TWO-STAGE Rotary Screw Air Compressors

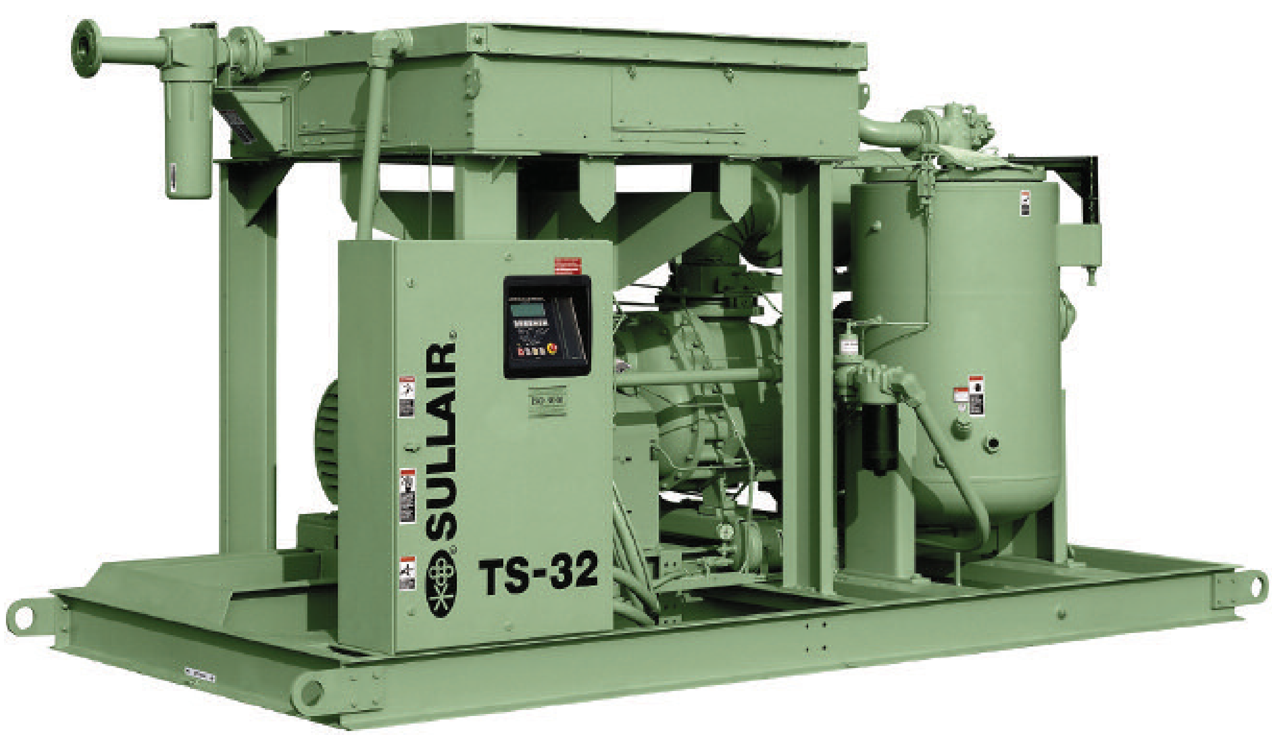
BY HARISH SHAH AND MARK PFEIFER

Two-stage (also known as tandem) rotary screw air compressors offer compressed air users, looking for higher efficiency and reliability, an alternative to single-stage air compressors. For compressed air systems with fluctuating demand, two-stage designs can offer optimal energy efficiencies as both a full-load machine or as a "trim" machine.

Two-stage Tandem Design

In a two-stage air compressor, compression work is split equally between two sets of airends. Processing the air through these two airends (or stages) is the fundamental design difference from the traditional single-stage (or one airend) design. For a 100 psig application two-stage designs take the inlet air at 14.5 psia and compress it to 40.75 psia in the inter-stage. The second stage will then compress the air to 114.5 psia (100 psig). Inter-cooling between the stages is achieved by injecting cool oil into the discharge air after the first stage. This air-oil mixture reduces the effective air temperature before compression begins in the second stage. The result of this design is an extremely efficient compression ratio of 2.8 for both stages.

In a traditional single-stage design, ambient air is drawn into the compression chamber at 14.5 psia (allowing for a slight pressure drop due to the inlet filter). The air is then compressed to 100 psig (114.5 psia) in one stage with a single airend set. The compression ratio of a single-stage design is 7.9.



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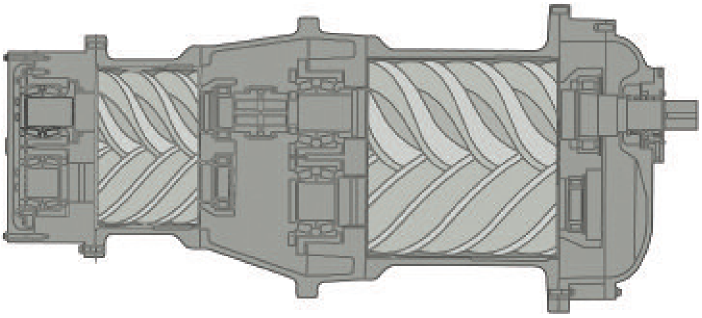
Two-stage designs experience lower internal losses (air leakage), than single stage designs. This is due to the reduced pressure differences between discharge pressure and inlet pressure in both stages. The two-stage design sees a gradual pressure progression from 14.5 psia (ambient intake) to 40.75 psia (interstage) to 114.5 psia (outlet discharge). Lower internal losses increase the efficiency of the two-stage design and allow for higher pressure capabilities.

The reduction in pressure differential between inlet pressure and discharge pressure, in two-stage vs single-stage designs, places reduced loads on the discharge bearings in the airends. This reduced load will result in longer bearing life and more infrequent airend replacement/maintenance.

Full-load Operation

Two-stage designs will provide, at full load, 11–13% savings over single-stage air compressor designs. Due to the more efficient compression ratios and reduced internal losses, specific power consumption in terms of kW per 100 cfm is reduced. A typical single stage compressor will consume 18–19 kW per 100 cfm delivered. A two-stage compressor will consume 16–17 kW per 100 cfm delivered (100 psig discharge and 140 F injection temperature).

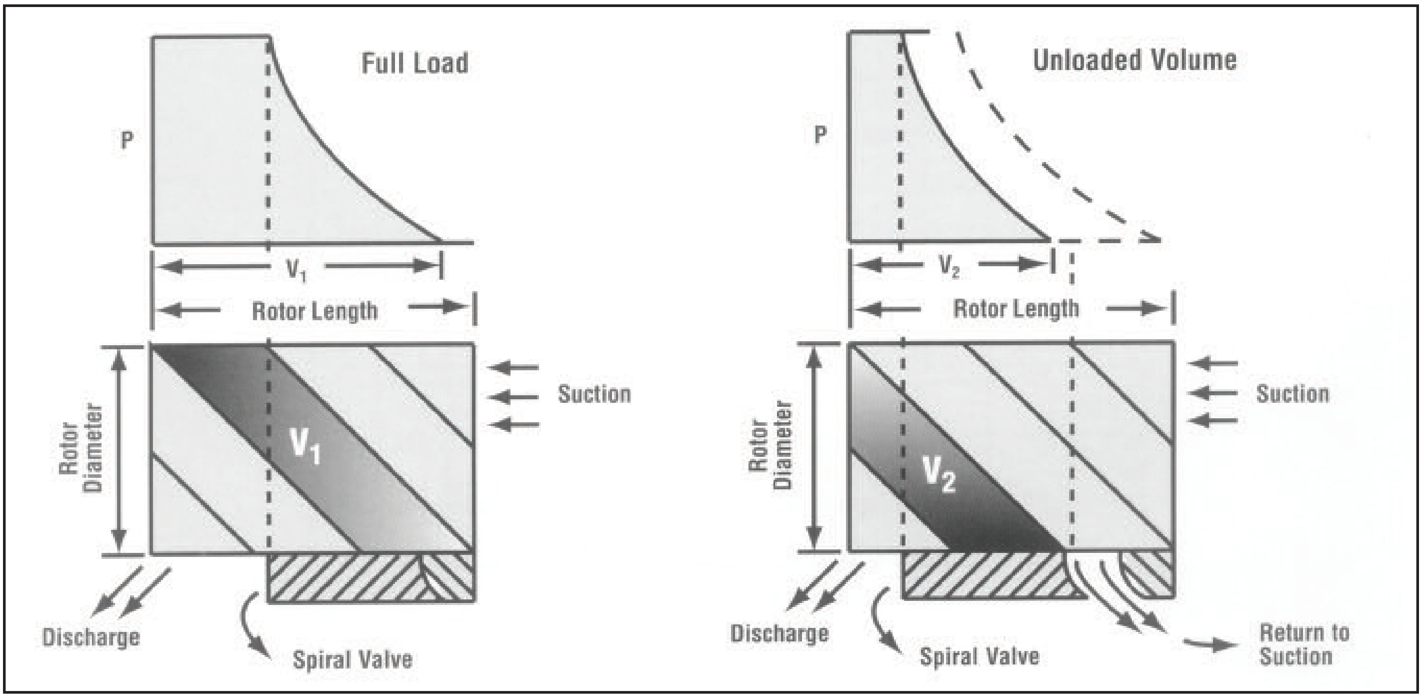


Partial-load Operation

Two-stage designs can be equipped with either Variable Speed Drives (VSD) or with Variable Displacement Controls (Spiral Valve) to further increase efficiencies when the same machine is faced with partial-load operating requirements due to fluctuating demand for compressed air. The advantage is that the same machine provides optimal energy efficiency in both full load and partial load conditions. Choosing between Variable Speed and Variable Displacement controls is a plant-specific decision to be made.

Spiral Valve Variable Displacement Control

The spiral valve activates automatically, when the unit is operating under partial load, and allows the compression of only the required quantity of air. In this manner, the spiral valve increases the efficiency of the compression process at 55–100% loads.



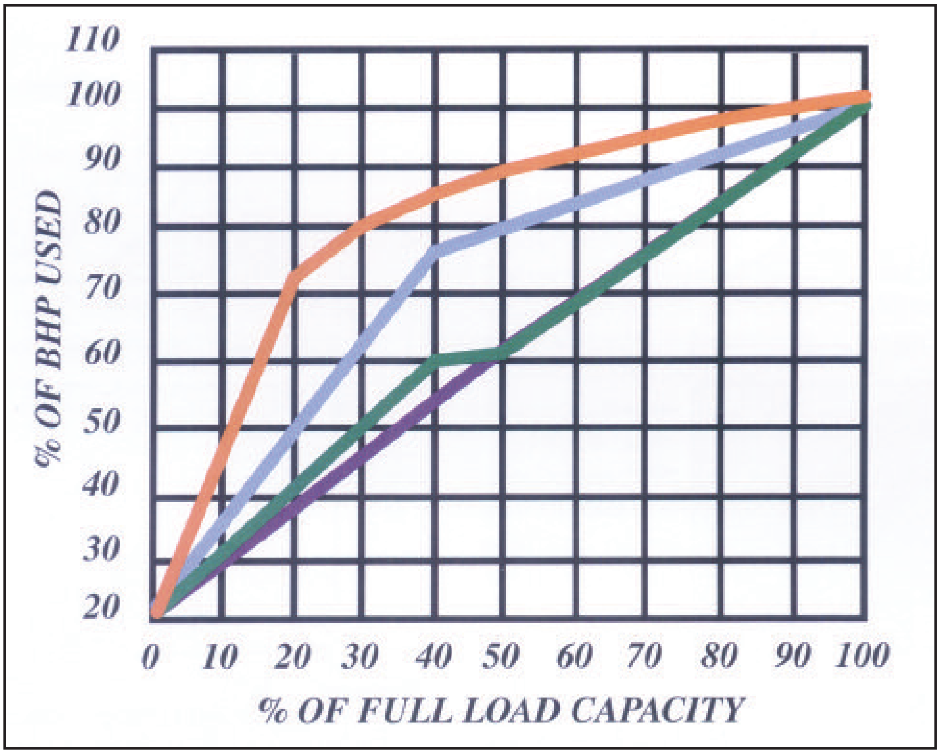
Spiral valve control allows some intake air to return to the compressor inlet. This action effectively reduces the rotor length and energy consumption.

The spiral valve progressively opens bypass ports connecting the compression chamber to the compressor intake in response to rising discharge pressure. As the discharge pressure rises (because more air is being produced than used), the spiral valve turns and opens internal bypass ports, which prevents some intake air from entering the compression chamber and consuming power. The progressive opening of bypass ports has the effect of reducing the length of the rotors after the lobes seal (and thus the displacement of the compressor) without choking the intake. This prevents a vacuum which causes the compression ratio to increase.

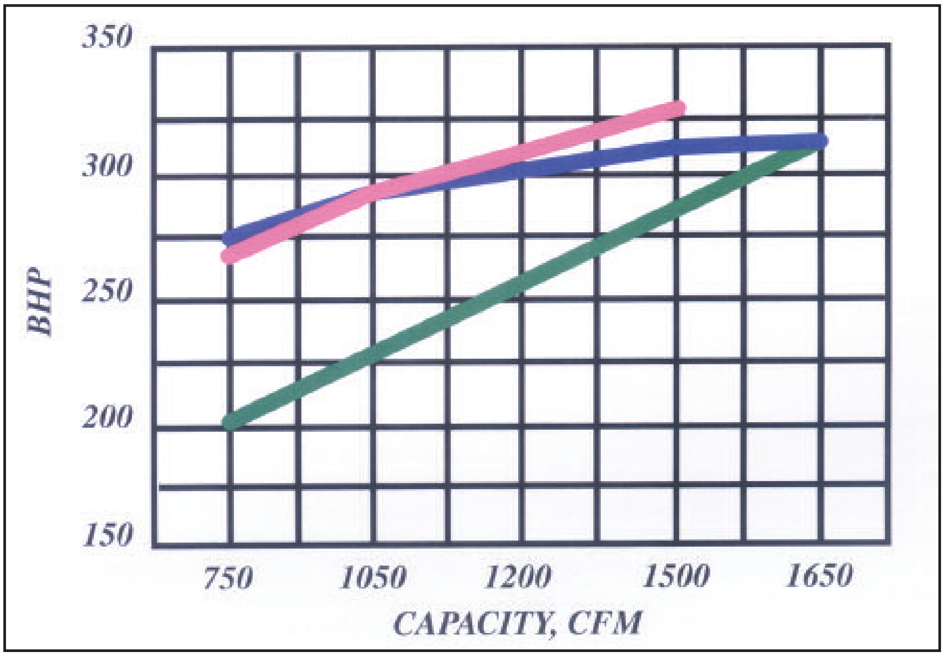
Variable Displacement Energy Savings

A variable displacement control matches compressor displacement to the output need. It provides significant power savings at part-load conditions when compared to compressors using load/no load or modulation controls.

Before a compressor can realize power savings with a load/no load control, the machine must first run into the upper range of modulation which can be as high as a 10 psig band before the machine will unload. This 10 psig unload point will cost a customer 5% of the motor horsepower on average. When the machine unloads it is done through a blow-down valve which takes several seconds to blow the air that is pressurized in the sump to atmosphere. As the demand calls for more compressed air, the machine must now repressurize the sump to provide more system air.



Compressor Control Method Performance Comparison
RED LINE: Actual Load/No Load Control
BLUE LINE: Modulation Control
GREEN LINE: Spiral Valve Control
PURPLE LINE: Theoretical Load/No Load Control



Power Comparison of 300 horsepower Models
RED LINE: Single-stage, 300 hp compressor with modulation control
BLUE LINE: Two-stage, 300 hp compressor with load/no load control (based upon 1 gallon per cfm air storage)
GREEN LINE: Two-stage, 300 hp compressor with spiral valve variable displacement control

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Modulation controls are one of the most common types of controls used on rotary screw compressors. Modulation control utilizes either an inlet butterfly valve or pneumatic inlet valve. As the plant pressure and capacity is met, the inlet to the compressor starts to close off. This limits the airflow through the rotors housing reducing the amount of air being compressed. The inlet valve modulates its position based on the system requirement.

Two-stage tandem air compressors offer efficiency advantages at both full load and partial load operating conditions. Spiral valve or VSD technology can further optimize the design for partial load conditions.

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Managing a Harsh Environment

The ambient environment for air compressors, at cement plants, can be harsh. Air compressors operate like a giant vacuum pump inhaling ambient air — along with everything entrained in the air. Cement dust is very abrasive and can severely affect the efficiency and longevity of a rotating piece of equipment like an air compressor. Once ingested into the compression chamber of the air compressor, this abrasive dust will wear on components and ultimately cause premature failure.

Compressor manufacturers offer filtration packages to combat harsh ambient conditions. Heavy-duty and high-dust intake filter arrangements are available. These filters will prevent cement dust from entering the compression chamber. The key is to have an effective maintenance program on the filters. Filters that collect dirt and begin to clog cause a change in the atmospheric pressure. This "vacuum effect" can reduce the efficiency of the air compressor.

The ideal solution is, of course, to find a way to provide the air compressor with a steady stream of clean, cool air in a positive pressure environment. If this is impossible, regular maintenance of the filter elements is much less expensive than a 5% reduction in compressor efficiency.

> "Reliable compressed air is critical to the operation of dust collectors in our cement plant. We have been very pleased with the consistent quality and quantity of air from our five two-stage air compressors. With good maintenance and preventative practices we continue to save over $50,000 per year in energy, while deferring the capital expense of airend replacements."

Plant Manager
Cement Plant in South Dakota