Compressors

To define simply, a compressor is a mechanical unit which increases the pressure of a gas by lowering its pressure or increasing its speed. Compressors are separated in two main groups according to the mechanism by which they generate compressed air as positive displacement or dynamic compressors. Compressor types and subcategories are shown in **Figure 1**.

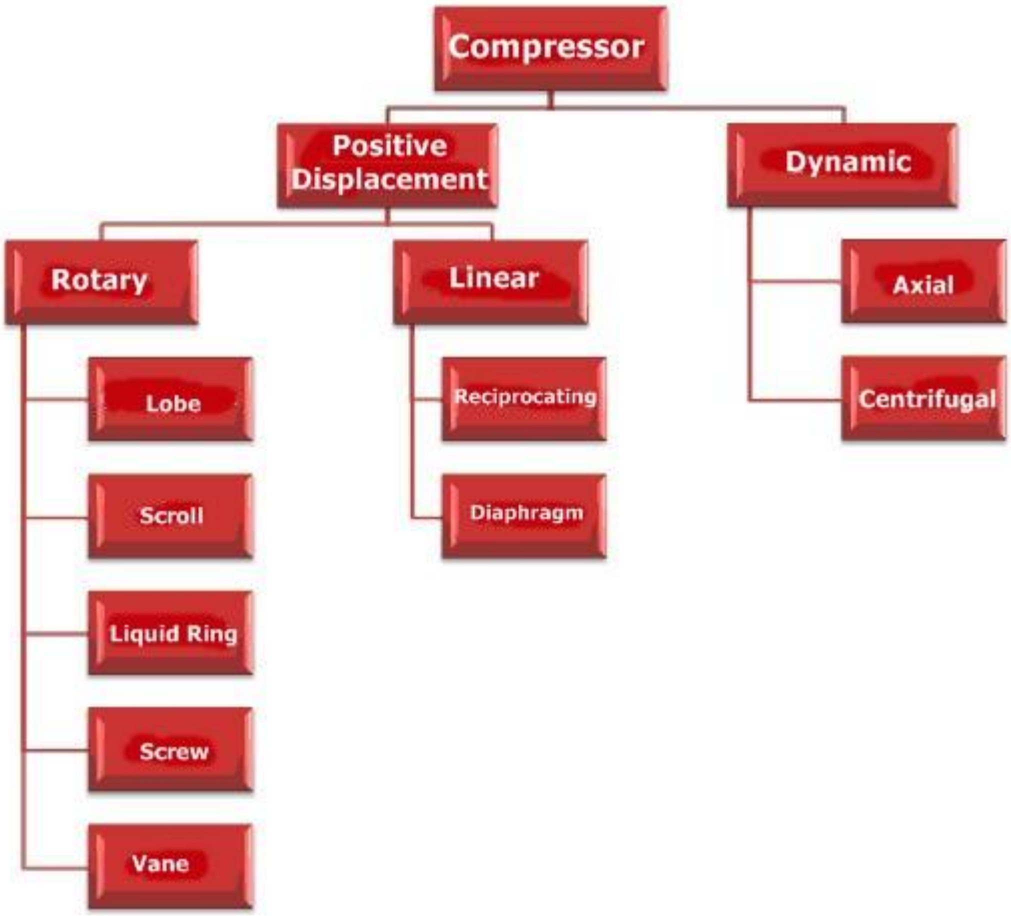

Figure 1. Compressor Types

1. Positive Displacement Compressors

In positive displacement compressors, after the determined amount of air is taken into the air compression chamber via the suction regulator, chamber volume is mechanically reduced and the pressure of the air is increased to the corresponding ratio until the desired pressure is achieved. This type of compressor is divided in two groups according to the type of mechanism employed to reduce volume: Rotary mechanism and linear mechanism compressors

Most common examples of rotary mechanism compressors are rotary claw, scroll, liquid ring, screw and rotary compressors. In compressors with linear mechanisms, reciprocating and diaphragm compressors are the most commonly used types.

1.1. Rotary screw compressors: The compression action of rotary screw compressors takes place in an airend formed by the interlocking of two rotors within a casing. Structure of the airend is shown in **Figure 2**. While the main rotor is driven by the compressor motor by direct coupling or through belt-wheel mechanisms, the supplementary rotor serves only to ensure impermeability of the work chamber during the suction and compression phases.

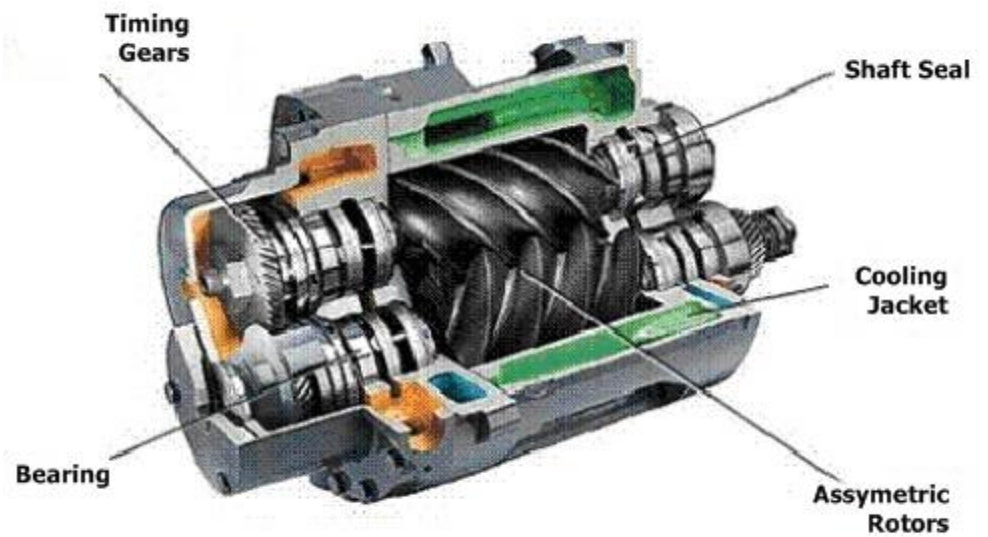

Figure 2. Structure of the Airend

The operating principle of the airend can be explained in four phases, as represented in **Figure 3**. In the **1st phase**, air is taken from the suction nozzle to the compression chamber. Outer cavities of rotors fill with air. In the **2nd and 3rd phases**, rotors turning in counter directions shut off the air suction nozzle, creating an area of compression between the casing and rotor cavities. Air moves along the rotor cavities, within the volume that is constantly decreasing due to the counter rotation of the rotors. In the **4th phase**, compressed air is discharged from the airend outlet.

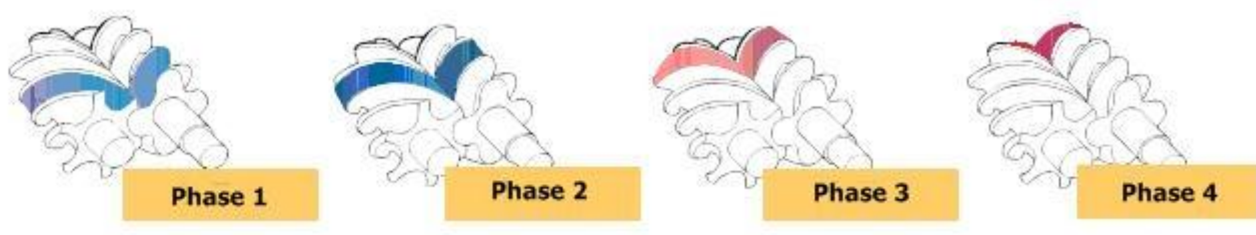

Figure 3. Operating Phases of the Airend

The appearance of an oil injected compressor and its supplementary elements has been presented in **Figure 4**. The general operating principle is as follows: Air that is taken into the airend by filtration from the suction nozzle is mixed with oil within the block and passes through the phases specified above, after which the compressed oil-air mixture is conveyed to the oil tank from the block outlet. After the oil tank this mixture is transferred to the air-oil separator, where oil and water are separated. Air that has been separated from oil is cooled by passing over the radiator and discharged over the air discharge valve to be conveyed to end use points. Oil that has been separated from the air is passed over the thermostatic valve. In the thermostatic valve oil is sent to the airend if it has not reached the optimum temperature determined according to the airend used in the system, and if it exceeds optimum temperature it is sent back to the oil tank by being cooled over the radiator.

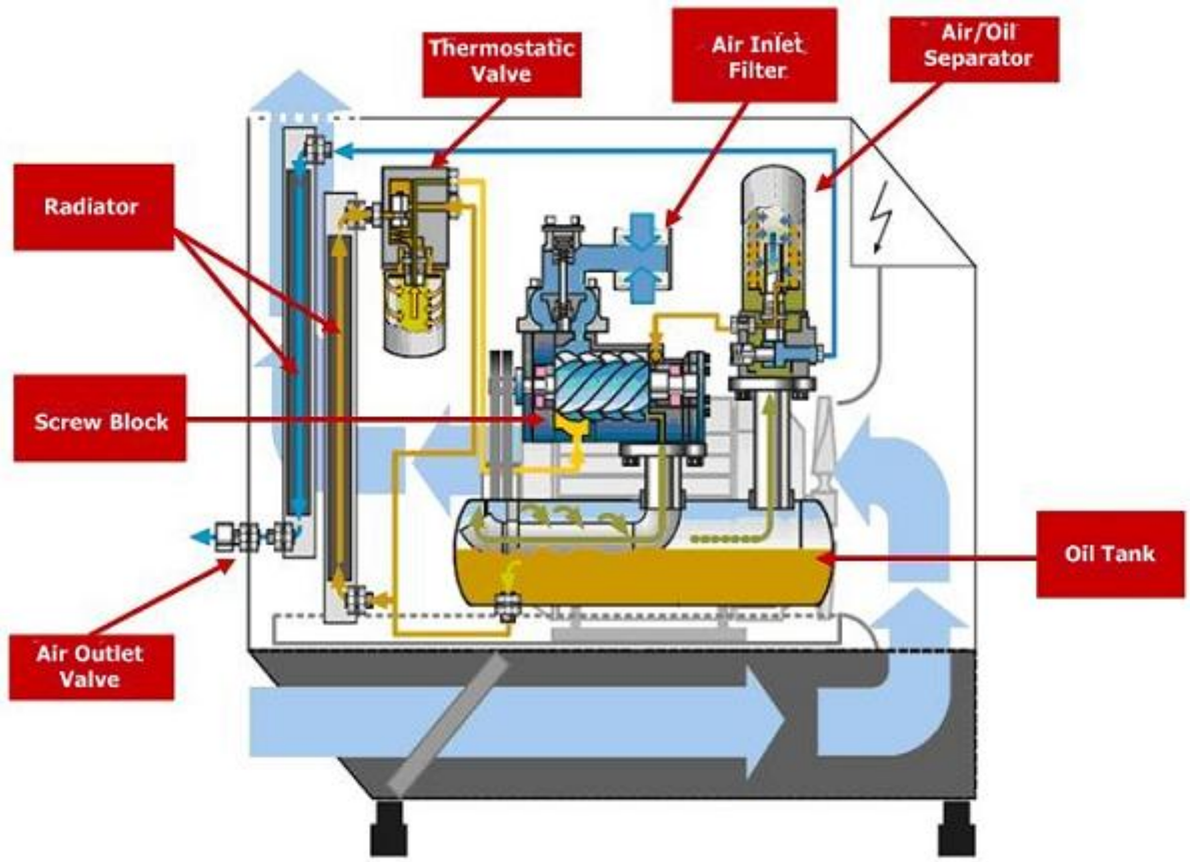

Figure 4. The Structure of an Oil Injected Screw Compressor

In industry in addition to oil injected models, oil free and water injected screw compressors are also preferred depending on the area of use. While oil free and water injected screw compressors are used predominantly in applications such as medical and food, with extremely low tolerance for oil in compressed air, these have lower operating pressures as compared to oil injected screw compressors.

1.2. Reciprocating compressors: Reciprocating compressors are used for oil and oil free compression and are included within the class of reaction compressors. As can be seen from **Figure 5**, a reciprocating compressor is basically composed of an oil pan, crank shaft, connecting rod, piston, suction and discharge valves.

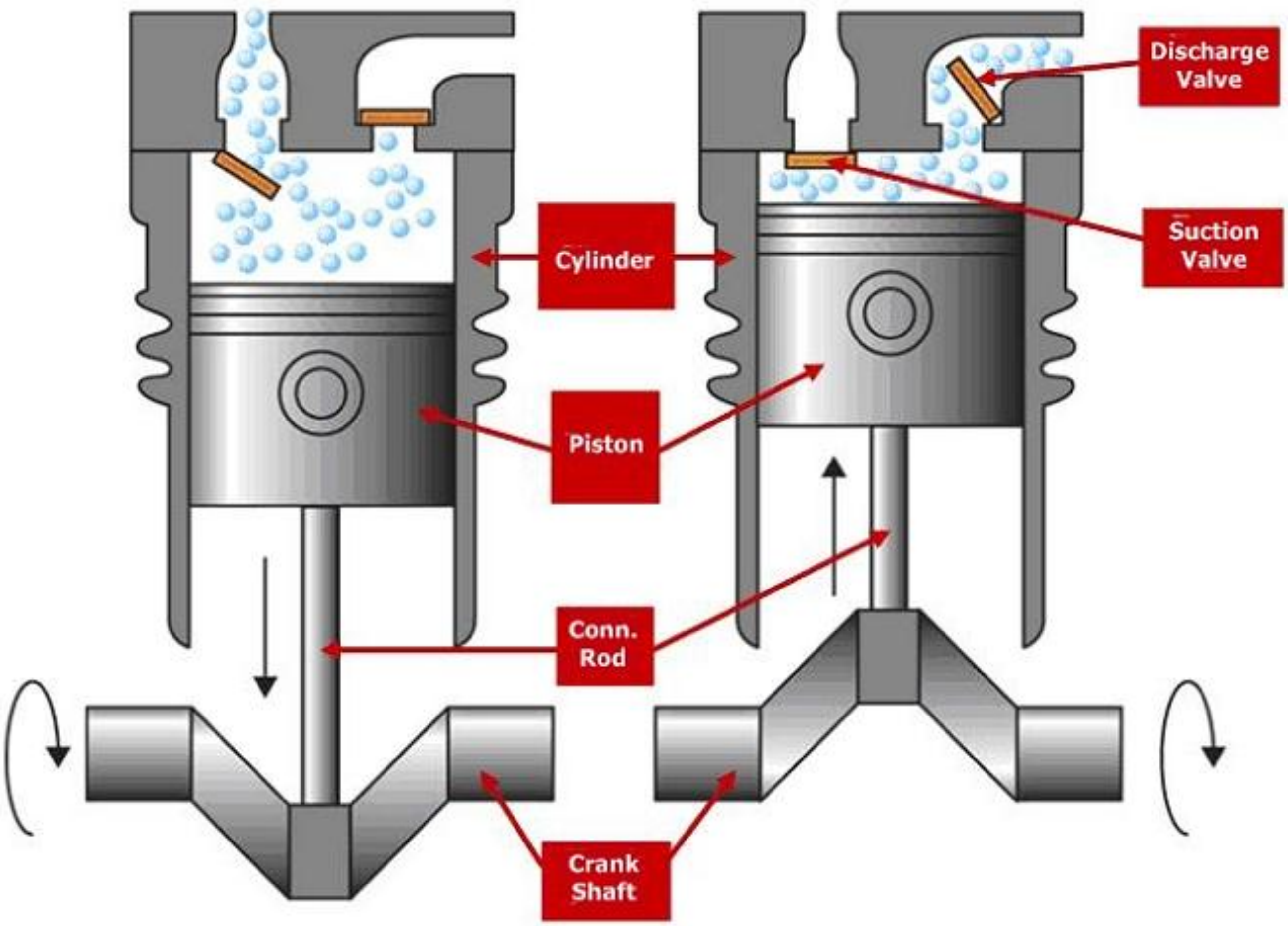

Figure 5. Structure of a Reciprocating Compressor

In single stage reciprocating compressors, the suctioned air is compressed within the same cylinder directly to the upper pressure value (usually 8-10 bar). These compressors can comprise one or more cylinders. Since the amount of air lost increases with increasing compression ratio due to the space between the ring and cylinder, they are usually better suited for low pressure or intermittent applications.

Double stage reciprocating compressors perform the air compression function in two stages. In the first stage (first cylinder) air is usually compressed to the square root of the desired pressure value. The air that has heated and expanded during compression is cooled by being passed through an intercooler and reduced in volume. In the second stage (second cylinder) compressed air received from the intercooler is compressed once again to the desired pressure value (generally between 10-15 bar) and made ready for end use.

In double acting reciprocating compressors, suction and discharge valves are positioned both below and above the cylinder, allowing air to be compressed twice in a single motor cycle. In this way, work performed per unit time is increased, saving energy.

Figure 6 shows diagrams of the compressor types discussed above.

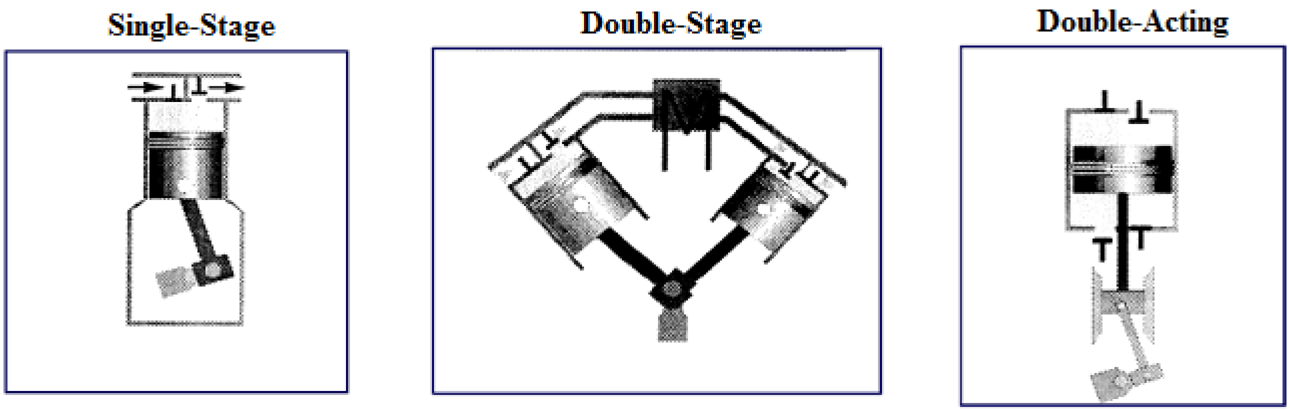

Figure 6. Types of Reciprocating Compressors

2. Dynamic Compressors

In dynamic compressors (also known as turbo compressors) the pressure of air is increased during the flow of air. In dynamic compressors this process occurs not with decreasing volume as in positive displacement compressors, but as a result of the process by which the speed which air has gained with the aid of rotating blades to static pressure by expanding through a diffuser. They all in two groups, axial and centrifugal depending on the flow of direction of air.

Unlike positive displacement compressors, in dynamic compressors, small pressure changes lead to large changes in flow. This allows changing the flow in a wide range without the need to change motor power.

The general structure of dynamic compressors has been presented in **Figure 7**.

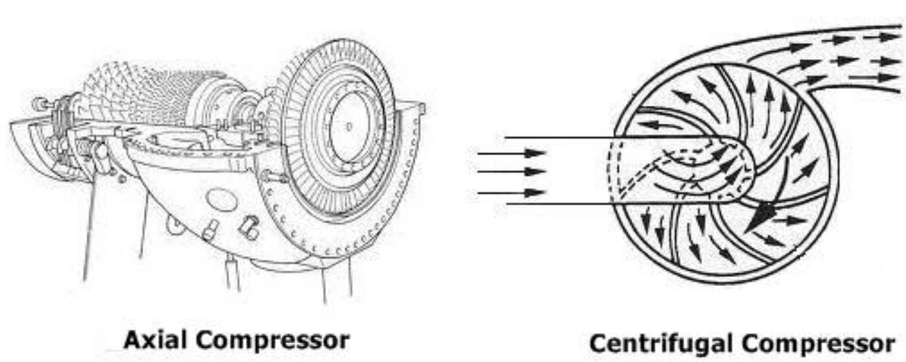

Figure 7. General Structure of Dynamic Compressors

3. Compressor Motors

Electrical motors are the primary sources of power used to drive the compressor system. The electrical motor used in a compressor should initially provide sufficient power to operate the compressor system, and continue to provide the system with power to maintain flow and pressure values in accordance with the compressor design parameters.

Tri-phase squirrel cage induction motors are usually preferred in compressor systems due to their silent operation, reliability and relative efficiency. The efficiency of an electrical motor is calculated using the ratio of the power transmitted to the motor shaft to the power drawn from the mains. Since electrical motors are used as primary power sources in many branches of industry, the priority of motor manufacturers is producing more efficient motors, allowing enterprises to reduce their operational costs as much as possible. There are three efficiency classes according to current standards: IE1, IE2, IE3.

IE1 motors are the least efficient motor group, that are not widely used in our day. This class of motor is also not widely manufactured due to its failure to comply with CE certification criteria. Class IE2 and IE3 motors are efficient motors that are more widely used. Although the use of IE2 motors is more common, many companies have begun to offer IE3 efficiency class motors as standard equipment in their products in order to minimize their expenditure of electrical energy.

Transmission of power from the electrical motor to the compressor system is usually performed through belt-wheel or direct coupled mechanisms. In the traditional belt-wheel mechanism, power is transmitted over the belt positioned between the wheels placed on the compressor shaft and motor shaft. In direct coupled transmission, 1:1 transmission is achieved via a coupling between the motor shaft and the compressor shaft. In direct coupled transmission losses do not occur during power transmission which allows more compact system design while requiring precautions to be taken in applications with high operating temperature. On the other hand, although nearly 5% transmission losses occur in belt-wheel transmission, long service life, vibration dampening feature and operation at low operational temperatures are among its significant advantages. **Figure 8** shows diagrams of these two mechanisms.

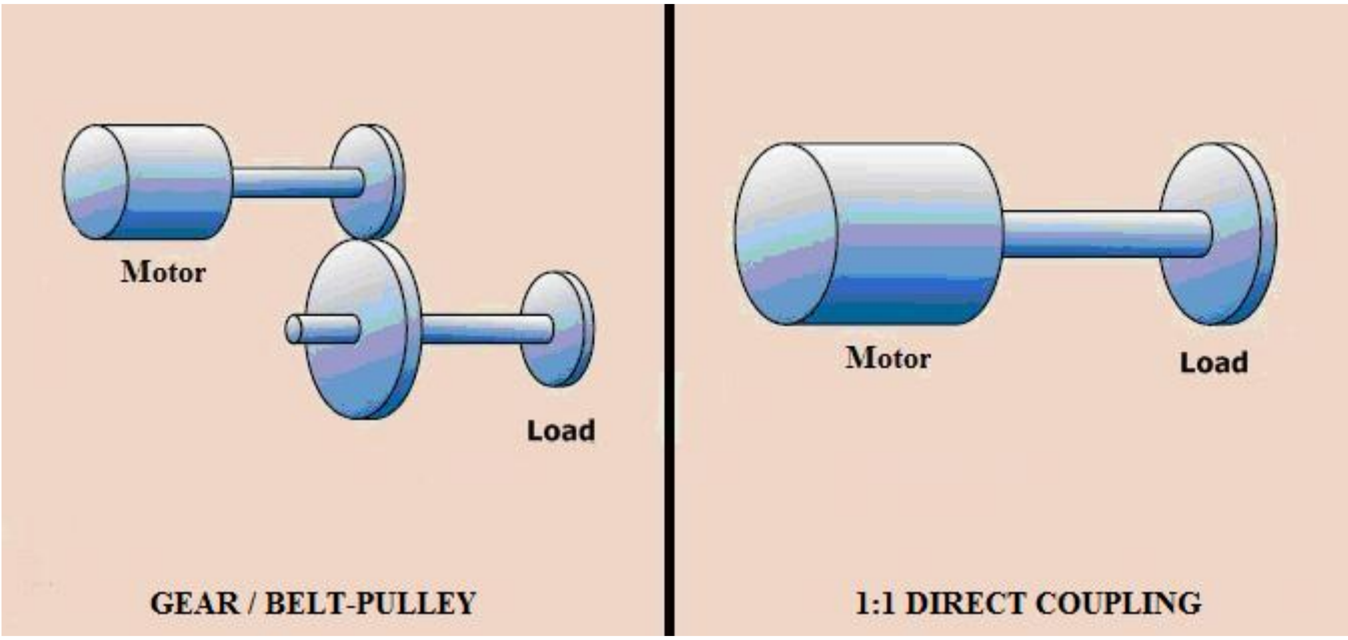

Figure 8. Motor Power Transmission Types

While electrical motors can be connected directly to the mains, input voltage or current can be regulated using various methods. Connecting the tri-phase electrical input to the electrical motor with a star or delta connector as shown in **Figure 9** is the most basic method of motor driving. In star connection, phase leads of motor windings are tied to form a common lead and 1 in $3^{1/2}$ of the mains electrical supply is applied to each winding. In delta connection phase leads of motor windings are connected one after the other, which means the mains voltage is applied to the windings. While current values are equal to the current drawn from the mains in star connection, in delta connection it is equal to 1/ $3^{1/2}$ of the current drawn from the mains. In star-delta connection the startup torque is reduced to 1/3 of the motor's nominal torque. It requires more maintenance due to the use of two or three switching equipment, and the motor is subject to electrical and mechanical strains in star-delta connection passes.

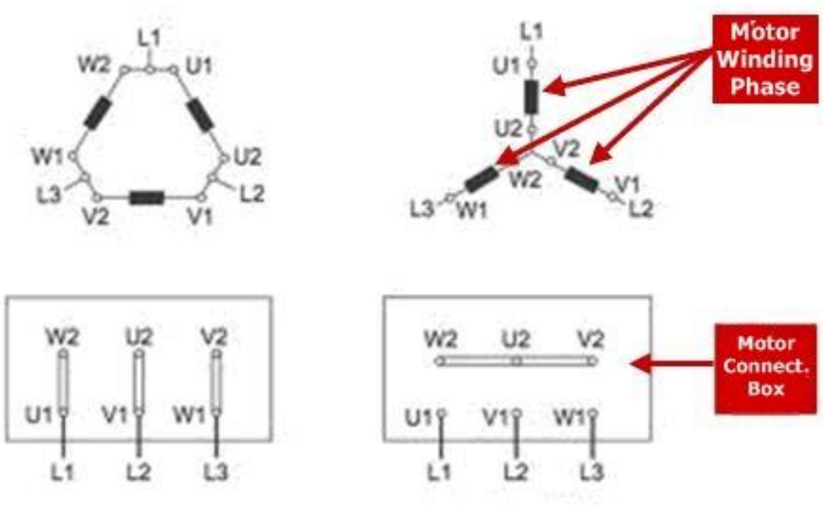

Figure 9. Star-Delta Motor Connection

Soft starters are notable for their more customizable nature as compared to star-delta connection. The possibility of variable startup torque, the absence of torque and mechanical peaks, its maintenance free nature and its being formed of a single switching device, it allows more effective and efficient use of the motor. **Figure 10** shows characteristics of the motor startup current in cases where soft starter is used and not used.

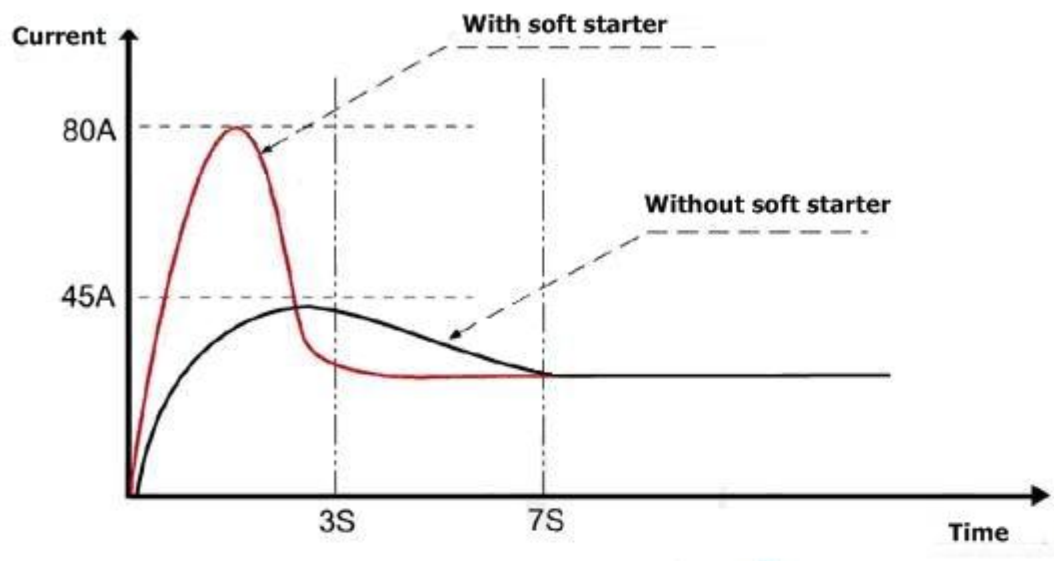

Figure 10. Impact of the Soft Starter on the Motor Startup Current

Unlike the soft starter, the variable speed drive (VDS) is an equipment which has the capability of regulating motor speed as well. While variable speed demands can be met through variable speed drives, energy efficiency is higher than with fixed speed motors. With these drives smoother motor drive, acceleration and torque control, and precise positioning can be performed.

4. Compressor Control Methods

It is rare for the compressor used in a plant to constantly work on full load. Therefore how the compressor's operation is controlled has a direct impact on the compressor efficiency.

4.1. On/off control: Though it is the most primitive control mechanism, it is also the most efficient when used correctly. It is as simple as switching the motor driving the compressor on and off, and the control function is performed with a pressure switch placed at the air tank outlet. This type of control is usually more suitable for compressor models electrical motors smaller than 30 hp. Considering the fact that frequent stop/starts of the motor will adversely affect service life due to motor over heating, care should be taken to select an air tank of the proper size and to set the pressure switch for wide pressure ranges.

4.2. Operating on load/on idle: In this control mechanism, when it a pressure switch detects that the desired pressure has been reached, the compressor shuts off the intake valve, taking the motor off load. Since the motor continues to operate even when it is off load, it continues to expend around 15-35% of the energy expended at full load, even though it performs no useful work during this idle period. For this reason, these systems are optionally equipped with times measuring idle time, preventing the motor from working in idle for long stretches.

4.3. Modulation: Modulation type control is the least efficient means of control that can be used solely in oil injected screw compressors. In modulation, the air taken into the compressor is limited through the suction regulator, regulating the flow of the obtained compressed air. Since even in systems where 100% modulation is implemented roughly 70% of the electrical energy expended in full load continues to be spent, usually the motor is kept at idle using the pressure switch, reducing energy consumption to around 30-15%.

4.4. Variable displacement: In some oil injected screw compressors, output capacities can be adjusted using special control valves such as spiral, rotary and popoff valves. With this type of control, output pressure and compressor energy expenditure can be precisely regulated without starting or stopping the motor or putting it on full load. For this type of control that is quite efficient for loads of 60% and higher, putting the motor on idle by using pressure switch in cases requiring 40% or less volume leads to significant energy savings.

4.5. Variable speed drive (VSD): The variable speed drive regulates motor speed using an integrated frequency inverter in order to meet variable compressed air demands. It is the most current type of control that is preferred to maintain constant pressure while meeting variable demands in both oil injected and oil free screw compressors. It is usually used in conjunction with on/off control and idle/on load operation of the motor, preventing unnecessary energy consumption below minimum motor speeds allowed by the drive. The issue that should be taken into account here is that in a compressor system operating constantly at 100% load, the VSD system can lead to higher energy expenditure than conventional systems due to inverter losses amounting to 5%. Therefore selecting this control type especially under partial load conditions is significant in terms of achieving significant energy savings.