Centrifugal air compressor basics

Key concepts Centrifugal compressors are most effective when running at full capacity. Choke and surge occur at the extreme ends of the performance curve and should be avoided. Compressor capacity should be stated at plant conditions, which are actual cubic feet per minute (acfm). Centrifugal air compressors are best suited to applications where demand is relatively constant.

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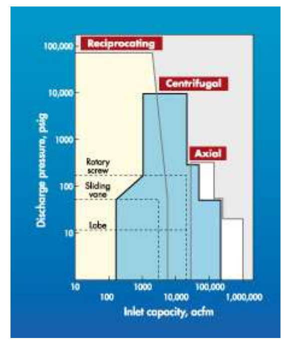
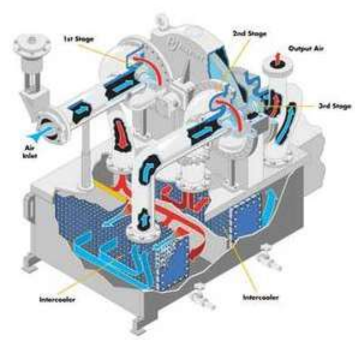
Key concepts



- Centrifugal compressors are most effective when running at full capacity.
- Choke and surge occur at the extreme ends of the performance curve and should be avoided.
- Compressor capacity should be stated at plant conditions, which are actual cubic feet per minute (acfm).
- Centrifugal air compressors are best suited to applications where demand is relatively constant or in plants where they can be used for base load operation, allowing other types of compressors to be used as trim machines to meet peak demands.
- Three-stage centrifugal compressors are generally more efficient than rotary screw types and can approach the efficiency levels of double-acting reciprocating compressors.
- The most common design has three stages for pressures in the 100-150-psig range. Designs with 8 stages can reach pressures up to 1200 psig. A water-cooled intercooler and separator between stages return the air temperature to approximately ambient and remove condensed moisture. An aftercooler and separator cool the air from the final stage and remove more moisture before the compressed air enters the plant air system.
- Centrifugal air compressors are dynamic machines. Air is compressed by the mechanical action of high-speed, rotating impellers imparting velocity and pressure to the air. Approximately half of the pressure energy is developed in the impeller, with the other half achieved by converting velocity energy to pressure energy as the air speed is reduced in a diffuser and volute.

An inherent characteristic of centrifugal air compressors is that as system pressure decreases, capacity increases. The steepness of the pressure head/capacity curve is dependent on impeller design. The more the impeller blades lean backwards from the true radial position, the steeper the curve.

Choke and surge

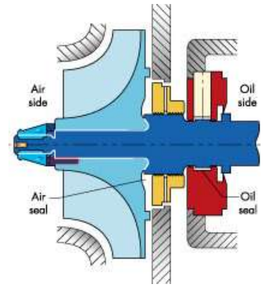


As system pressure continues to decrease, air delivery from the compressor increases until the velocity somewhere in the compressor reaches the speed of sound. At this point, flow is choked because further reduction in system pressure does not result in additional air delivery.
Maximum discharge pressure of the compressor is a function of the intersection of the surge line and performance curve. When air system pressure increases, the compressor supplies less air until its natural surge point is reached. At this point, the compressor is unable to maintain a steady flow of air into the system.
When this point is reached, backflow from the system through the compressor occurs until a momentary equilibrium is established between the compressor and the system.

This backflow is referred to as surge.
This phenomenon is roughly equivalent to the stalled condition of an airfoil. Under this condition, compressor operation moves from surge point to some pressure point below it on the performance curve. When the compressor continues to operate against sustained, excessive system pressure, operation moves up the curve and surge occurs again.
Neither choke nor surge is desirable and should be avoided.

They can both result in excessive vibration and temperatures, which can damage the compressor. Control systems that allow the compressor to function without reaching the choke or surge condition should be based on prevailing environmental conditions, which do affect compressor performance.
Most standard air compressor packages are designed for an ambient temperature of 90 F and near-sea-level barometric

pressure. The dynamic nature of the compressor results in the pressure head generated by each impeller increasing as air density increases.



The compressor mass flow and standard cfm (scfm) capacity at a given discharge pressure increase as the ambient temperature decreases. A capacity control system adjusts the output of the compressor to maintain a desired system pressure and operates the compressor within motor horsepower limits. The control system regulates airflow with an inlet throttle valve or guide vanes. The throttled surge point limits the amount of reduction in flow rate at a given pressure. Centrifugal air compressors provide lubricant-free air. Lubrication used for speed-increasing gears and high-speed shaft bearings is kept away from the compression chambers by shaft seals with air purge and vent connections . Because they are high-speed machines, these compressors must have shaft vibration monitors for recording operational trends and protecting the equipment. Automatic control of the compressor is typical and improved by the use of microprocessors, which monitor pressure/capacity/temperature characteristics, as well as main drive motor current draw.

Centrifugal compressors are most effective when running at full capacity. To achieve this condition, a survey of all compressed air consumption must be made. That's the easy part. The difficulty comes in selecting a compressor to meet these needs.

Do you select a compressor that delivers standard cubic feet per minute (scfm) or actual cubic feet per minute (acfm)?
One of the most confusing areas of specifying air compressors is defining capacity. Since it is critical to getting a properly sized compressor, specifying capacity must be done correctly. Start with the part that is common - cubic feet per minute (cfm). This figure is the volume of air that is compressed each minute and is measured at the inlet to the compressor.

Most pieces of production equipment have their compressed air requirements defined in terms of standard cubic feet per minute. This term defines the weight of air because it refers to air density at standard conditions: 14.696 psia, 60 F, and 0% relative humidity (RH). SCFM is not meant to define the conditions at a plant; it is meant to tie all compressors to a common set of conditions.

Once the scfm requirement is determined, the supplier has the responsibility to provide the proper compressor. Since compressors are normally rated in actual cubic feet per minute capacity, acfm must be converted to scfm. The conversion is accomplished by applying the following formula:

$acfm = scfm \times P_{std} / P_1 - (P_{sat\,1} \times RH_1) \times T_1 / T_{std}$
Where: P_{std} = 14.696 psia
P_1 = barometric pressure at plant site, psia
T_1 = ambient air temperature on design day, R
(R = F + 460)
$P_{sat\,1}$ = saturation pressure at P_1 and T_1 ,psi (value from steam tables)
RH_1 = ambient relative humidity at plant on design day (expressed in decimal form)
T_{std} = standard temperature, R (60 + 460 = 520)
For example, assume the following:
125-psig discharge pressure
1000 scfm
Site conditions: T_1 = 95 F, P_1 = 14.1 psia, and RH_1 = 80% (0.8). From the steam tables, Psat = 0.8153 psi.

To provide 1000 scfm the compressor must deliver 1167 acfm at the plant site conditions. If the plant were at an elevation of 7000 ft, P_1 would be 11.34 psia and the acfm would increase to 1468.
When specifying compressed air requirements, pick a design day that represents a worst case scenario. For a compressor, hot humid days are a worst case. Pick a realistic maximum temperature summer day. Do not pick extreme conditions to be conservative. This selection results in a less efficient compressor system.

Compressor losses must also be accounted for. They are added to the required scfm to determine the capacity of the compressor. What about inlet cubic feet per minute (icfm)? This unit is used by vendors to establish conditions at the inlet flange of the compressor. ACFM is measured at the plant site. The difference in most cases is the inlet filter. It causes a drop in air pressure as the air flows through and must be taken into account when estimating compressor performance.

Inlet control

Two devices are used to control the inlet flow to a centrifugal air compressor: inlet butterfly valve (IBV) and inlet guide vanes (IGV). They are usually mounted at the inlet to the first stage. Both are actuated by the compressor control system as a reaction to system demand. The result of their action is the same, but their operating principles are different.
There is no difference between an IBV and IGV when the compressor is operating at 100% load. In the throttle range of the compressor, these devices act to change the pressure the first-stage impeller sees. Density of the air decreases as the pressure drop increases. As the density decreases, the mass flow produced by the compressor also decreases.

A centrifugal compressor can be throttled this way until the throttle surge point is reached. Fig. 5. Adjustable inlet guide vanes can provide up to 9% energy savings. (Courtesy Atlas Copco Compressors, Inc.)
With a butterfly valve, airflow into the impeller eye is straight in. Air enters the impeller, where it is spun, given velocity, and projected into the diffuser section of the compressor stage.

The driver provides the horsepower to the compressor stage, causing the air to turn in a radial direction and develop velocity. Because air enters the impeller axially, the driver must provide all the energy required to spin the air.
An IGV has movable vanes positioned so that the inlet air to the impeller eye is caused to swirl in the direction of impeller rotation (Fig. 5). The flow angle to the impeller eye increases as the vanes are closed.

With increased angle, the first-stage impeller is required to do less work than is required with an IBV.
IGVs are used to improve the overall efficiency of compressors. Its benefit is seen only when the compressor is being throttled. If a compressor is fully loaded most of the time, do not add mechanical complexity by specifying an IGV.

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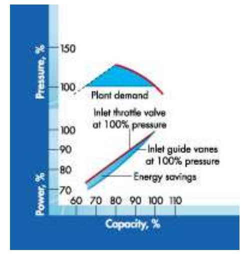
Causes of premature surge

Dirty intercoolers-Increased air temperature reduces air density into the compression stage, resulting in reduced stage pressure ratio and reduced rise to surge. Dirty inlet filter-Reduces the pressure into the first stage, resulting in a lower natural surge point. A lower natural surge point reduces the throttle range.

Hot coolant-Increased air temperature reduces air density into the compression stage, resulting in reduced stage pressure ratio and reduced rise to surge.

Hot inlet air-Increased air temperature to the first stage reduces air density into that stage, resulting in reduced stage pressure ratio. Since pressure is multiplied as air moves through a multistage compressor, the first stage has the most dramatic effect on rise to surge. Driver input speed-Ability for a centrifugal compressor stage to make pressure decreases as the square of the stage speed. A reduction in driver input speed dramatically affects the total machine pressure ratio and the rise to surge.

General installation guidelines



Foundation: While the foundation need not be as massive as that for a reciprocating compressor, it must be sufficient to provide a permanently rigid, nonwarping support. The foundation should be designed to avoid possible resonance with running frequencies of the compressor and drive train.

Crane facilities: Overhead cranes are needed not only to install the compressor, but also for maintenance.

Space: Ample space should be provided to permit easy handling during erecting.

Accessibility: The compressor should be installed where it can easily be observed and maintained.

Cleanliness: The compressor should be installed and maintained in a clean area. Outdoor installations require particular attention. Piping and wiring: The compressor should be located to require minimum piping and wiring runs. A compromise could be made in favor of ease in operation.

Instrumentation: Instruments should be mounted in a central location and in easy view of the operator, particularly during startup.

Preventive maintenance outline
There is no single, established approach to an effective maintenance program for every compressor installation. It is important to tailor the maintenance program to each installation.

Daily

- Check lubricating and seal oil reservoirs
- Check lubricating and seal system oil filters
- Check operation of all coolers and traps
- Review all supervisory and process instruments
- Listen for noise level and pitch changes
- Visually inspect for leaks and loose parts
- Check differential pressures across intake filters, intercoolers, aftercoolers, and interstage separators
- Observe levels in sight flows for abnormal level changes

Weekly

- Verify the calibration and operation of all protective alarm and trip devices through actual test
- Monthly
- Make a vibration survey of each bearing housing
- Test the performance of all intercoolers, aftercoolers, and oil coolers
- Lubricate the linkage, pins, and slide bars of all control valves, valve positioners, and guide vane positioners
- Analyze oil samples from lubricating and seal oil reservoirs

At major shutdowns

- Inspect couplings
- Verify alignment of all couplings
- Clean and inspect all journal bearings
- Clean and inspect all thrust bearing assemblies
- Inspect oil baffles for signs of rubbing, plugged drain holes, or chipped touch points
- Remove the casing cover for an internal inspection if performance levels or maintenance schedules dictate
- Drain and clean each lubrication and seal system
- Remove and inspect process check valves
- Inspect expansion joints Inspect speed increasers
- Check the calibration of all instruments and alarm and trip devices
- Follow the driver manufacturer's recommended inspection and maintenance procedures

Advantages/disadvantages of centrifugal air compressors

Advantages

- Completely packaged for plant or instrument air up through 500 hp
- Relative first cost improves as size increases
- Designed to deliver lubricant-free air
- Does not require any special foundations

Disadvantages

Circle	Company	Flow range,	Horsepower	Max. stages in	Max. single train	Min standard	Driver

- Limited capacity control modulation, requiring unloading for reduced capacities
- High rotational speeds require special bearings and sophisticated vibration and clearance monitoring
- Specialized maintenance considerations

		icfm	range	one gearbox	discharge, psig	pressure, psig	options
Note: Driver options, D = diesel engine, E = electric motor, T = turbine							
221	Atlas Copco Compressors, Inc. atlascopco.com	2000/5000	500/1200	3	150	80	E
222	Cooper Turbocompressor turbocompressor.com	550/80,000	100/25,000	8	1200	20	D, E, T
223	Elliott Co. elliott-turbo.com	600/20,000	200/4000	3	175	100	E, T
224	Gardner Denver, Inc. gardnerdenver.com	2000/7600	400/1500	3	150	90	E
225	Ingersoll-Rand Co. ingersoll-rand.com	1100/28,000	200/5250	5	350	10	D, E, T

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