-C).
- Some controls can also provide for a maximum unloading valve (UV) position to be programmed. This allows the owner to minimize inefficient operation during periods of low demand by limiting unloading operation to a point between (B→C).

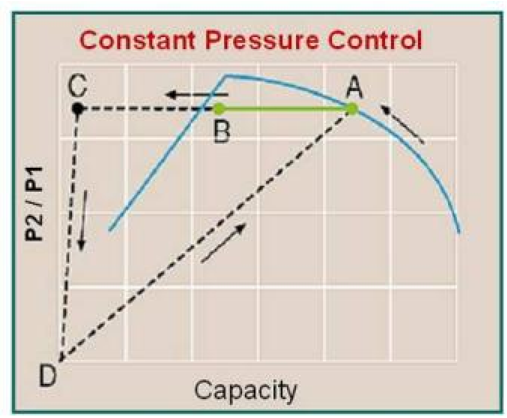


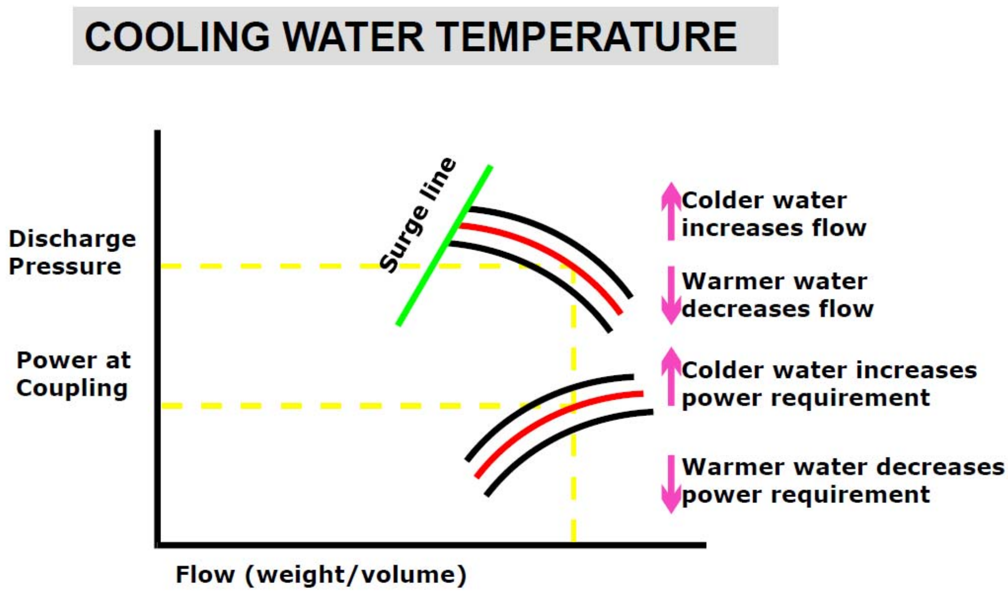
Fig. 2

The constant pressure control system is designed to continuously control the air output while keeping the net pressure fluctuations to a minimum. Constant pressure is critical in many applications.

Impact of External Factors on Regulation

Typical turndown ratios for a centrifugal design are 30-40% while operating in auto dual mode. The percentage depends on inlet air conditions as mentioned above, and will typically be larger at cold temperatures and smaller in hot summer conditions. In centrifugal design there is a trade-off between the aerodynamic efficiencies and turndown. Larger turndowns can be achieved, but result in lower aerodynamic efficiency. This analysis has to be made in cooperation with the manufacturer based on required flow profiles to determine optimum system design.

These figures show effect of variables like inlet temperature, inlet pressure and cooling water temperature



How Surge Occurs in Centrifugal Compressors

Surge is the phenomenon of aerodynamic instability that can occur in centrifugal compressors. The pressure rise in centrifugal compressors is created by imparting high velocity (kinetic energy) to flow path of air through the impeller. The later conversion of velocity to pressure (potential energy) occurs in the diffuser, and possibly in the volute, if the compressor is so equipped.

Due to this limitation, any single compression stage cannot increase the pressure head above a limit of about 2.5 ratios (depending on design).

If the centrifugal compressor experiences surge during compressor operation, it is considered to be running in an unstable condition. Manufacturers take into consideration surge events when designing their compressors and thus the occurrence of a single or even multiple surges will not reduce the life or damage the compressor. A qualified technician should be called in if repeated surging is occurring. Manufacturers all use surge anticipation control to ensure reliable operation. There are several different methods to accomplish surge control:

Surge Control and Protection

CAGI members have designed surge control and protection into their products. Surge is a situation that can be avoided. Surge control and protection is available for both auto-dual and constant pressure controls systems. In fact, as part of system start up, technicians manually surge the compressor to set up the control system.

Motor current control:

The motor current can be correlated with compressor flow. As flow decreases, the motor current will also decrease. This can be correlated to the surge point of the compressor. With this control, when the motor reaches the minimum current set value, the unloading valve will start opening to prevent the compressor from surging. This method is simple and straight-forward; however it does not always optimize the actual turndown range of the compressor.

Surge anticipation control optimization:

To optimize surge anticipation control, the controller monitors the actual position of the surge line with respect to the existing ambient inlet conditions, and prevents the compressor from surge by opening the unloading valve when the compressor flow reaches to surge point. This control optimizes the turn down and allows the compressor to run at actual turndown based on existing ambient inlet conditions.

Modern control systems employed by most manufacturers result in trouble free, reliable and efficient operation. With several control methodologies to choose from, customers can optimize their centrifugal compressor performance to suit the application needs. Understanding the impact of environmental conditions on compressor performance allows for further improvement in reliability and efficiency.

CAGI's Centrifugal Compressor Section members: Atlas Copco, FS Elliott, and Ingersoll Rand have trained engineers to assist and guide users through selecting the right size compressor and options of the centrifugal compressor for their operation. A compressor system assessment is recommended when upgrading and/or replacing existing systems to ensure that system performance is maximized. CAGI members can also assist in the operation of existing equipment and systems.

For more detailed information about CAGI, its members, compressed air applications or answers to any of your compressed air questions, please contact the Compressed Air and Gas Institute. CAGI's educational resources include e-learning coursework on the *SmartSite*, selection guides, videos, and as well as the Compressed Air & Gas Handbook. For more information, contact the Compressed Air & Gas Institute, tel: 216-241-7333, email: cagi@cagi.org, or visit www.cagi.org.

November, 2015