Air Compressors

By: Richard L. Bullard. CEM
Bullard Industrial Technologies, Inc.

Practically every industry, world-wide, depends on compressed air, in varying degrees, to support one or more of its processes. Machine tools, painting processes and production machinery for most manufacturing operations use compressed air as the motive force driving and operating their machinery. The newest and largest coal fired power plants use large quantities of compressed air for soot blowing of the heating surfaces of their boilers and to a lesser degree for pneumatic control systems. Many HVAC systems in large buildings, college campuses, hospitals, etc. use pneumatic controls for these systems.

There are three basic designs of air compressors, each one having inherent advantages and disadvantages. The reciprocating, or piston-type of air compressor was the first design of an air compressor and still today, remains a viable type of compressor for the right application. The rotary screw design was the next design to be widely used in industry. Both the reciprocating and rotary screw designs are considered to be positive displacement types of compressors. The next major breakthrough in air compressor technology was the centrifugal type which is not a positive displacement type.

Reciprocating Compressors

Reciprocating compressors are positive displacement using one or more pistons within a cylinder as the compression/displacement element. They are considered to be positive displacement because the exact volume of air that enters the cylinder is the same amount that leaves the cylinder, under a greater pressure. The close clearance between the cylinder wall and the outer wall of the piston is maintained by the piston ring, thereby compressing the air as it moves through the cylinder. There are 2 designs of cylinders used in reciprocating compressors, lubricated or non-lubricated.

Lubricated cylinders require oil to prevent wear to the cylinders, pistons, and piston rings that are usually of cast iron construction. Some of that oil is carried out of the cylinders and may or may not be permitted to enter the compressed air piping distribution system. If the equipment being supplied with air cannot tolerate lubrication oil entrained in the air, it is removed from the air leaving the compressor cylinders, usually using coalescing type of filtration systems.

The advantage of the lubricated design is that wear is reduced to a minimum and therefore very little maintenance is required. The disadvantages of having to remove the oil from the air are that there is a significant pressure drop across the coalescing filter system which reduces the efficiency of the compressor and the maintenance that is required of the filtration system.

Photograph 1 These reciprocating compressors are powered by 1,000 hp synchronous drive motors. These reciprocating compressors are not considered oil-free, they can be near oil free and capable of reducing oil consumption by retrofitting to carbon-impregnated Teflon piston rings and Teflon wear bands. Each of these units only consumed one- gallon of oil per day. Any oil that is carried over is removed from the air by 0.01 Micron coalescing filters on the compressor discharge which remove 99.5% of the oil, making them virtually oil-free.

Oil-free reciprocating air compressors utilize Teflon piston rings that require no lubrication and in some cases aluminum pistons that are much lighter than cast iron and do not "drag" in the cylinders which also requires lubrication to prevent wear. The disadvantages of the non-lubricated design is that high quality crankcase seals are required to prevent migration of oil from the crankcase sump into the cylinders, the Teflon piston rings require frequent replacement as they continually wear away and there is sometimes a concern with Teflon "dust" from piston ring wear migrating out of the cylinders and into the compressed air distribution piping which may cause problems with the equipment in the system that is using the air.

Capacity control of reciprocating compressors is achieved by variable speed drivers such as steam engines and steam turbines and variable speed-controlled electric motors. Constant-speed compressors utilize a 5-step clearance control system to operate the units at partial loads in increments of 25% of capacity. Each cylinder is equipped with four clearance pockets with each pocket having a piston-operated valve that open incrementally to partially unload the cylinder and conversely, close to load the cylinder.

Most reciprocating compressors dissipate heat buildup via water-jacketed cylinders, intercoolers between the stages and after-coolers for final heat and moisture removal from the discharge air.

Reciprocating compressor capacity is limited to about 12,000-cfm @ 125-psig for a double, 2-stage unit due to the amount of floor space and foundation necessary.

Rotary Screw Compressors

Rotary screw compressors are also a positive displacement type of compressor. A rotary screw compressor is comprised of two or more interlocking “screws”, which resemble gears, lobes or cams that mesh and turn together in the casing to pull the air into the meshing mechanism. As the air is pulled in and “squeezed” through the mechanism it leaves the casing under a higher pressure than that which it entered.

Rotary screw compressors are built in two-basic designs: Flooded and oil-free. The flooded rotary screw compressor will carry over oil with the air being discharged from the compressor. Oil separators of the filter/baffle design are utilized on the discharge of flooded rotary screw compressors to minimize and practically prevent any oil carryover. The separators remove sufficient oil to limit the carryover to @ 5-ppm and their design permits returning most of the oil removed from the air back to the sump of the compressor for re-use. 100% oil removal can be further accomplished by installing coalescing filters downstream of the separator.

The capacity of flooded rotary screw compressors can be controlled by on/off operation, inlet throttling slide valve or turn valve operation and by speed regulation.

Flooded rotary screw compressors will operate for several years without any major maintenance required provided the oil, oil filter and oil separator are changed at regular intervals.

Oil - free rotary screw compressors utilize the same compression design as the flooded screw but employ non-contacting carbon ring seals to prevent oil from entering the compression zone of the machine, thereby producing oil-free air. While flooded rotary screw compressors can be controlled to very low capacities by inlet throttling, dry screw compressors cannot, due to excessive heat buildup at low loads. This limits their overall operating efficiency compared with the flooded design.

Single stage rotary compressors utilize an external, fan-cooled after-cooler for heat removal from the final effluent. Multi-stage design use water-cooler intercoolers between the stages to dissipate heat buildup. Rotary screw compressors are built to displacements as high as 2,500-cfm @ 125-psig.

Centrifugal Compressors

Centrifugal compressors are not positive displacement and utilize two or more rotating elements called impeller assemblies to compress the air much the same way a centrifugal pump creates hydraulic pressure with water; by imparting velocity energy to a mass (air) and converting it into pressure energy.

Each impeller rotating at very high speed imparts primarily radial flow to the air which then passed through a volute or diffuser to convert the residual velocity into pressure energy. Each impeller assembly is driven by a common gear, called a bull gear, which is directly connected to the prime mover. Centrifugal compressors are driven typically by electric motors or steam turbines.

Centrifugal compressor design employs 2, 3, 4 or 5 stages of compression. Multiple staging minimized heat generation through the individual stages thus permitting less heat loading of the intercoolers between the staging.

Capacity control of centrifugal compressors by throttling the air inlet to the unit, throttling the air outlet and by varying the speed. Centrifugal compressors are built to capacities as high as 15,000-cfm @ 125-psig.

The primary advantage of the centrifugal design is the small footprint and ease of installation as they are skid-mounted and do not require elaborate foundations. Disadvantages include high initial cost, repair and rebuilt costs due to close bearing and impeller tolerances and high rotative speeds of the individual impeller assemblies.

RB