TECHNICAL ARTICLE PROGRAM (TAP)
Compressed Air: The Best Choice
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TAP #102

Written by John Kharsa, Sullair Corporation

Pressure Ratio Modulation in Two Stage Oil Free Screw Compressors

Compressor designs have operating temperature limitations dictated by the capability of coatings, materials, allowable distortion, etc… For various reasons, in two stage compressor designs the discharge temperatures of each stage are not balanced throughout the operating envelope. This condition results in one stage operating at a higher temperature than the other, thus becoming the limiting factor in the ambient temperature, altitude and pressure capability of the entire compressor system. This imbalance results in limitations in the following areas:

- Temperature capability: Ambient temperature capability is reduced since it is dictated by the stage operating at the higher temperature.

- Altitude capability: For a given discharge pressure, an increase in altitude increases the second stage pressure ratio, resulting in a higher second stage discharge temperature. This temperature will be higher than the first stage discharge and becomes the limiting factor in the altitude capability of the equipment.

- Discharge pressure capability: For a given inlet conditions, an increase in discharge pressure increases the second stage pressure ratio and its discharge temperature. This temperature will be higher than first stage discharge and becomes the limiting factor in the discharge pressure capability of the equipment.

- Inlet modulation: Inlet modulation in oil free compressors without the ability of balancing the pressure ratio of each stage causes unacceptably high temperatures. To avoid unacceptable temperatures, capacity control is currently achieved by sudden loading/unloading of the compressor. This action either fully opens or closes the compressor inlet valve, allowing 100% or near zero air flow. During cycling (load/unload) the compressor parts are exposed to sudden load and thermal fluctuations, which can adversely affect reliability.

Pressure ratio modulation:

The difference in the pressure ratio, inlet air temperature, efficiency, etc… between the two stages, causes an imbalance in the discharge temperature of each stage. In addition, for a given discharge

pressure, the pressure ratio of the second stage and its discharge temperature increases with an increase in altitude. Conversely, for a given inlet conditions, the pressure ratio of the second stage and its discharge temperature also increase with an increase in discharge pressure. Consequently, the second stage discharge temperature becomes the limiting factor in the ambient temperature, altitude and pressure capability of the compressor. For some compressors, this imbalance exists from sea level to the maximum operating altitude of the equipment.

Pressure Ratio Modulation
in Two Stage Oil Free Screw Compressors

Introducing a mechanism, which permits pressure ratio modulation, can reasonably eliminate the imbalance in the discharge temperature of each stage, and its limitations. A simple mechanism, which consists of a needle valve and tubing between the discharge and interstage circuits can be used to accomplish this task (Fig. 1). *This mechanism is only beneficial in applications where the second stage discharge temperature is higher than first stage discharge*. The mechanism is utilized to gradually boost interstage pressure, thereby, reducing the second stage pressure ratio and increasing the first. This is accomplished by gradually opening the needle valve, allowing minimal amount of pressurized discharge air to flow to interstage. The feed line should be routed upstream of the inter cooler. The re-circulated hot air is then cooled through the intercooler before it enters the second stage. Consequently, the first stage discharge temperature increases and the second stage discharge temperature decreases. Optimum pressure ratio is reached when the first and second stage discharge temperatures are reasonably equal. The amount of air re-circulation depends on the difference between the two discharge temperatures; the larger the difference, the more air re-circulation is required. Balancing the discharge temperature of each stage results in higher ambient temperature, altitude and system pressure capability.

In two stage screw compressors capacity is governed by the first stage, and consequently is not affected since bypassing takes place only around the second stage. Simulated testing revealed moderate improvements in altitude and ambient temperature capability without affecting inlet capacity. Figure 2 shows an example of the altitude capability improvement that can be achieved with this system. Discharge pressure capability improvement vs. ambient temperature follows the same trend. A very slight and acceptable increase in input power may be experienced. However, this increase may be offset by the reduction in input power draw for those applications that are operating at altitude.

Pressure ratio modulation can be achieved with one of two control modes:

- Manual:

  The operator manually adjusts the needle valve, thereby boosting interstage pressure, until the 1st and 2nd stage discharge temperatures are reasonably equal. Once the desired pressure ratio is achieved, the valve handle is locked in position. This approach may be suitable for fixed installations.

- Automated:

  In this mode, pressure ratio modulation is achieved by connecting an electrically driven needle valve to a controller. The controller will be programmed with a relationship between second stage discharge temperature and valve opening, as well as the maximum allowable difference between the discharge temperature of each stage. During operation, the controller automatically adjusts the needle valve opening, until the 1st and 2nd stage discharge temperatures are equal within the set range. This mode of control is desirable for rental compressor applications, where the site operating conditions can vary drastically depending on the location.

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Inlet Modulation:

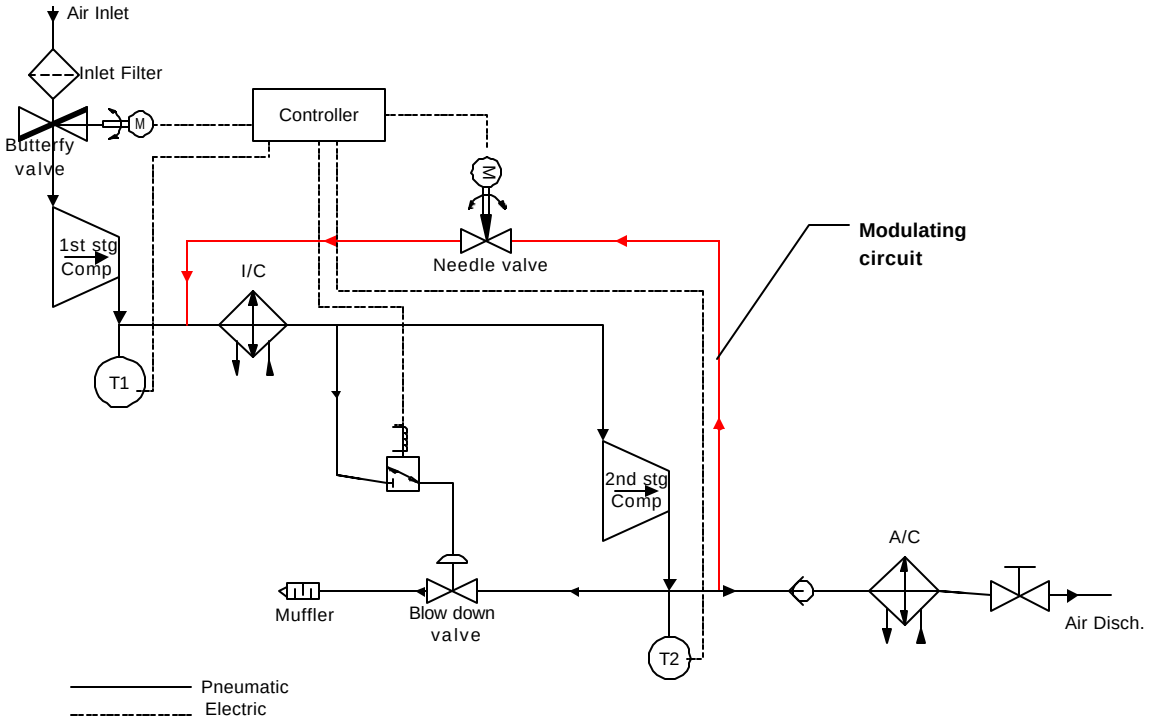
Today's oil free compressors do not modulate the inlet valve, but rather operate in a sudden load/unload mode to prevent discharge temperature spikes. This mode of operation exposes the compressor parts to sudden load and thermal fluctuations, which can adversely affect reliability. Since gradual closure of the inlet valve creates a vacuum at the compressor inlet, similar in effect to an increase in altitude, the incorporation of a pressure ratio modulation system provides the ability for limited intake modulation. The degree of intake modulation depends on the maximum acceptable stage discharge temperature and the maximum ambient temperature expected at a given site. The higher the ambient temperature the lesser the degree of modulation.

Intake air flow can be controlled by adjusting the intake valve opening, while simultaneously modulating the pressure ratio of each stage. To overcome any temperature spikes, the intake and bypass needle valves (Fig. 1) shall be operated simultaneously and in reverse of each other i.e. when the intake valve gradually closes, the needle valve opens and vise versa. This function can be accomplished by utilizing two electric driven valves (intake and bypass) and integrating their operation into a control system. With this system the compressor capacity can be reduced until the discharge temperature reaches the maximum acceptable limit, at which point, the compressor unloads. Unloading is achieved by an action taken by the controller, which nearly closes the intake valve while simultaneously opens the blow down valve.

While running in the unloaded mode, if the discharge air pressure, $P_{d,}$ reaches the load value, the controller loads the compressor by fully opening the intake valve and simultaneously closing the blow down valve. The controller then adjusts the needle valve to nearly balance the discharge temperature of each stage.

Such arrangement avoids the temperature spikes associated with capacity modulation of oil free two stage compressors. In addition to slight reduction in power consumption, capacity modulation reduces load/unload cycling, leading to a reduction in the load and thermal fluctuations imposed on the compressor and increased reliability.

Pressure Ratio Modulation
In Two Stage Oil Free Screw Compressors



Oil Free Two Stage Screw Compressor
Simplified System Schematic

Figure 1

PRESSURE RATIO MODULATION
IN TWO STAGE OIL FREE SCREW COMPRESSORS PRESSURE RATIO MODULATION

Pressure Ratio Modulation
in Two Stage Oil Free Screw Compressors

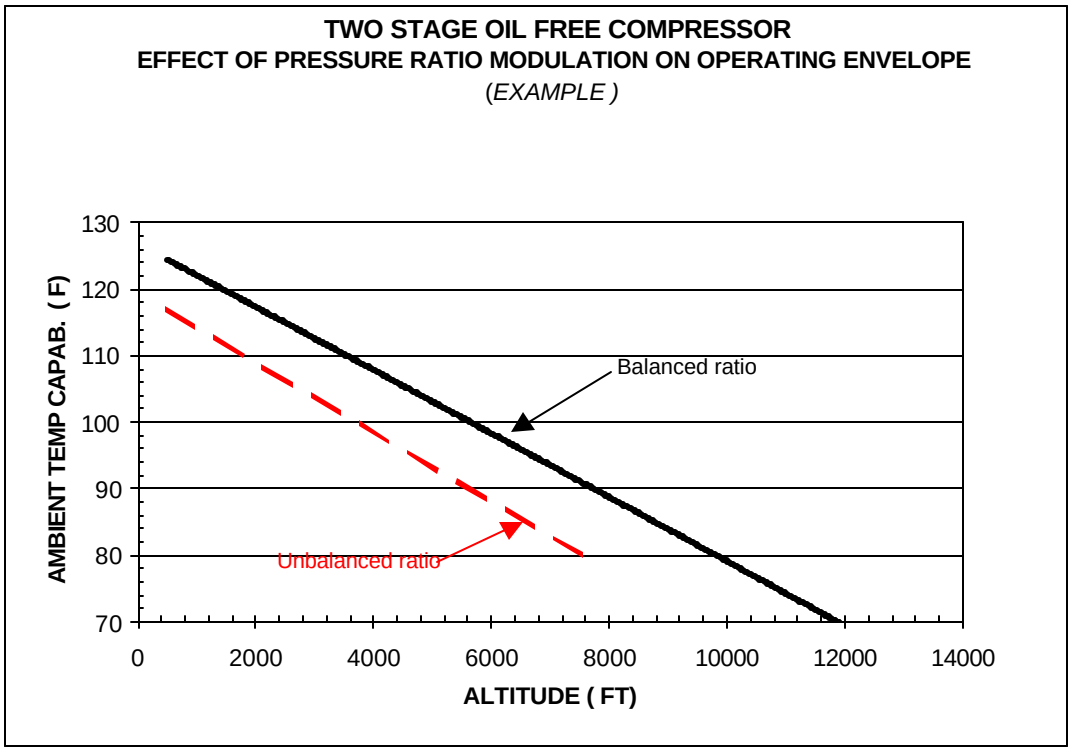


Figure 2