CENTRIFUGAL COMPRESSORS — NOT JUST A BASELOAD COMPRESSOR ANYMORE

By Richard Huguenor

This entry discusses how the modern multi-stage integrally geared centrifugal compressor has a wide range of pressures, flow, and turndown and can be used as both a baseload and for trimming compressor applications.

History

Centrifugal compressor technology has been around a long time. The origin can be traced back to the year 1689, when French physicist Denis Papin and Dutch physicist Christian Huyghens collaborated by experimenting with an air compressor, using centrifugal force to compress air. As the physics community gained a better understanding of fluid and thermal dynamics, the centrifugal compressor evolved from a crude single impeller blower into the multi-stage modern compressor we use today.

Fundamentals of Compression

A centrifugal gas compressor's fundamental compression components consist of four components:

- **Inlet** – a pipe-like structure guiding the gas into the compression chamber
- **Centrifugal Impeller** – typically a high strength disk mounted on a shaft with a raised center supporting radial blades
- **Diffuser** – a flat donut shaped plate surrounding the outside of the impeller often with raised stationary blades
- **Collector** – a structure collecting the compressed gas. Also known as a volute or scroll

These components together are called a "Compression Stage". Several stages can be used in series to obtain a variety of flows and pressures. When multiple stages are installed on a common frame using a single motor input shaft, it is then referred to as a "multi-stage integrally geared compressor."

The process of compression starts with a gas entering the inlet pipe. The inlet guides the gas into the high-speed rotating Centrifugal Impeller. Centrifugal force from the impeller increases the velocity of the gas to a high speed. As the gas exits the outer diameter of the impeller, it enters a narrow gap between the inlet and diffuser plate. This narrow space, along with the diffuser blades, causes the high-speed gas to slow down rapidly. This sharp deceleration causes the air molecules in the gas to compress, thus increasing the gas density and relative pressure. The pressurized gas is contained in the collector and efficiently moved out of the compression stage. This method of compression is referred to as "dynamic compression."

Flow and Pressure Design

Compressor manufacturers design the compression stages with a variety of shapes and sizes to produce different flows and pressures. Generally, the higher the pressure, the more stages are used. The greater the flow, the larger the compressor stage components become. Most modern centrifugal compressors have a fixed speed main driver motor. This is because dynamic compression relies on the gas achieving a high velocity imparted by the impeller. If the impeller were to slow down, the dynamic compression process would be greatly diminished. Therefore, the impeller speeds are not generally changed to control flow or pressure.

Dynamic Flow and Pressure Control

There are typically three methods used to control flow and pressure:

1. **Inlet Modulation** – the gas entering the inlet of the first compressor stage is throttled using the inlet valve. As the inlet valve closes, the gas flow and shaft horsepower are reduced. Inlet modulation is used to change the flow of the compressor, relative to the demand of the compressed air system to which it is connected. These flow changes are monitored and controlled by a modern microprocessor control system measuring the pressure of the compressed air system.

2. **Loading and Unloading** – during low flow demand, it may be necessary to unload or stop the flow of the compressor. This is done by closing the inlet valve completely and opening a bypass valve after the final compression stage. While the impellers are still rotating at full speed, no air compression occurs. This method is used if the compressed air system can tolerate pressure fluctuations between 5 and 10 psi, as the compressor will be loaded and unloaded as needed during low flow periods.

3. **Blow-Off** – during low flow demand, instead of unloading the compressor, we blow off excess air. This is done by keeping the compressor loaded with the inlet valve nearly closed. The bypass valve is partially open, allowing excess compressed air to be blown off into the atmosphere, while the compressor continues to supply compressed air to the compressed air system. This method is used when the compressed air system can only tolerate pressure fluctuations between 1 and 5 psi.

The Bad Reputation of Blow-Off

The multi-stage integrally geared centrifugal compressor has gained mainstream acceptance as a reliable and energy efficient compressor for large air flow applications. Centrifugal compressors also have a persistent reputation of being a baseload compressor -- not suitable for compressed air systems with large changes in demand. This myth is based on early centrifugal compressor designs where the typical Inlet Modulation turndown was only 10-20% less than full flow. This means the compressed air system flow demand drops from 100% to 60%, the older design centrifugal compressor would inlet modulate down to 80% flow, deliver 60% flow to the compressed air system, and blow-off 20% to atmosphere. Blowing 20% off to atmosphere is seen as an energy waste. As a result, plant operators familiar with the older centrifugal compressors may avoid them today when they know that their compressed air system has flow variations of more than 20%.

Modern Technology Eliminates Blow-Off

Traditional impeller design involved manual calculations and experimentation by trial and error. With the introduction of Computational Fluid Dynamics computer simulations in the 1990's, impeller design and performance was drastically improved. Engineers could now run thousands of simulations in the computer to find the best performance, efficiency, and turn-down.

Another advancement is the modern controller. Microprocessor controllers are fast and powerful and can run many control loops simultaneously. This results in faster control valve responses, to changing demand, along with better overall energy efficiency. The centrifugal compressor of today can have up to 50% turndown, covering a large range of flows and pressures. Having more turndown means the centrifugal compressor can be installed in a compressed air system with large flow variability and not blow-off during low flow applications.

One Compressor for All Applications

The modern centrifugal compressor has come a long way over the years to become a reliable and efficient part of a compressed air system. Centrifugal compressors typically have a long lifespan and lower maintenance cost than any other type of compressor. As oil free compressors, they provide ISO Class 8573-1 Zero air quality. Oil-free air requires less filtration downstream and less product and equipment contamination. The high turndown and higher efficiency qualifies the centrifugal compressor for most energy rebate programs offered by local utilities. Overall, the centrifugal compressor can meet the requirements of most compressed air systems and should be considered as a first choice when selecting an air compressor.