Module No. – F021

Centrifugal Compressors – Operation

Introduction
In the module titled Centrifugal Pump Operation, a lot of important introductory information was provided prior to actual pump operational procedures. That information included certain recommendations that would help an operator become familiar with equipment long before operating it. Many of those suggestions will be provided in this module also.

No one should attempt to operate a piece of equipment until they have been adequately trained and have demonstrated their ability to do so. No matter how simple a task appears, there is always the potential for personal injury, equipment damage and plant disruptions.

Written procedures, produced by equipment manufacturers and/or experienced plant personnel, are usually provided for compressor operation. These written procedures must be followed. Operators should become familiar with them and know where they are kept for easy reference. In this module, general information will be provided for compressor operation, but these do not replace established procedures.

Compressor Installation
Before starting any compressor, there is certain information an operator should know. One of the most important things is the nature of the gas being compressed. Is it toxic? Is it corrosive? Where is the source of the gas? Where does it go after compression? What pressures and temperatures are involved? These and many other questions should be answered long before an operator starts a compressor. In cases where a new compressor arrives at a plant, operators should be involved with the commissioning (initial startup and testing) if possible. During this stage, operators can acquire a lot of useful information.

The following suggestions involve new compressor installation:
• An operator should begin the familiarization process as soon as a new compressor arrives at the plant and is initially inspected for damage that might have occurred during transit. Determine the purpose and future location of the compressor. Look carefully at its construction. Is it a single-stage or multi-stage design? What types of sealing devices does it have? How will it be driven? What information can be found on the nameplate? Did any documentation (installation instructions, operating parameters, startup procedures, etc.) come with the compressor? Since this is likely the case, find out where that information is kept. The process of becoming knowledgeable about a piece of equipment makes its operation much easier to learn.
• When installation of the compressor begins, observe as much as possible. Note the method used to secure the compressor in its location. Watch as the compressor is coupled to and aligned with its driver.
• Observe an electrician connecting power to the motor if the compressor is motor-driven. If the motor rotates backwards when first tested, the electrician will have to make the necessary wiring connections to correct the problem. Where is the breaker to shut off power to the motor? At what speed will the compressor and motor rotate? That, and other information, is likely indicated on the motor nameplate. Where is the compressor start/stop control? Can the compressor be started only locally (i.e. right at or near the compressor) or is it remote-start or both? Can it start automatically?
• Concerning ductwork and piping connected to the compressor, some of the questions that must be answered are the following:
  Are there dampers or vanes in the ductwork at compressor inlet and/or outlet? (Generally, dampers are rectangular in shape and vanes are in the shape of a segment of a circle, like a slice of pie.) This information could provide clues concerning the type of control system used on the compressor.
  Are piping and ductwork installed so that no strain is placed on the compressor? This could lead to vibration, bearing wear and seal damage. Is provision made for piping/ductwork expansion and contraction? Where are
valves located (including any in auxiliary systems such as lubricating oil)? What kinds of valves are used? Are all valves, controls, etc. easily accessible and clearly indicated?

- Look at all instrumentation associated with the compressor. Are there gages to indicate suction pressure and discharge pressure? Are there pressure gages on either side of the inlet filter? Higher than normal inlet filter pressure differential is an indication that the filter is dirty. Are there lights, often green or red, to indicate if the compressor is operating? Which colour indicates "ON" and which colour indicates "OFF"? Are there any visual alarms, such as a light to indicate that the suction filter is becoming dirty? Are there any audible alarms, such as a buzzer to indicate low lubricating oil pressure? Are there automatic shutdown devices, such as a temperature switch to stop the compressor if discharge temperature becomes too high? Instrumentation is a critical aspect of equipment operation and an operator must understand it completely before startup.

- If there are any fittings, instrumentation, devices, etc. that are not familiar, these should be clarified before attempting to start a piece of equipment.

- Look for any details related to personal safety in the area of the compressor. Should certain personal protective equipment be worn in the area? Should warning signs, barriers, etc. be warranted? Make any concerns known before equipment operation.

Operators obviously can't know everything about equipment installation and commissioning, but a competent operator learns as much as possible about a piece of equipment before attempting to operate it.

**Pre-start Checks**

No piece of equipment, whether new or old, should be started unless an operator has performed the necessary pre-start checks. If one assumes that equipment is ready to start, the consequences can often be personal injury or even death. At the very least, equipment damage will likely occur.

Because pre-start checks depend on so many variables (type of equipment, size, purpose, etc.) the information presented here must be considered as only a guide. These guidelines do not replace established procedures. An important component of plant operation is clear communication. For example, if instructions were given to "Start C1", it is possible that there is more than one compressor called "C1". It is also possible that the instruction was to "Start P1" (likely a pump designation), but the listener did not hear clearly, with potentially disastrous results. Be absolutely sure that communication is clear and concise. Only after instructions are understood should an operator proceed to the location of the compressor.

After one arrives at the correct location, a quick, general check of the area is a good idea. Notify anyone in the immediate area that the equipment is about to be started so they won't be startled by noise, etc. If any activity (such as maintenance) is occurring in the area, ask about it before starting the equipment. If any activity is occurring that could affect equipment operation, report this to your supervisor immediately. Report unsafe conditions (for example, a missing coupling guard) or any other concerns (for example, a loose nut on a damper linkage) immediately.

The sequence and content for the following pre-start checks are not suitable for all centrifugal compressors. The list is a guideline only and, again, is not a substitute for plant operating procedures.

1. One of the first steps always is to verify lubrication for bearings, such as checking oil levels in bearing housing sight glasses. Some bearing housings are supplied with cooling water to limit oil temperature. If so, cooling water valves might have to be opened.
2. If possible, verify that inlet filters are not plugged. In the case of an air compressor, this might be done visually.
3. If the compressor seals use sealing liquid or buffer gas (these are explained in the module titled Centrifugal Compressors - Equipment Description), these will be put into service before starting the compressor.
4. It is usual practice to start a centrifugal compressor with no flow through the machine. As is the case with centrifugal pumps, the reason for this is to limit the amount of electric current draw by the motor on startup. This action prolongs the life of the motor. Thus, if applicable, verify that dampers are closed.
5. Dampers (if there are any) on small compressors could be manually operated. These, in some cases, can be stroked (i.e. opened and closed) prior to startup to prove that they are working satisfactorily. If dampers are not manually operated, other checks might be needed. For example, if dampers are operated pneumatically,
one should verify that air supplies to damper operators are available, perhaps by visually checking certain valves in the air supply are open.

6. Depending on the amount of instrumentation associated with the compressor, there could be other required checks. Some compressors are fitted with devices to prevent startup until certain conditions are met. For example, dampers on the compressor inlet might be fitted with a position switch. If this switch does not indicate the inlet dampers to be closed, the compressor will not start. The switch position (thus, damper position) can be visually checked prior to startup.

Always try to be nearby when a compressor or any piece of equipment is started. Verify that applicable dampers, automatic cooling water valves, etc. operate as required. Check for equipment vibration and unusual noises, smells, etc. Report any unusual findings immediately.

After the compressor has been started and initial running checks have been completed, regular inspections should be made at certain intervals. These intervals vary, but should be more frequent during the first few hours of operation. As always, look for fluid leaks, listen for unusual noises, be aware of odd smells, and carefully touch equipment components (such as bearing housings) to detect vibration. Visually look at all indicators (oil level gages, temperature gages, pressure indicators, etc.) to ensure the compressor is operating safely and efficiently.

**Control Modes**

Because of the wide variation in compressor sizes, complexities, applications, etc. there is also a wide selection of control modes. Some of these will be explained briefly in this section.

**Start/Stop Control**

This is the simplest method of compressor control. It is often used on small air compressors installed in a system having a vessel (called an air receiver) for storing compressed air. A pressure-actuated switch monitors pressure in the receiver. When this pressure drops to a pre-determined value, electrical contacts inside the switch close to start the compressor motor. The compressor starts and causes receiver pressure to increase to some value above the compressor cut-in value and the compressor stops. As air is used, the compressor eventually starts again and the cycle continuously repeats.

Start/stop control is very simple. Because centrifugal compressors operate most efficiently when they are at full capacity, this is also the most economical method of compressor control, because the compressor is either not running or is at full capacity. However, there are a couple of serious drawbacks.

1. A surge of electrical current flows into the motor every time it is started. Numerous frequent starts drastically reduce the life of the motor.
2. Frequent starts necessitate a large storage vessel and the associated equipment/fittings it requires. Thus, the overall cost of the system increases significantly.

**Continuous-run Controls**

This type of control system eliminates the need for repeated motor starts/stops. As the name implies, the motor runs continuously. The two main types of continuous-run controls are called two-step control and modulating control. In both cases, the compressor is fitted with vanes or dampers, usually at the compressor inlet.

In two-step control mode, when compression is not required (i.e. demand for compressed gas decreases) some method is used to stop further compression. In many cases, a pressure switch on the compressor discharge senses when pressure is adequate and causes inlet dampers to fully close, thus preventing further compression. When the discharge pressure falls to a certain lower pressure, the switch causes the inlet dampers to open fully, resulting in maximum gas compression. Thus, the compressor is either fully loaded or not loaded, resulting in maximum efficiency. If this type of control system is in place, there must be a suitably-sized gas storage vessel. If storage capacity is inadequate, the compressor will not be at idle (not compressing) for a sufficiently long time to achieve any significant cost savings. Inadequate storage space also results in dampers operating more frequently, resulting in shortened life as the parts move more frequently.
Another type of continuous-run control, known as modulating control, is much better at matching gas supply and demand. If the flow of compressed gas exiting the compressor increases, resulting in a discharge pressure decrease, inlet dampers are opened slightly to allow more compression and maintain a steady discharge pressure. Conversely, if gas flow decreases, resulting in a discharge pressure increase, inlet dampers are closed slightly to reduce the amount of compression. In this manner, discharge pressure remains fairly constant at all times. Overall compressor efficiency is higher with this method and a method of gas storage is not as critical as with the two-step control method.

**Variable Speed Controls**
This type of control system, as the name implies, causes centrifugal compressor rotational speed to be changed to meet gas flow demands. In some cases, the speed of a specially-designed motor, to which a centrifugal compressor is coupled, is increased or decreased to meet compression requirements. Speed is varied by changing electrical frequency, so that these motors are referred to as variable frequency drives. (The meaning of the term "frequency" is discussed in modules dealing with electricity and is not important here.) These motors are quite expensive and not a practical choice for smaller compressors. A steam-driven turbine or a gas turbine could also be used for large centrifugal compressors.

**Inlet Control**
This common method of compressor control makes use of a device, such as a valve, at the inlet to the compressor. As discharge pressure changes with gas flow variations, the device opens or closes sufficiently to maintain a fairly constant discharge pressure. The type of valve chosen, of course, is important. As discussed in the module titled Types Of Valves, not all valves are suitable for throttling (regulating) flow. A butterfly valve might be suitable for use at the inlet to a centrifugal compressor.

A better choice for inlet control is the use of inlet guide vanes. This control method can result in substantial (up to about 9%) cost savings if the compressor is often at less than full capacity. See Figure 1.

![Figure 1 Inlet Guide Vanes](image)
Referring to Figure 1, notice that there are a certain number (not always eight as in this case) of blades in a circular casing. Each blade is in the shape of a segment of a circle and each blade is pivoted along its axis. The blades are interconnected via an external ring. When the external ring is rotated, all of the blades rotate on their axis, at the same rate, allowing more or less gas into the compressor. The control linkage can be operated electrically or hydraulically by the control system. Manual operation is also possible.

The economic benefit from this device is due to the manner in which gas enters the compressor. As the gas flows through the inlet vanes, it is caused to rotate by the shape and angle of the space between the blades. The gas is given a rotating motion in a direction that is the same as that of the first-stage impeller. Thus, the motor does not have to work as hard (compared to straight entry provided by a valve) to begin rotation of the gas, resulting in power and cost savings.

Anti-surge Control
In the module titled Centrifugal Compressor Introduction, the concept of "compressor surge" was introduced. Surge occurs when flow through the compressor is less than a certain minimum; compressor discharge pressure falls below the pressure in the discharge piping and gas begins to flow backwards through the compressor. Compressor discharge pressure then becomes higher than the pressure in the discharge piping and flow resumes in the normal direction. This process can be repeated several times in a very short time period. Thus, in simple terms, surge is a series of flow reversals.

Some of the causes of surge are:
- compressor fouling (i.e. internal blockage)
- blockage in the suction or discharge piping
- equipment, such as inlet vanes, malfunction
- loss of compressor speed, perhaps caused by driver malfunction
- operator error, such as manually closing inlet vanes
- changes in pressure, temperature or composition of gas

The effects of surge can vary. The compressor might simply not operate as effectively. On the other hand, severe compressor vibration can result, leading to potential compressor damage. At the same time, damage to connected ductwork and piping can occur. Increased noise levels, erratic gas pressures and vibration in ductwork and piping systems are some of the indications of surge.

Anti-surge control systems ensure that a centrifugal compressor operates at a minimum flow that is above that where surge begins. If the compressor is handling relatively safe gases, such as air, the control system could simply cause a valve in the discharge ductwork to open. This valve would allow compressed air to be vented safely to atmosphere. In cases where gas can't be safely vented to atmosphere, a valve in the discharge ductwork could be opened to allow gas to flow through a recirculation (or recycle) line back to the compressor inlet. Again, this would ensure a certain minimum flow through the compressor.

Anti-surge control systems might use gas flow, differential pressure between compressor inlet and discharge, driver power, etc. or a combination of these and other measurements. Some of the systems are very complex. Figure 2 is an illustration, showing only some of the main components, of a very simple anti-surge control system. Compressor differential pressure and gas flow are measured, then these values are transmitted to a controller that causes the recycle valve to operate. The dotted lines indicate that the control system in this case is pneumatic and the valve is also operated pneumatically.

Figure 2 Anti-surge Control
One can now appreciate why choices of compressor and system components is so critical. Anti-surge controls and equipment must be carefully selected also, no matter what method is used to prevent surge. Some of the reasons for this are:

- Unnecessary or excessive recirculation of gas is not economical. The driver is providing energy to the gas, via the compressor, but the energy is not being used to move all of the gas to the discharge ductwork.
- When gas is compressed, some of the energy supplied to the gas, via the driver and compressor, is converted to heat. Thus, the gas temperature increases. For this reason, heat exchangers are often provided at the compressor discharge to cool gas leaving the compressor. Excessive gas recirculation results in higher gas cooling requirements, meaning that some of the energy supplied to the gas is simply removed from the gas and wasted.
- The anti-surge system must be capable of acting quickly, but not so often that equipment, such as the recycle valve, experiences excessive wear.