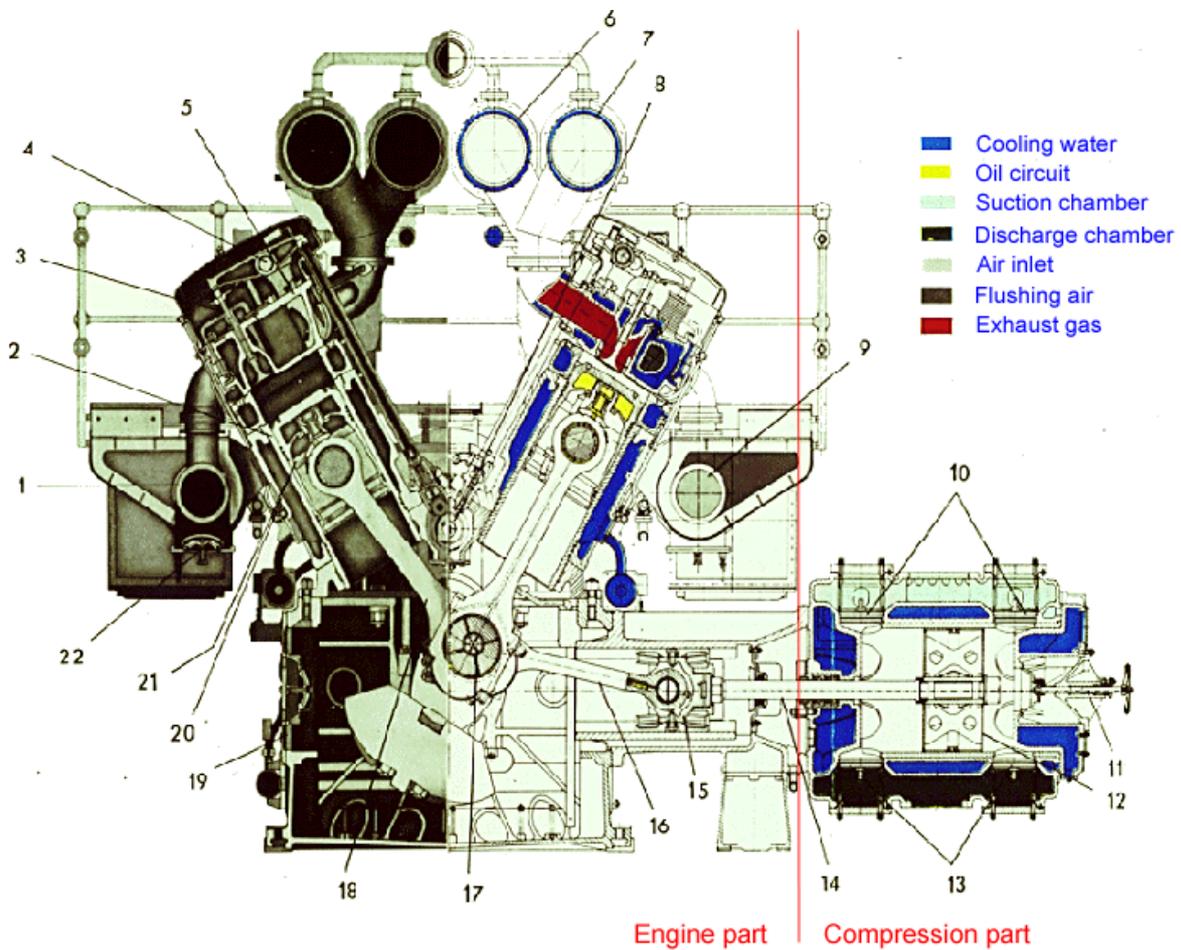




TOTAL



EQUIPMENT

COMPRESSORS

**TRAINING MANUAL
COURSE EXP-PR-EQ130
Revision 1**

EQUIPMENT

COMPRESSORS

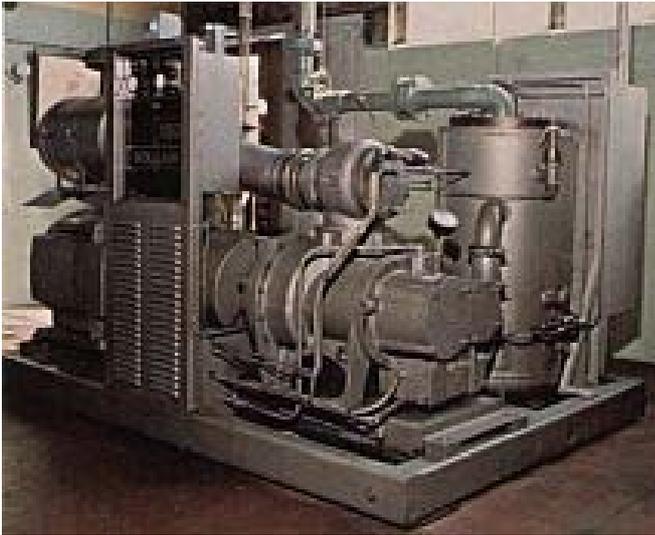
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1. THE FUNCTIONS OF COMPRESSORS

1.1. INTRODUCTION



Compressors are mechanical devices that enable the pressure of a GAS to be increased.

Compressors have a wide range of applications.

Figure 1: Example of a screw (or worm) type air compressor

The following list provides examples of operational applications for these machines:

- ✦ production of compressed air (instrument air, air for cleaning parts, for painting, etc.);
- ✦ compression and displacement of process gases;
- ✦ transport of materials in powder form ("pneumatic" transport of powders);
- ✦ production of vacuums and negative pressures (distillation, vacuum crystallization, evaporation, etc.);
- ✦ sanitation of enclosed areas ventilation, air conditioning, etc.);
- ✦ stirring of fermentation tanks.

1.2. THE MAIN CATEGORIES

Compressors can be divided into four main categories, which will be described in detail in the following chapters:

- ✦ Reciprocating (volumetric)
- ✦ Rotary (volumetric)
- ✦ Centrifugal
- ✦ Axial flow

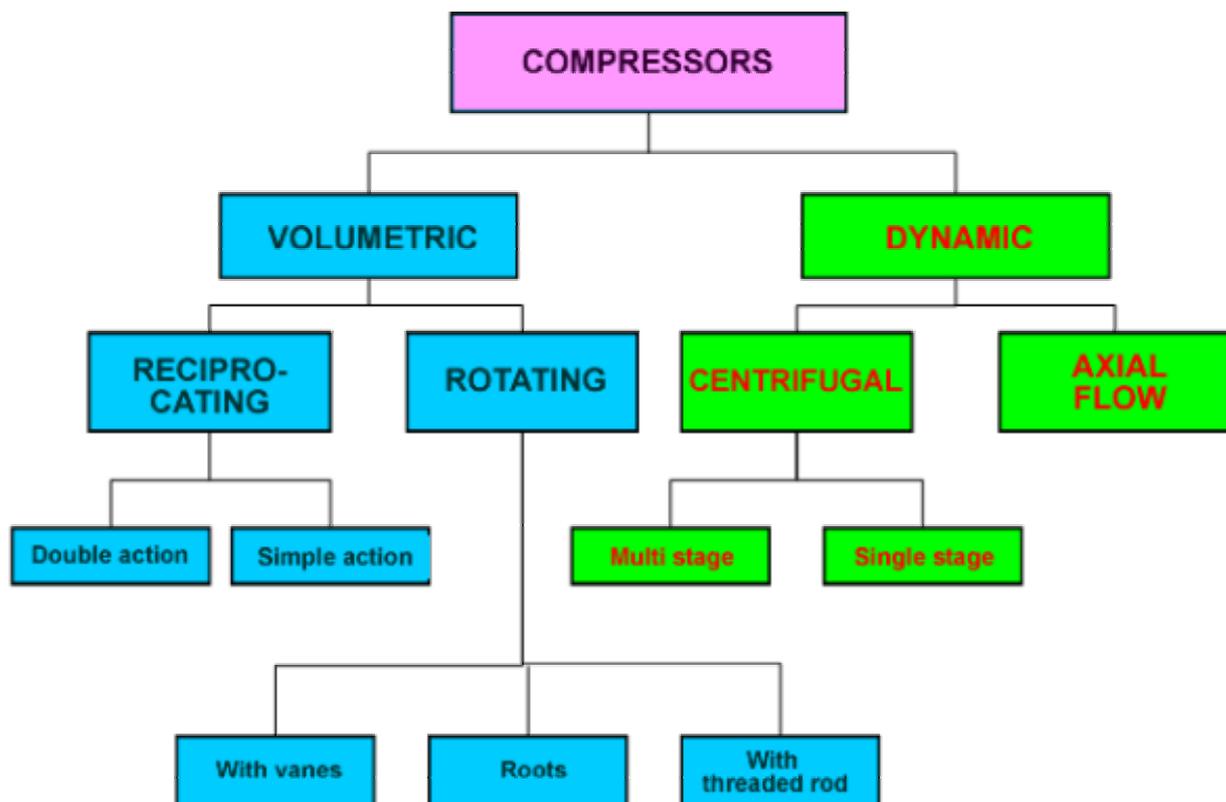


Figure 2: Main categories of compressors

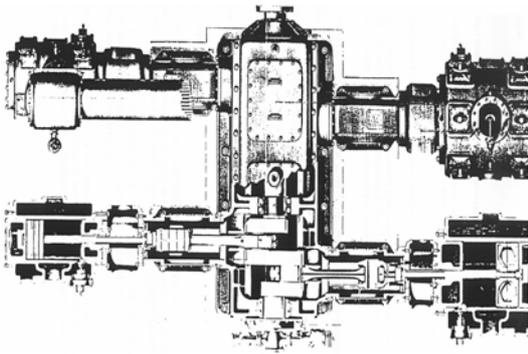


Figure 3: Reciprocating compressor

Figure 4: Screw-type rotary compressor

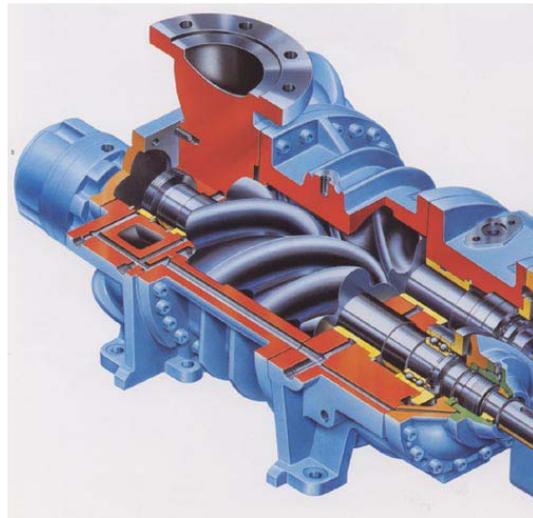
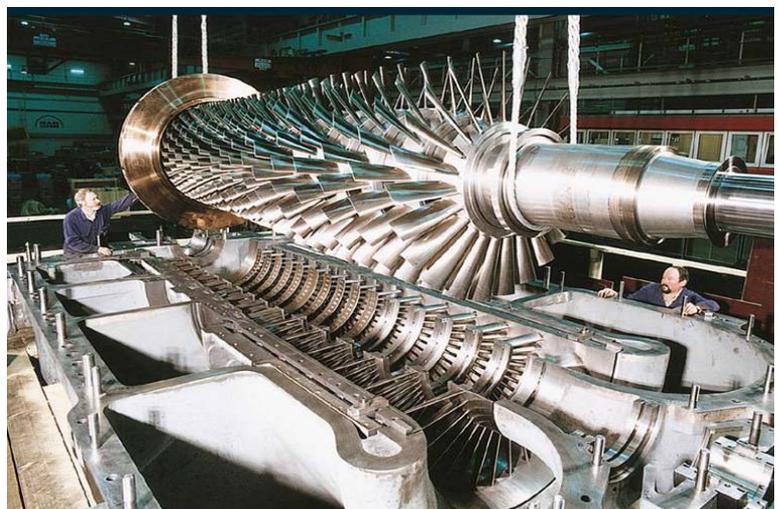


Figure 5: Centrifugal compressor

Figure 6: Axial flow compressor



Type of compressor	Volumetric compressors		Dynamic compressors	
	Reciprocating	Rotary	Centrifugal	Axial flow
Advantages	<p>Well adapted to low flow-rates</p> <p>Can propel gases at all pressures</p> <p>Relatively flexible to operate</p>	<p>Can propel gases at a wide range of flow-rates</p> <p>Regular flow</p> <p>Satisfactory reliability</p> <p>Flowrates more regular than with reciprocating compressors</p>	<p>Well adapted to medium and high gas flow-rates</p> <p>Relatively flexible to operate</p> <p>Excellent reliability</p>	<p>Very high efficiency</p> <p>Well adapted to very high flow-rates and to moderate pressures</p> <p>Excellent reliability</p>
Disadvantages	<p>Pulsed flow</p> <p>Moderate reliability for the valves</p> <p>A back-up machine is required</p>	<p>Not suitable for high pressures (50 bars max.)</p>	<p>Not suitable for low flow-rates</p> <p>Surging at low flow-rates makes operation sensitive</p> <p>High price</p>	<p>Large rotors, delicate and costly to manufacture</p>

Table 1: Advantages and disadvantages of the various compressor types

1.3. THE VARIOUS APPLICATIONS

The choice between a reciprocating compressor and a centrifugal compressor will depend on the pressures to be obtained. Other parameters also need to be taken into account for the final choice (size, weight, price, etc.).

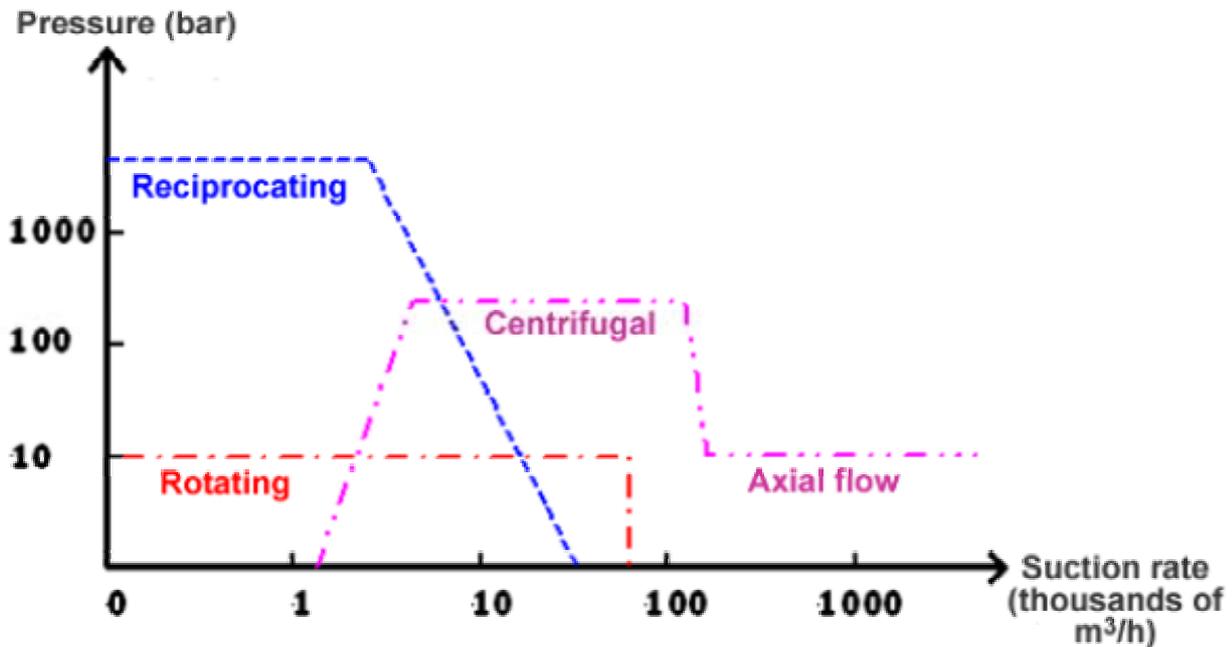


Figure 7: Application ranges for the various compressor types

2. OPERATING PRINCIPLE OF COMPRESSORS

2.1. RECIPROCATING VOLUMETRIC COMPRESSORS

Reciprocating compressors comprise one or several pistons that move inside a cylinder.

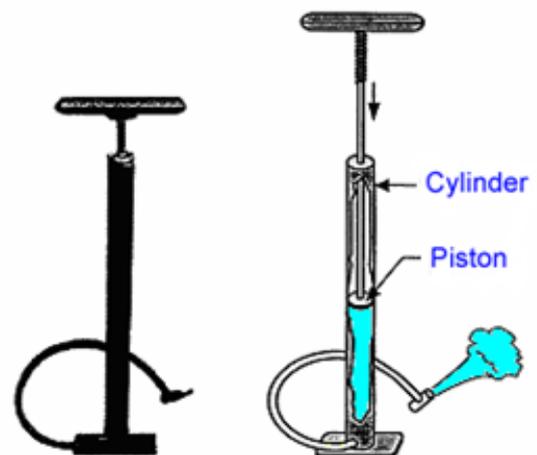
When the piston is displaced, a volume of gas is drawn in through the side opposite from the piston displacement.

Reciprocating compressors are widely used in petrochemicals, where the gas flow-rates are low to medium and the compression ratios are high.

A typical example of the reciprocating principle is the bicycle pump.

The body of the pump is called the **CYLINDER**.
The part that moves inside the cylinder is called the **PISTON**.

Figure 8: Example of a bicycle pump



When the piston starts to move downwards, the air contained in the cylinder is expelled from the cylinder, via the hose connecting the pump to the bicycle. The air pressure in the tire increases each time this operation is repeated

When the piston moves towards the top, a new volume of air is drawn into the cylinder.

If the piston compresses the gas only on one stroke ("to" movement) then the compressor is said to be a single-effect compressor. If the piston compresses the gas on both strokes ("to" + "from"), the compressor is said to be a double-effect compressor.

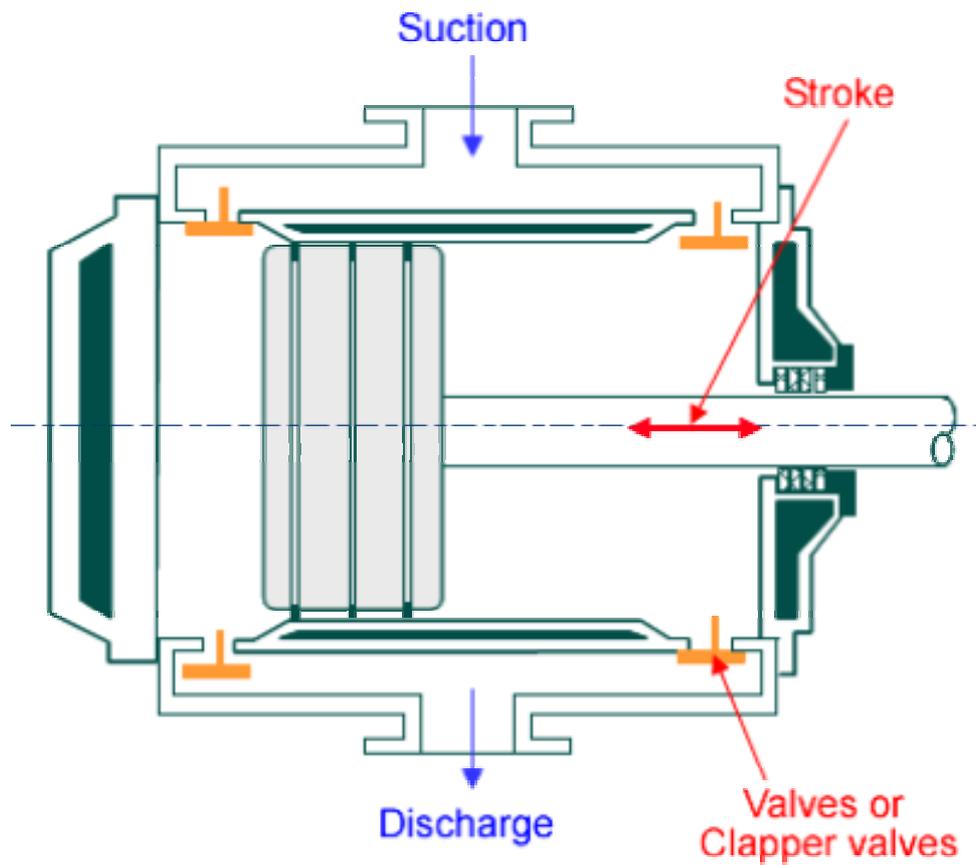


Figure 9: Diagram of a double-effect piston

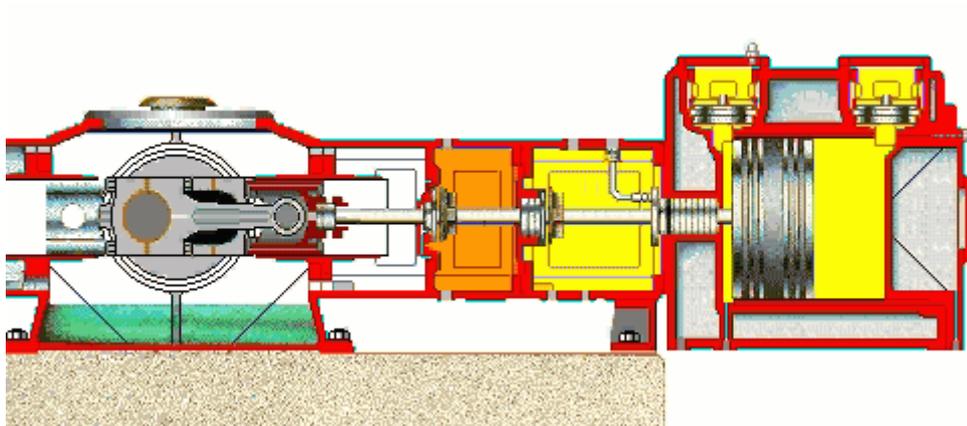


Figure 10: Double-effect compressor

In a piston reciprocating compressor, the compression is produced by one or several cylinders.

A piston moves with a reciprocating movement in each of the cylinders, driven by the connecting rod from the moving section.

In the chamber, the piston separates two chambers (or effects) whose volume varies as the piston moves.

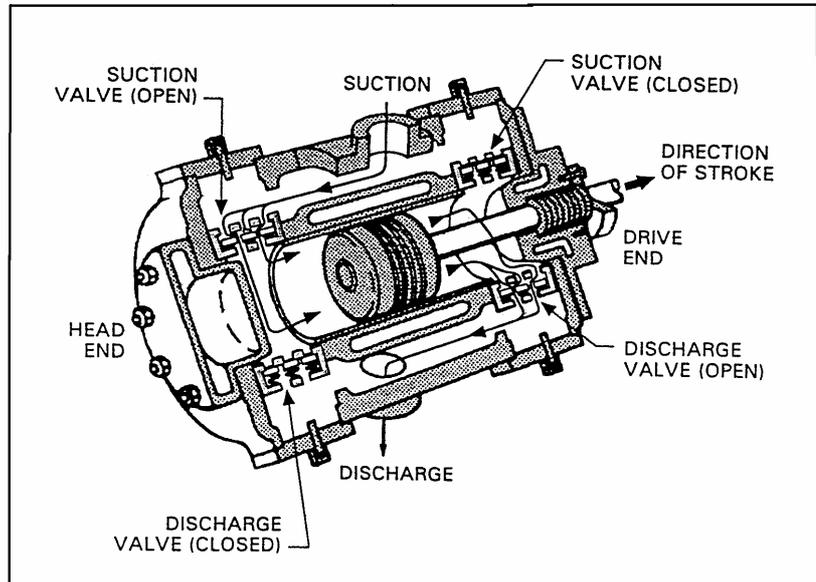


Figure 11: Cross-section of a double-effect cylinder

The suction and discharge of the gas in each of the effects is controlled by suction and discharge valves or clapper valves, respectively. The valves are opened by the difference in pressure on either side of the valve concerned.

Depending on the size of the cylinder, each effect can have 1 to 4 suction valves and as many discharge valves.



Figure 12: Examples of valves

2.2. ROTARY VOLUMETRIC COMPRESSORS

2.2.1. The vane compressor

This type of compressor consists of a stator in which an eccentric rotor rotates. This rotor has grooves that contain sliding vanes which are pressed against the wall of the stator by centrifugal force.

Under the effect of centrifugal force, the vanes are continuously pressed against the cylinder. The volume between the two successive vanes is variable.

The gas drawn in by the progressive increase in volume is then trapped between two vanes and carried to the discharge.

In this discharge area, the volume decreases and the compressed gas escapes into the discharge pipe.

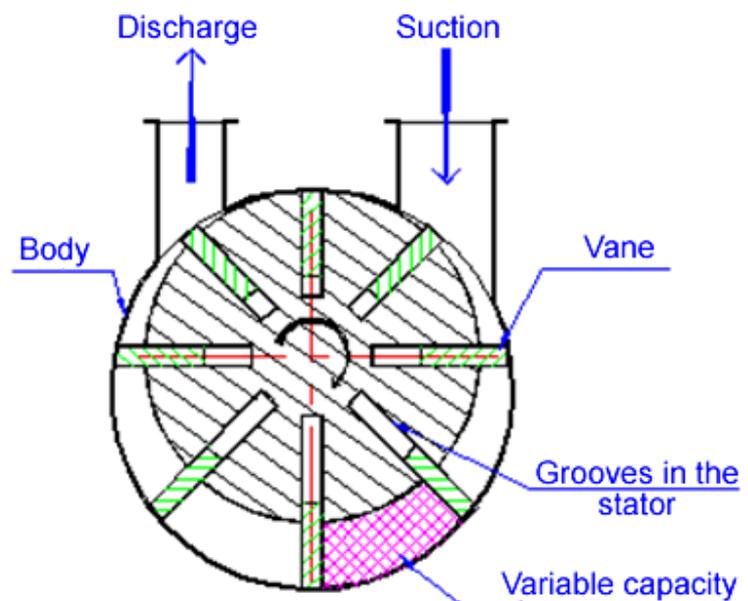


Figure 13: Vane compressor

2.2.2. The screw (also called worm) compressor

The moving part consists of two screws (or threaded rods) which mesh with each other.

These screws rotate in opposite directions. The gas passageway is parallel to the axes of the two screws.

The female screw always has one more screw turn (or thread) than the male screw, with a different profile.



Figure 14: Male and female screws

The gas is progressively compressed as it passes through volumes that become smaller and smaller until it reaches the discharge tube (the chambers are formed by the walls of the body and the threads of the two screws).

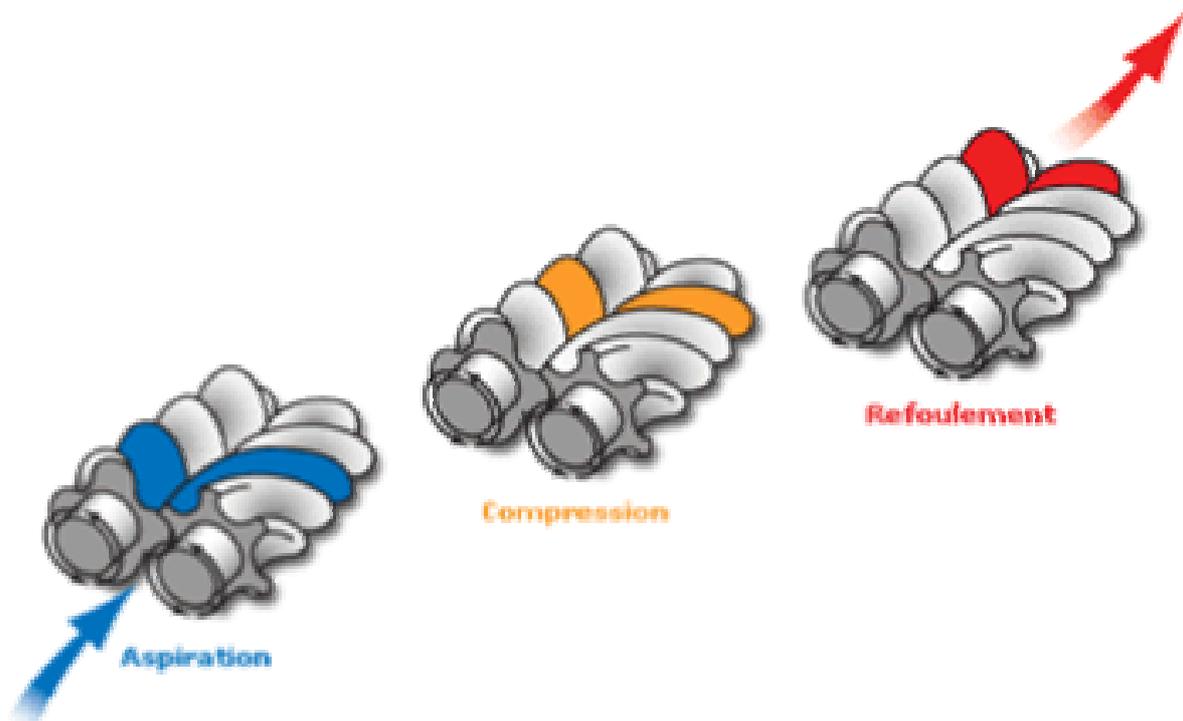


Figure 15: Compression cycle

It can be said that a groove acts as a cylinder whose volume is progressively reduced by a lobe that fills it, acting as the piston.

1st phase: Suction

On the suction tube end, a flute fills with gas for as long as it is in contact with the suction aperture.

2nd phase: Compression

Due to the rotation of the rotors, the flute is separated from the suction aperture. The gas imprisoned in the flute is compressed because the volume available for it is reduced by the meshing of the lobes of the male rotor with those of the female rotor.

3rd phase: Discharge

Compression ends when the flute reaches the edge of the discharge aperture. The compressed gas is then discharged regularly until the discharge aperture is closed off again.

Comment:

To ensure a continuous flow of gas at the discharge end, the system is designed so that there are always two flutes in contact with the suction and discharge apertures. One flute therefore communicates with the discharge aperture before the previous one is completely empty and moves beyond it.

2.2.3. The lobe compressor (Roots)

These compressors comprise two meshed rotors which have a lobe profile.



They are housed in a body with two orifices, one for suction and the other for discharge.

Figure 16: Lobes

The meshing of the two rotors is obtained by means of a pair of synchronisation gears (also called timing gears) located outside the machine.

The clearance between the two rotors can be between 0.1 and 1 mm, depending on the type of machine.

The shafts of the rotors are supported by bearings, which are located on the outside. Sealing between the internal chambers and the outside is provided either by packing glands or by mechanical packings.

The two rotors are driven in opposite directions.

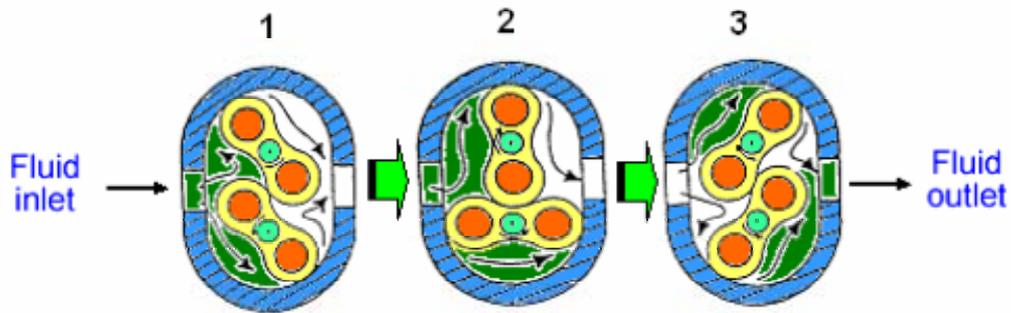


Figure 17: Principle of operation of a lobe compressor

The gas is entrained by the rotation of the lobes, from the suction to the discharge, without any variation in volume between the inlet and outlet.

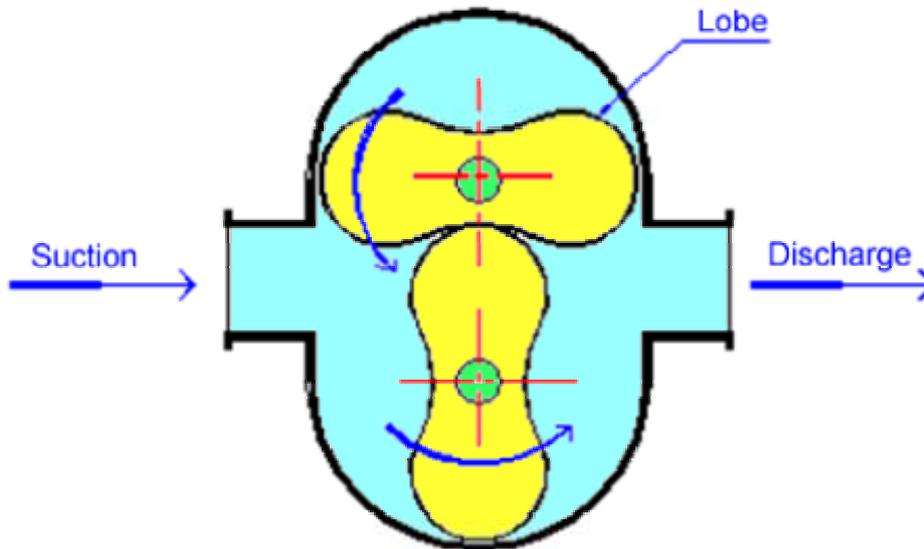


Figure 18: Principle of operation of a lobe compressor

As the rotors turn without any contact between them, no lubrication is necessary and the compression is therefore free from impurities.

General specifications

- ✦ flow-rate: 200 to 30,000 m³/h
- ✦ usual compression ratio: 1.2 to 1.8
- ✦ standard rotation speed: 1 500 to 2 000 rpm

2.3. CENTRIFUGAL COMPRESSORS

These are machines in which the exchange of energy takes place between a wheel equipped with vanes that rotate around a shaft, and a permanent flow of fluid.



Figure 19: Centrifuge compressor

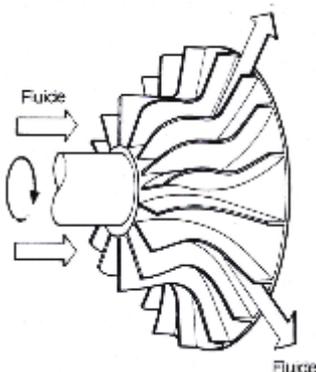
A centrifugal compressor is a dynamic compression device that uses centrifugal force to increase the pressure of the gas between one point and another.

Figure 20: Wheel of a centrifugal compressor (1)

The centrifugal compressor is classified as dynamic in contrast to a positive displacement (reciprocating machine).



It consists of:



- ✦ a wheel with vanes that rotate around its shaft
- ✦ a guide vane in the same axis as the wheel
- ✦ a spiral manifold with an increasing cross-section, called a volute or scroll.

Figure 21: Wheel of a centrifugal compressor (2)

The gas enters the machine through the guide vane assembly, in line with the axis of the main shaft, and the centrifugal force generated by the rotation of the compressor wheel projects it towards the outside of the wheel. It acquires a lot of kinetic energy that is transformed into pressure energy in the manifold, which has an increasing cross-section.

At the input and output of each wheel, the gas is guided by parts of the stator that constitute:

- ⊕ **The gas intake duct** of the intake flange of the first wheel;
- ⊕ **The diffuser** at the outlet of each wheel. In the diffuser, the pressure of the gas is increased by reducing its velocity; this is achieved due to the increase in cross-section.
- ⊕ **The return duct** which guides the fluid at the outlet of the diffuser, and conveys it to the inlet of the next wheel.
- ⊕ **The discharge volute** which conveys the gas to the discharge flange

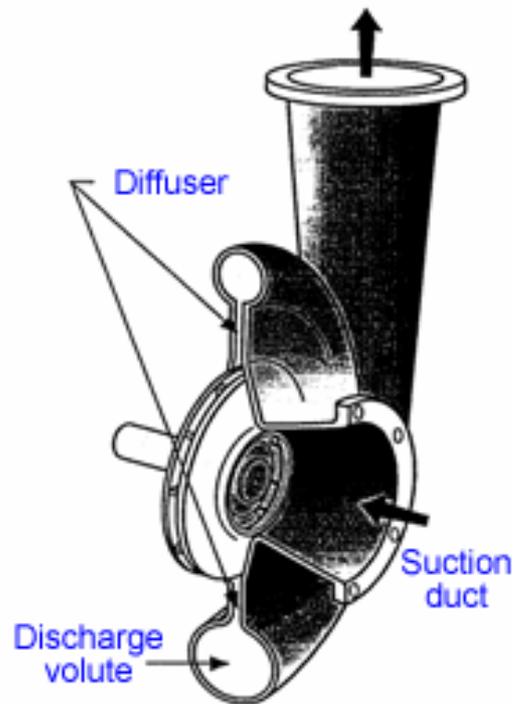


Figure 22: Diffuser and volute

2.4. DYNAMIC AXIAL COMPRESSORS

The gas passes through the compressor parallel to the axis of the rotating wheel.

The rotor sucks in and accelerates the gas.

The velocity of the gas is then reduced in the stator.

This decrease in velocity causes an increase in pressure.

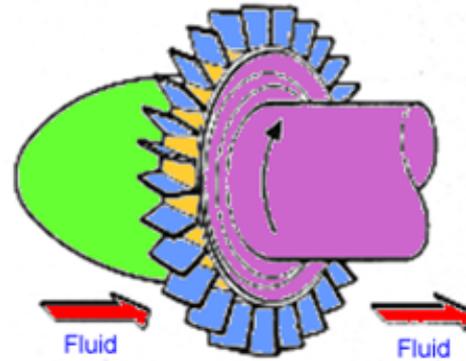


Figure 23: Principle of the axial compressor wheel



Figure 24: Axial compressor wheel

3. THE VARIOUS TYPES OF COMPRESSOR

3.1. RECIPROCATING VOLUMETRIC COMPRESSORS

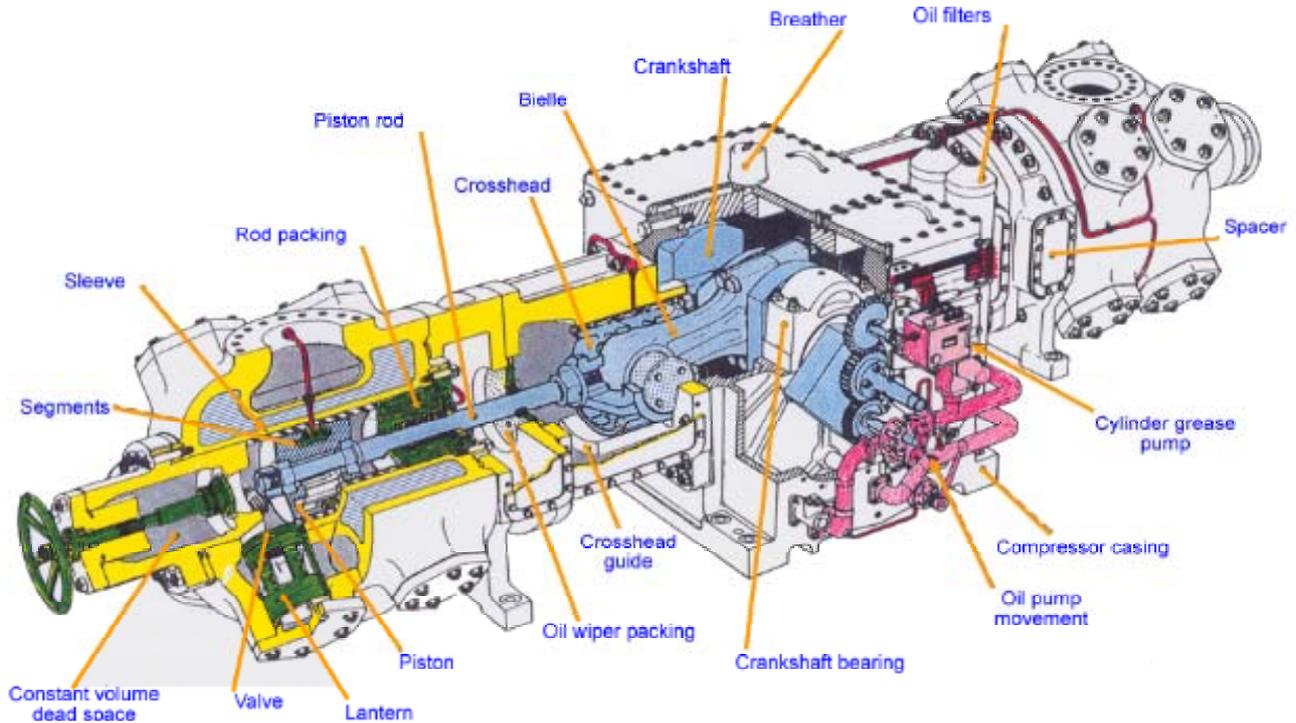


Figure 25: Reciprocating volumetric compressor

A reciprocating volumetric compressor is made up of two sections:

- ⊕ The "**gas**" section, which comprises the pistons, the valves (or clapper valves) and the other parts that take part in the compression of the gas.
- ⊕ The "**motion**" section, which transforms the rotary movement into a reciprocating movement, and which is not in contact with the gas.

3.1.1. The gas section

The gas section mainly consists of:

- ⊕ The pistons
- ⊕ The valves or clapper valves

3.1.1.1. The pistons

The pistons are usually made of metal and sometimes of aluminum alloy, for reasons of weight and expansion. They are equipped with piston rings for to provide sealing with respect to the cylinder wall and to align the piston.

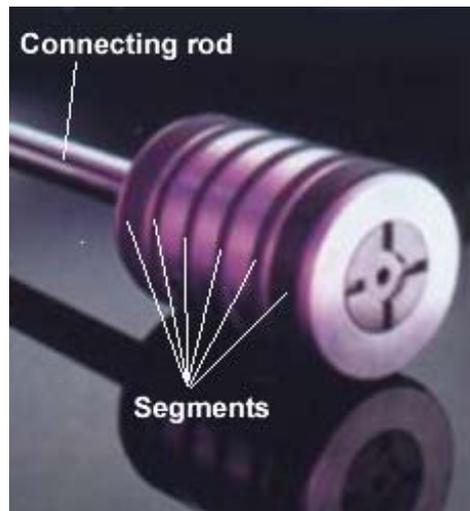


Figure 26: Piston of a reciprocating compressor

3.1.1.2. The valves (also known as clapper valves)

The valves operate as check valves. They consist of a fixed part that is secured to the cylinder of the compressor, and a clapper that is free to move inside the fixed part.

Figure 27: Valves of a reciprocating compressor



As shown in the photos, the valves are subject to many mechanical forces during their opening and closing phases, and also to relatively high temperatures.



Figure 28: Valves

The deterioration of a valve results in abnormally high cylinder temperatures during the operation of the compressor, and a loud clicking noise from the valves.

It is ABSOLUTELY ESSENTIAL to check the intake and discharge temperatures of the cylinders every day, or even several times a day.

Figure 29: "Hoerbiger" valves



The following problems can occur on these valves:

⊕ **Valve sealing problem**

Consequences:

- ▶ Poor compression.
- ▶ High temperature in the cylinder due to the temperature rise of the compressed gas.

⊕ **Burst valve**

Consequences

- ▶ Possible debris in the cylinder, resulting in a deterioration of the sealing between the cylinder and the piston.
- ▶ Risk of piston failure.
- ▶ Shut-down of the machine due to vibrations.

3.1.2. The motion section

The motion section transforms the rotary motion into a reciprocating motion.

The components of the motion section are:

- ⊕ **The crankshaft:** this is supported by several pillow blocks and has eccentric shaft sections known as **crank pins**, on which the connecting rods are articulated.
- ⊕ **The piston rods:** There is one connecting rod per cylinder. The big end is the end which rotates on one of the crank pins of the crankshaft. The small end is the part that of the connecting rod that rotates on the cross-head pin.
- ⊕ **The cross-heads**, also known as **slipper blocks**. There is one cross-head for each cylinder, and therefore for each connecting rod. The cross-head are guided by slipper guides which impose a rectilinear movement. The piston rod of each cylinder is secured to the corresponding cross-head.

It is the "connecting rod + cross-head + guide" assembly that enables the continuous rotary motion of the crankshaft to be converted into a reciprocating rectilinear motion that is communicated to the piston by the piston rod.

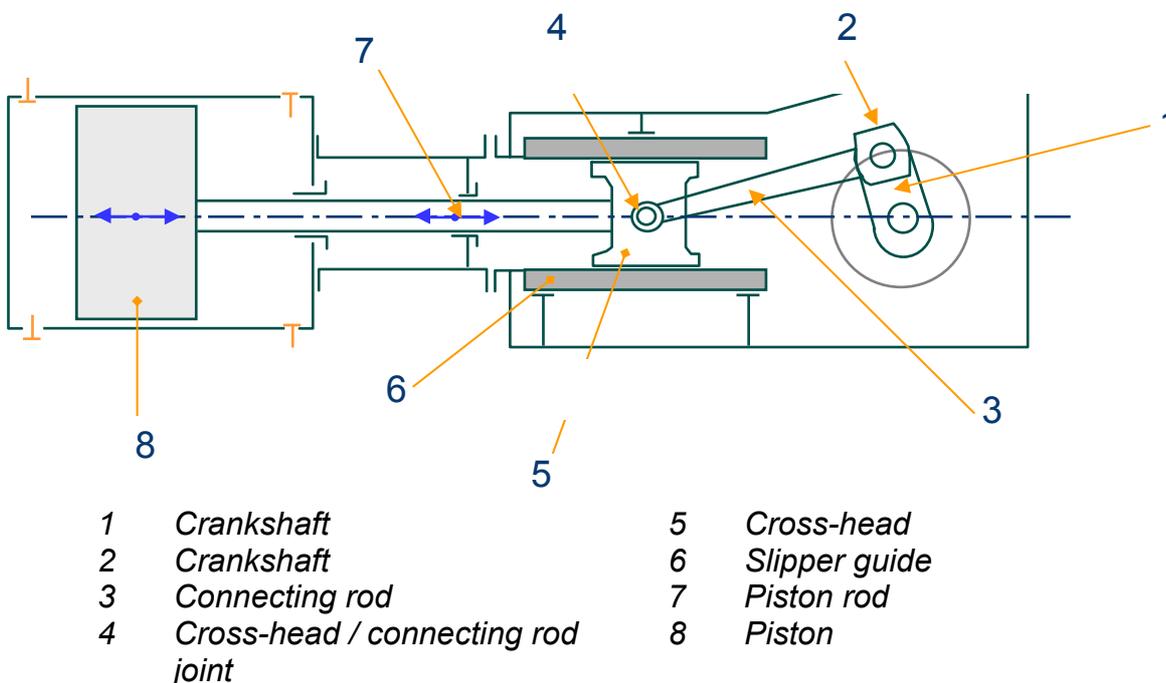


Figure 30: Motion section of a reciprocating compressor

The various components of the motion section are housed in the block or casing.

Each cylinder is connected to the block by a spacer (or intermediate section), which can comprise either one or two intermediate compartments if the gas to be compressed is dangerous.

3.1.3. Sealing of the "gas" section

3.1.3.1. Sealing between the piston and the cylinder

In order to maintain proper sealing between the cylinder and the piston, and to facilitate the piston displacement, the latter is surrounded by a series of piston rings.

For double-effect pistons, two sets of piston rings are provided:

⊕ Carrier ring

This ring distributes the weight of the piston around the cylinder and guides the piston in the cylinder in order to maintain appropriate rod movement and coaxiality between the cylinder and the piston. Certain pistons are mounted without carrier rings, thereby requiring lubrication.



Figure 31: Carrier rings

⊕ Sealing ring



This ring provides sealing between the front and rear effects.

Figure 32: Piston rings

3.1.3.2. Sealing between the piston rod and the "motion" section



This sealing is provided by the **packing** of the piston rod. It consists of a stack of rings which press against the rod and prevent the gas from passing.

The packings are usually connected to the LP torch system in order to evacuate any gas trapped between them.

Figure 33: Piston rod packing

There are secondary seals and nitrogen barriers in the safety spacers.

3.2. ROTARY VOLUMETRIC COMPRESSORS

These machines have an undeniable advantage in that, unlike reciprocating compressors, they produce a constant flow rather than a pulsating flow.

There are basically three types of volumetric compressor in use:

- ▶ rotary lobe type compressors,
- ▶ rotary screw compressors (helical),
- ▶ rotary vane compressors (for example used to compress flare gas).

3.2.1. The vane compressor

Operating characteristics:

⊕ Suction volume flow	:	200 to 5 000 m ³ /h
⊕ Compression ratio	:	up to 7
⊕ Rotation speed	:	1 500 rpm
⊕ Peripheral velocity	:	16 to 17 m/s

3.2.2. The screw compressor

This type of compressor is often used in our installations to supply the instrument air and utility air systems.

There are two types of screw compressor:

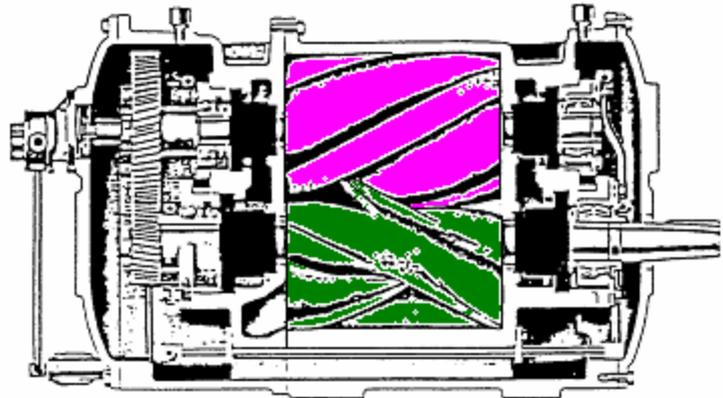
- ⊕ non-lubricated screw compressors,
- ⊕ lubricated screw compressors.

3.2.2.1. Lubricated screw compressor

The component parts are the same as for the non-lubricated compressor.

In lubricated compressors, oil is purposely mixed with the air at the compressor intake.

Figure 34: Cross-sectional view of a lubricated Screw Compressor



In the case of lubricated screws, the synchronisation gears are not necessary, as the screws are in contact with each other. Its presence serves three purposes:

- ⊕ to absorb most of the heat generated by compression, which makes it possible to reduce the temperature of the gas and increase the efficiency,
- ⊕ to lubricate the pillow blocks,
- ⊕ to improve the efficiency of the machine by reducing the internal leaks, due to its presence between the lobe and the casing.

The fluid discharged into the compressor block is a mixture of compressed air and oil. It is directed to a triple effect separator in which the air is cleared of the oil it contains.

Final purification of the air is achieved by means of a de-oiling cartridge with a high separation capability. The oil is therefore fully recovered and, after passing through a cooler, returns to the compressor under the effect of the pressure.

However, this type of compressor is no longer recommended due to the risk of fire experienced on a few installations.

Effectively, when the screws are worn or suffer from increased mechanical play, the oil vaporises and ignites in the contact of air and the hot parts.

General characteristics

- ⊕ Intake volume flow: 150 to 20,000 m³/h
- ⊕ Discharge pressure: up to 50 bars
- ⊕ Rotation speed: 3 000 to 20 000 rpm
- ⊕ Peripheral velocity: 20 to 40 m/s

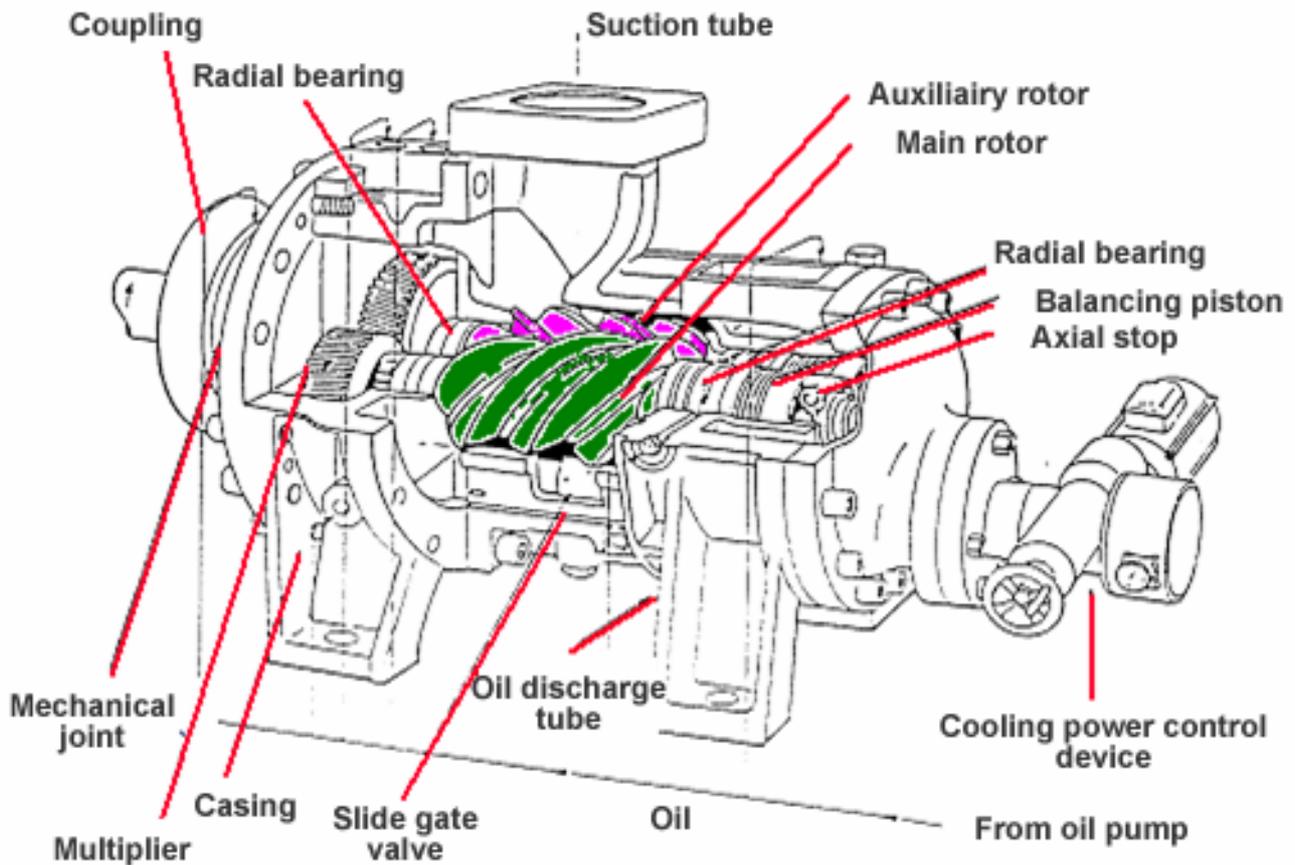


Figure 35: Cutaway and internal view of a lubricated screw compressor

3.2.2.2. Non-lubricated screw compressor

With practically the same constitution as the previous compressor, the absence of any metal-to-metal contact practically eliminates all risk of wear to the compression parts and avoids power loss due to friction.

3.3. CENTRIFUGAL COMPRESSORS

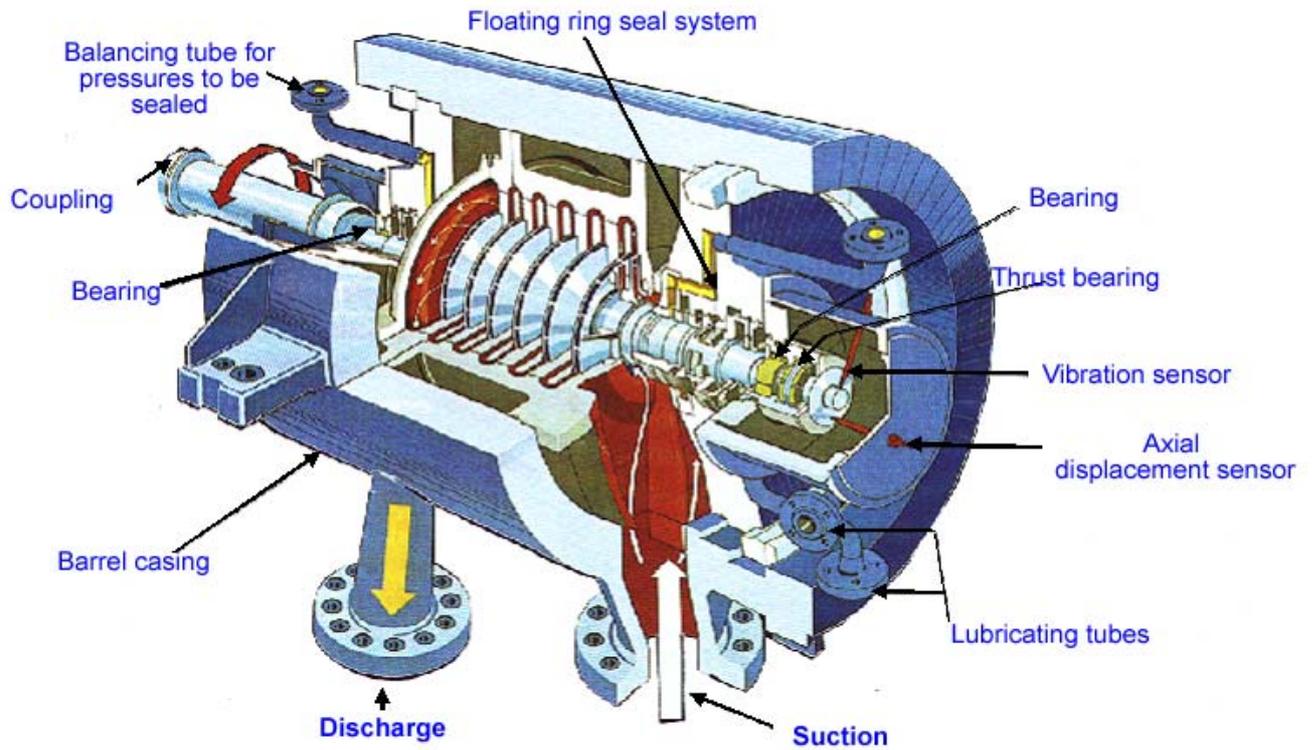


Figure 36: Centrifugal compressor with vertical mating face (Barrel)

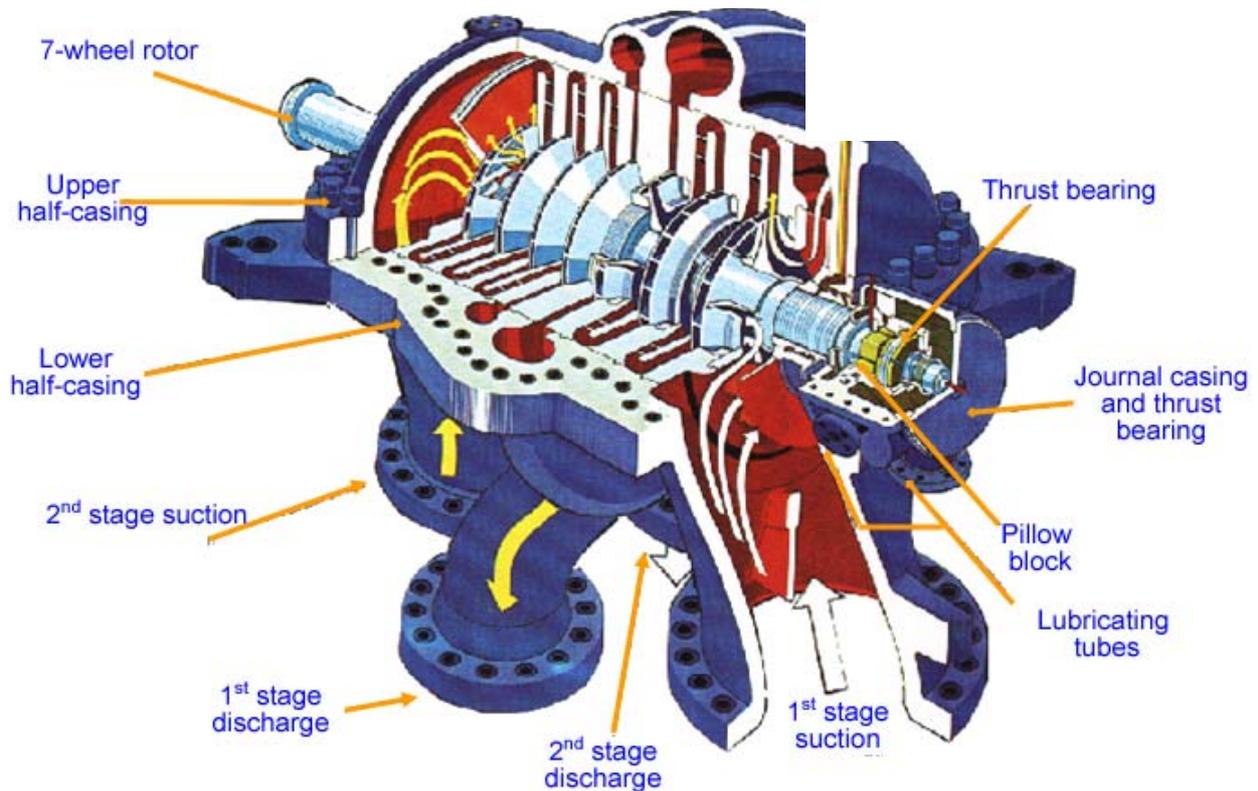


Figure 37: Two-stage centrifugal compressor with horizontal mating face

3.3.1. Rotor and compressor casing

3.3.1.1. General

The casing of a compressor must fulfill a certain number of functions:

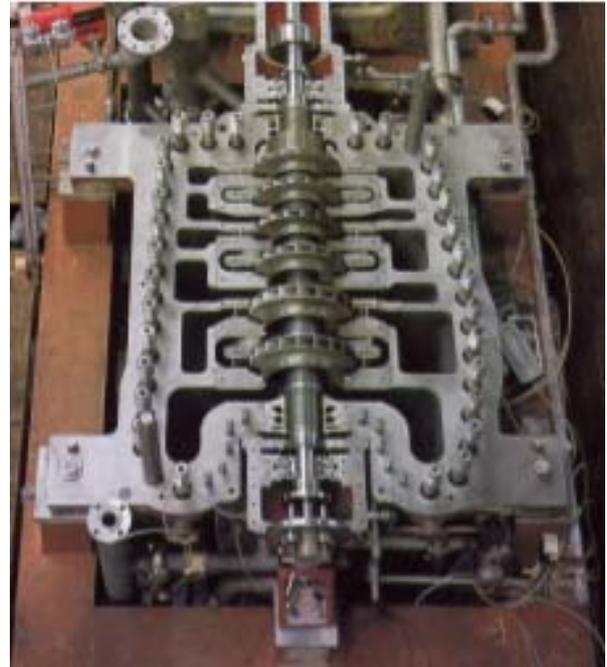
- ⊕ **It houses all the internal parts of the compressor:** rotor with its pillow blocks, its thrust bearing and its sealing devices; stator with the parts that make up the diffuser and the return duct; vibration or axial displacement sensor.
- ⊕ **It provides the connection** to the process by means of intake and discharge flanges.
- ⊕ **It provides the mechanical strength** of the entire machine to withstand the internal pressure, and the sealing of the internal chamber with respect to the atmosphere.
- ⊕ **It supports** and locates the compressor.

3.3.1.2. Stator design

Stator with horizontal mating faces: This design is used for low and medium pressures between 40 and 100 bar . The stator is manufactured in two parts, which are assembled with a horizontal parting line (metal-to-metal contact).

This configuration is adopted for axial compressors and centrifugal compressors producing low and medium pressure levels.

Figure 38: Stator with horizontal mating faces



Stator with vertical mating faces ("barrel"): this is used for high pressures . This configuration is adopted for high-pressure centrifugal compressors.

Figure 39: Stator with vertical mating faces

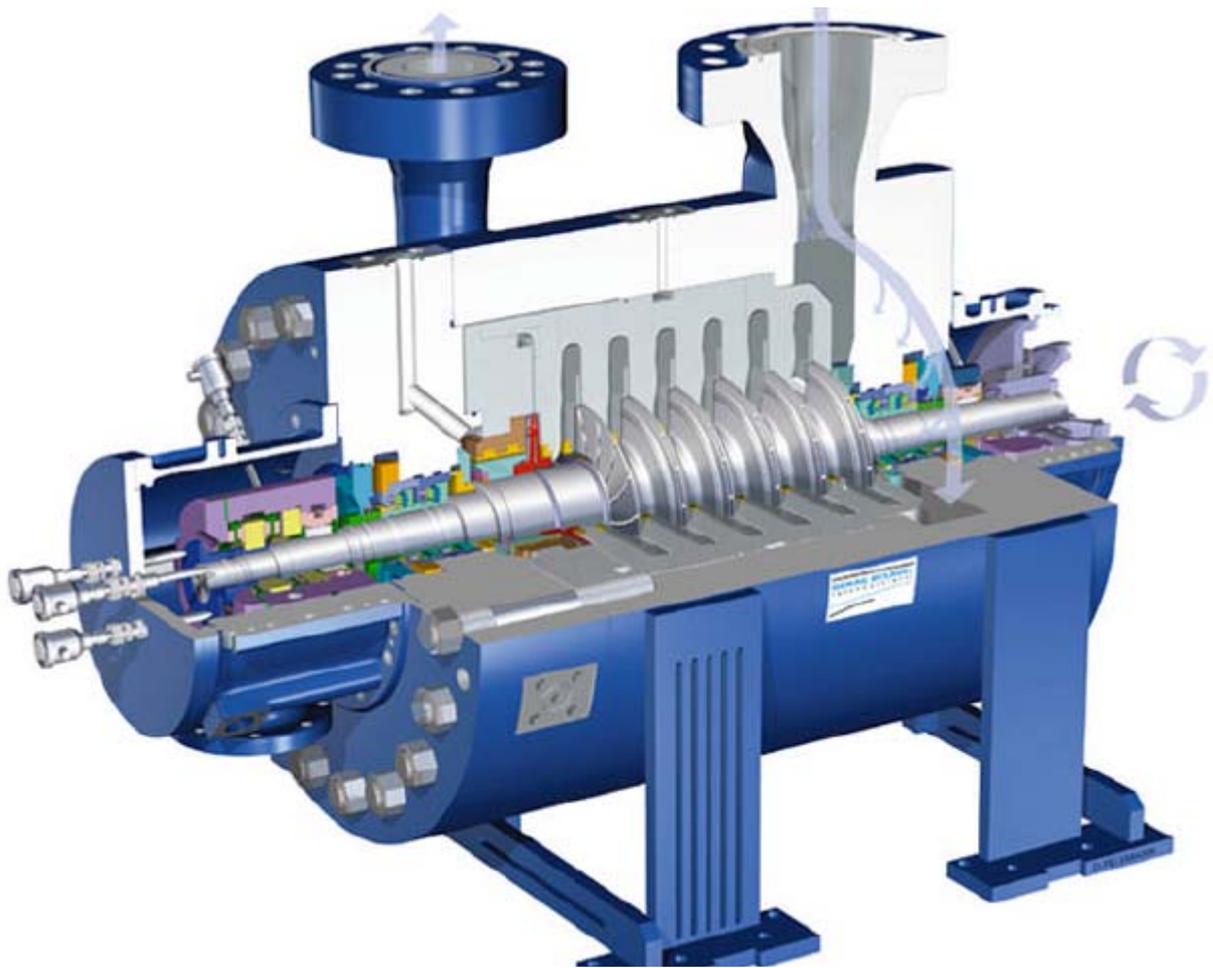


Figure 40: Centrifugal compressor

3.3.1.3. The rotor

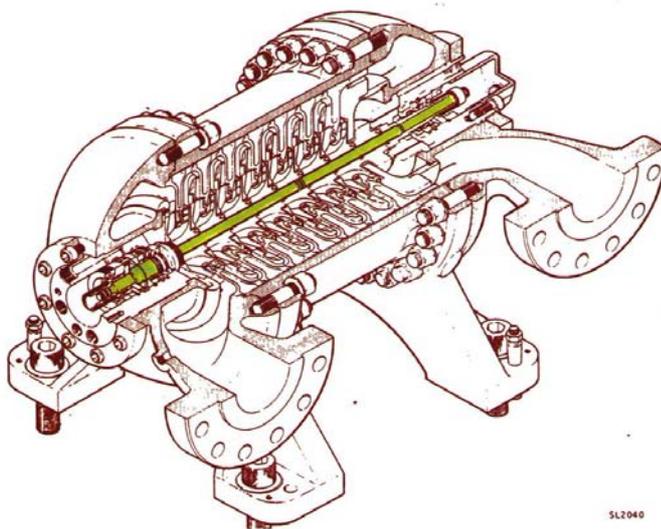
The rotor, which is driven by a coupling, is rotationally guided by two pillow blocks, which are generally located one at each end.

These bearings can consist of plain pillow blocks or can be equipped with linings, which are better suited to high rotation speeds and high loads. Although still rare, magnetic bearings are currently being developed and starting to appear.

The axial positioning of the rotor is ensured by a thrust bearing located at the end of the rotor (usually on at the end opposite to the coupling (EOC)). This thrust bearing usually consists of liners that press against a collar on the shaft.



Figure 41: Rotor with wheels



The axial force against the thrust bearing is generated by the difference between the pressure on each wheel and any thrust due to coupling. To achieve the right balance in the mobile part in the stator, a collector called a balancing line may be installed. It can be considerably reduced by astutely arranging the wheels (dual-flow wheels or back-to-back wheels), or by using a balancing piston or drum.

Figure 42: Positioning of the rotor

3.3.1.4. Centrifugal compressor wheels

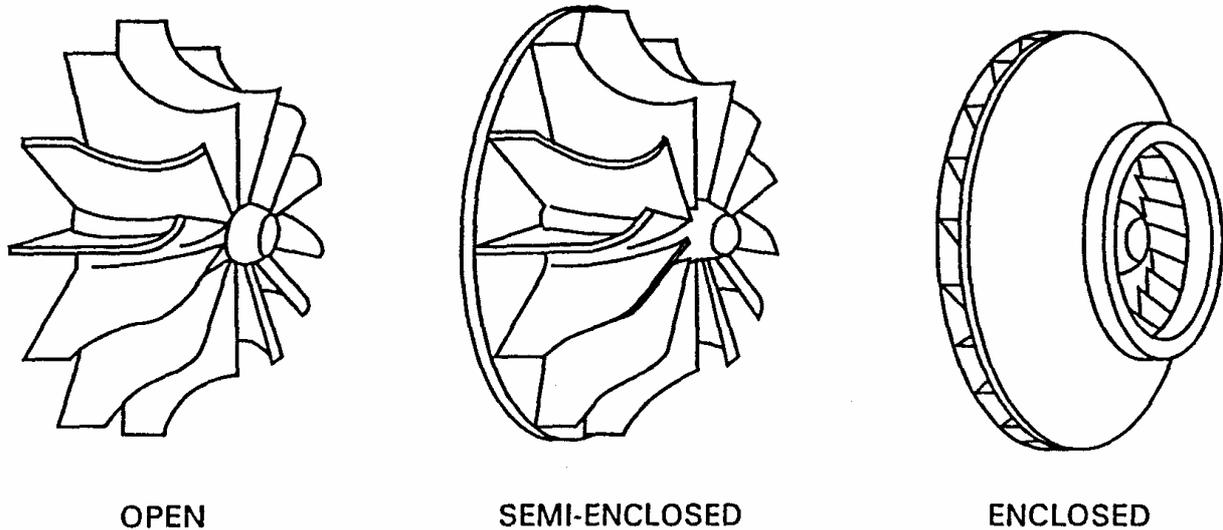


Figure 43: Centrifugal compressor wheels

The open wheel is used for medium flow-rates and high discharge pressures. It is only used in single-stage compressors.

The semi-enclosed wheel is used for high flow-rates. This type of wheel can be used to equip multi-stage or single-stage compressors.

The enclosed wheel is mainly used in multi-stage compressors.

The wheels enable the required quantity of gas to be compressed under the operating conditions.

These wheels are mounted on a shaft, the complete assembly constitutes the rotor, whose rotation speed can exceed 20,000 rpm.

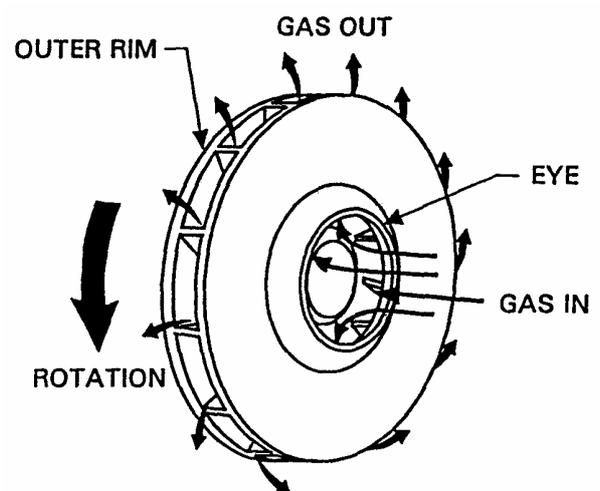
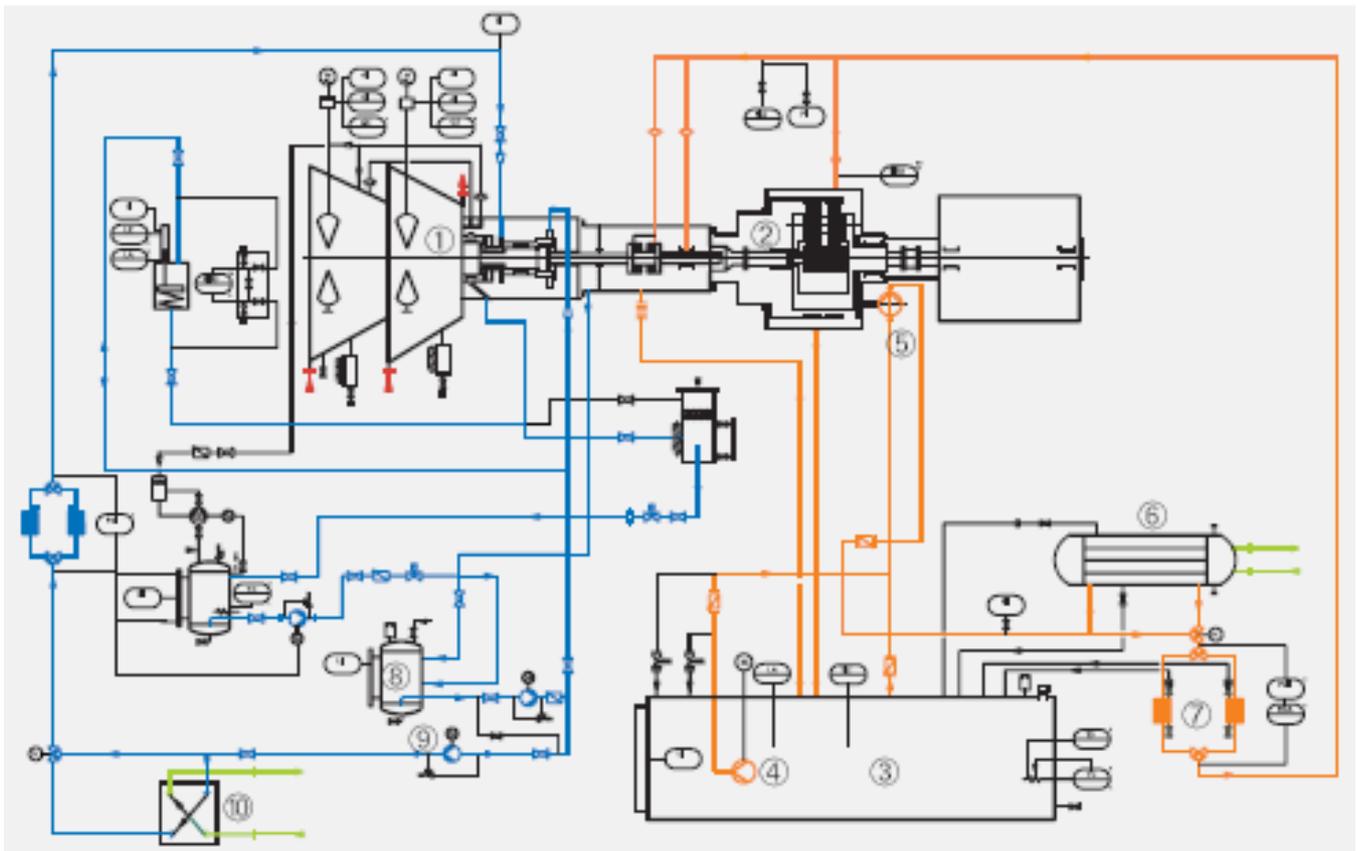


Figure 44: Operating principle of a wheel

3.3.2. The oil sealing system



- | | |
|-----------------------------|----------------------|
| 1/ Turbo compressor | 6/ Lub oil cooler |
| 2/ Spur type gear | 7/ Lube oil filter |
| 3/ Lub oil tank | 8/ Seal oil tank |
| 4/ Auxilliary lube oil pump | 9/ seal oil pump |
| 5/ Main lube oil | 10 / seal oil cooler |

	Lube oil supply	The lube oil supply lubricates mechanical parts such as bearings.
	Seal oil supply	The seal oil supply contributes to sealing by creating an oil barrier against potential gas leaks.
	Refrigerant (CoolingSystem)	Used to control the system's oil temperature. If the oil is too hot, its fluidity may increase and it will not do the job it is supposed to do.
	Cooling water	Used to evacuate calories stored in the coolant and participating in the temperature regulation.

Figure 45: Typical sealing system

See course on packings for details of operation.

The following photos are given as examples only. Seal packings will be covered in a specific course.

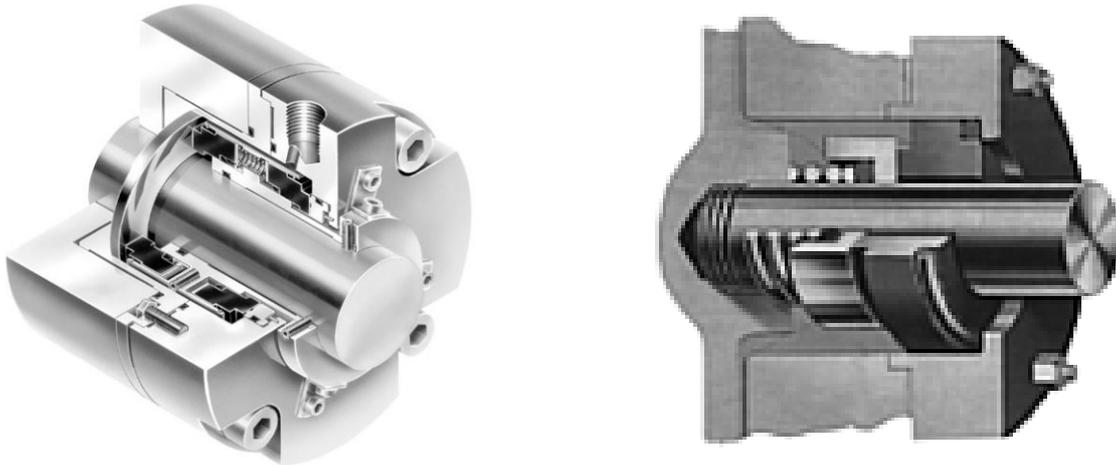


Figure 46: Examples of seal packings

The system is designed to:

- ⊕ produce an oil pressure in excess of the gas pressure,
- ⊕ maintain this pressure until the machine comes to a complete standstill in the case of a cut-out,
- ⊕ create this pressure before the machine is started up, and for the time it takes to heat up the drive turbine in the case of turbo-compressors.

This fluid can be an inert gas or a gas that is specific to the case of sealing by means of labyrinths or dry packings.

A seal labyrinth is a type of seal used in compressors. Labyrinths do not completely stop leaks but greatly reduce them. For this reason, labyrinths are generally used as seals between the different stages of a compressor.

As for a shaft seal, they are often used in combination with other types of seals.

Sealing is particularly important (if there is a leak to the outside, there is a risk to human life) and is therefore regularly checked and monitored by safety alarms and systems.

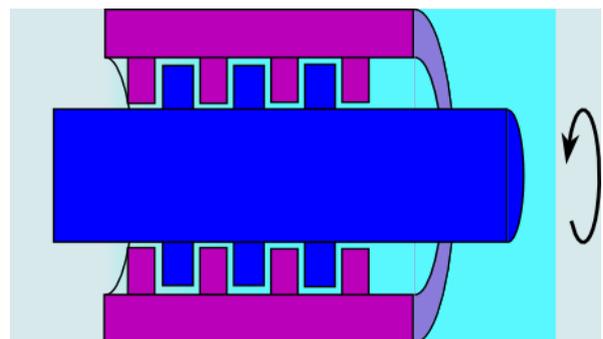


Figure 47: Seal labyrinth

The system comprises:

- ⊕ the oil tank or reservoir,
- ⊕ the oil pumps,
- ⊕ the coolants,
- ⊕ the filters,
- ⊕ a pressurized oil accumulator tank,
- ⊕ the pressurized oil distribution pipes,
- ⊕ the non-contaminated oil return pipes, which return the oil to the main oil tank at atmospheric pressure,
- ⊕ the contaminated oil return pipes, which return the contaminated oil to the scavenge tank at the gas pressure,
- ⊕ the drain valves and the main oil tank,
- ⊕ the monitoring, warning and safety equipment.

3.3.3. The gas sealing system

The principle of operation of the spiral-grooved gas packing is based on an equilibrium of the aerostatic forces and aerodynamic forces to provide a minimum and stable interface seal.

The aerodynamic forces are only produced in rotation. During rotation, the spiral grooves play an essential part by generating an opening force that enables an acceptable interface clearance to be obtained.

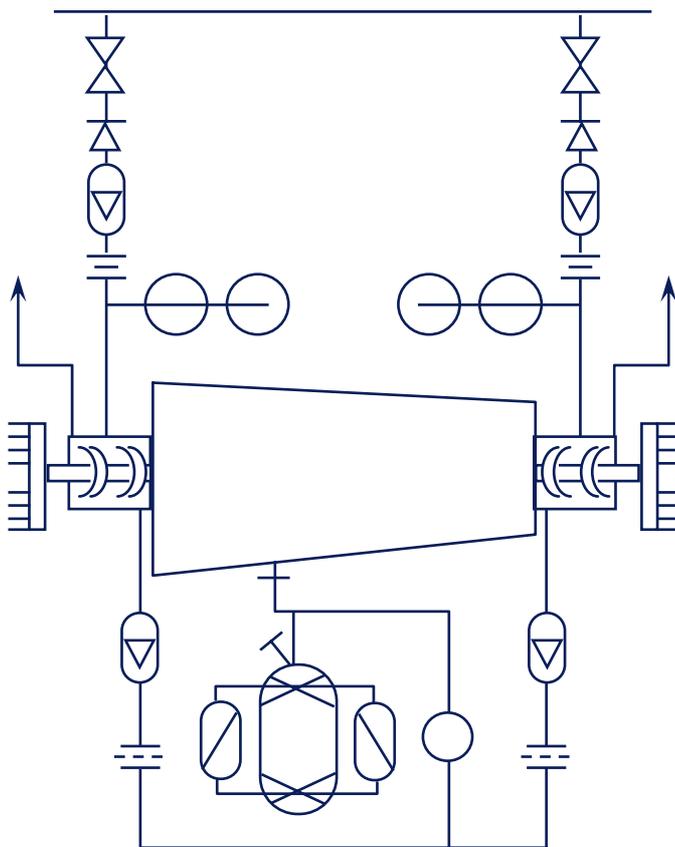


Figure 48: Functional diagram of a gas packing monitoring system

3.4. DYNAMIC AXIAL COMPRESSORS

Axial compressors are used to generate high flow-rates.

Constitution

These compressors are made up of the following components:

- + **Inducer blades** (adjustable inlet guide vanes): Their purpose is to guide the fluid as it enters the wheel. They enable the characteristics of the compressor to be adapted to the variations in the characteristics of the system it supplies. In other words, the volume of fluid can be maintained constant by adjusting the position of these blades.



Figure 49: Adjustable blades

- + **Diffuser:** Its purpose is to convert the dynamic pressure of the fluid into static pressure by reducing the velocity. The vanes in the diffuser are sometimes adjustable, in which case they play the same part as the adjustable inlet guide vanes.

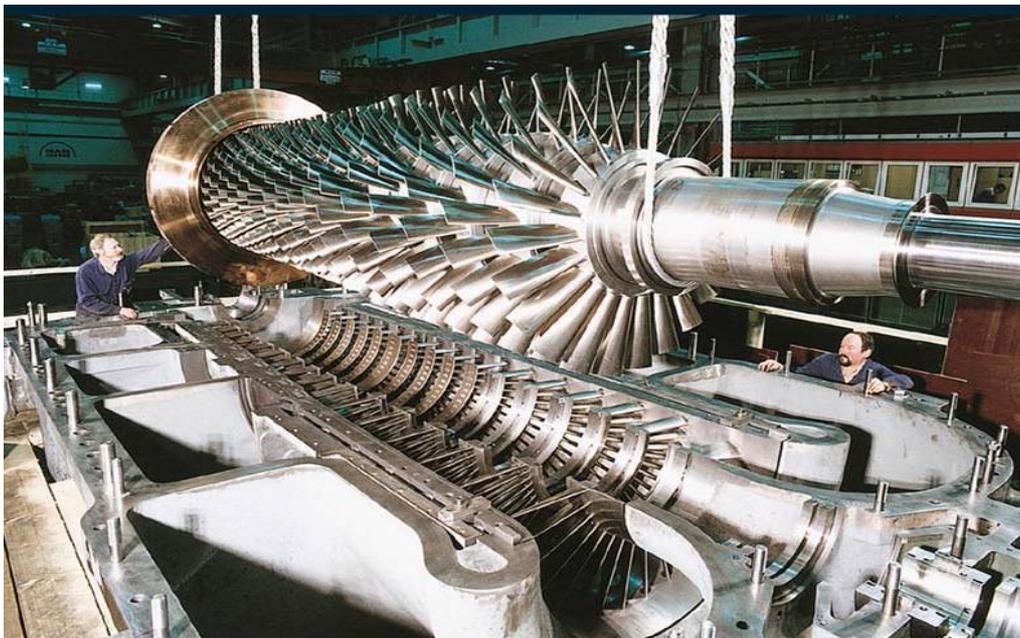


Figure 50: Axial compressor rotor

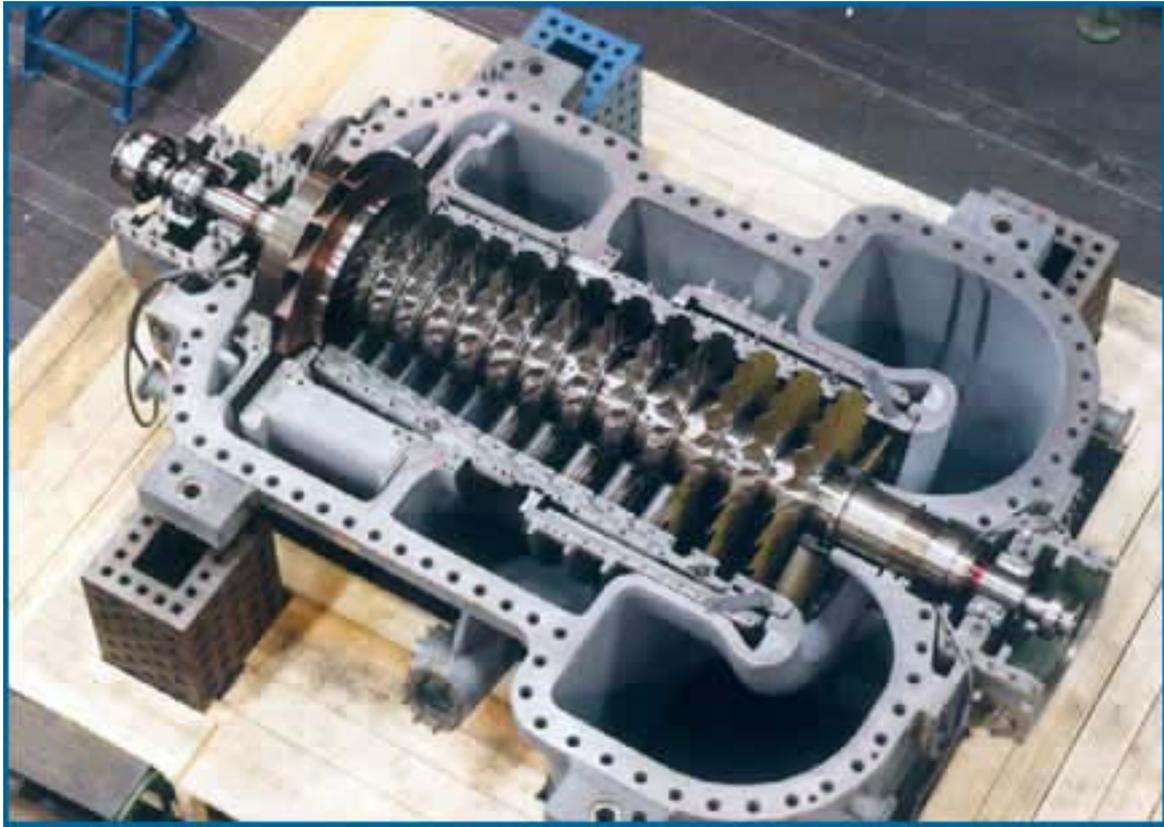


Figure 51: Dynamic axial compressor

3.5. TURBO-EXPANDERS

The turbo-expander consists of an expansion turbine which is "linked up" to a compression stage, which recovers the energy produced by the expansion of the gas.

Figure 52: Turbo-expander



The expansion of gas with a pressure reduction ratio has its main applications in the gas industry (recovery of natural gas condensates), in the petrochemical industry (recovery of ethylene from pyrolysis gas) and in the production of oxygen by separation of air.

In all these applications, the main objective is the generation of low temperatures, and sometimes also the adaptation of the gas pressure to the process used.

There are 3 main sections:

- ⊕ **The expander casing** and the parts that are attached to it: adjustable inlet guide vane actuator grid and their discharge diffuser support.
- ⊕ **The compressor casing** which contains the main components.
- ⊕ The purely mechanical section, which is located between the previous two sections and is connected to them via the 4 **inlet / outlet** pipes.

Description of the expander casing section.

The gas enters from the top and exits axially.

A grid of adjustable vanes enables the flow to be shut off automatically (thus also enabling a progressive start-up), and opened to varying degrees in order to vary the flow-rate and therefore maintain an acceptable efficiency of the expansion system.

Since a part of the expansion occurs in these vanes, the decrease in temperature and the slightest formation of ice or various types of hydrate, or even the presence of dust, will tend to block the system and prevent the regulation from operating.

Description of the compressor casing section

The casing is obtained by machining cast or welded rough parts, and comprises an axial inlet and a tangential outlet.

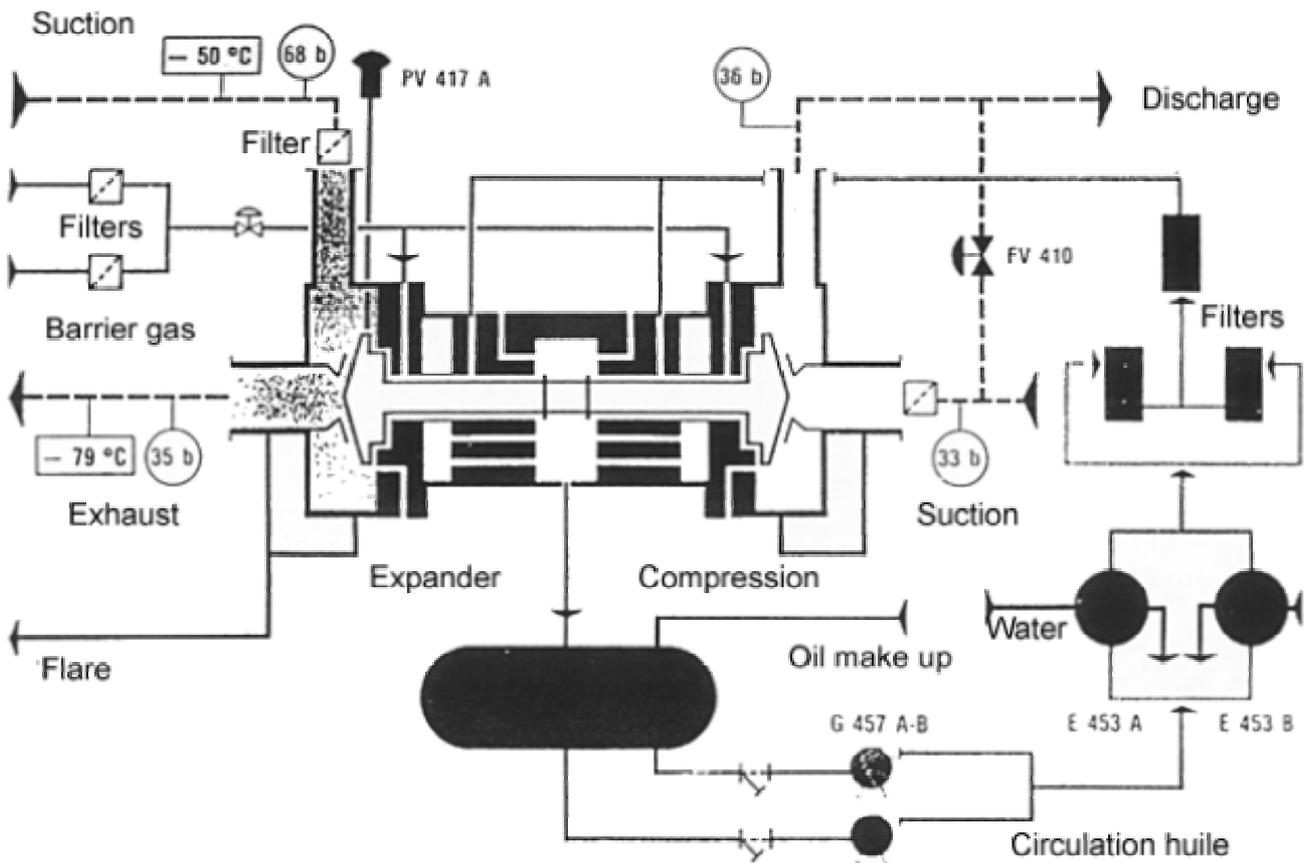


Figure 53: Principle of operation of a Turbo-expander

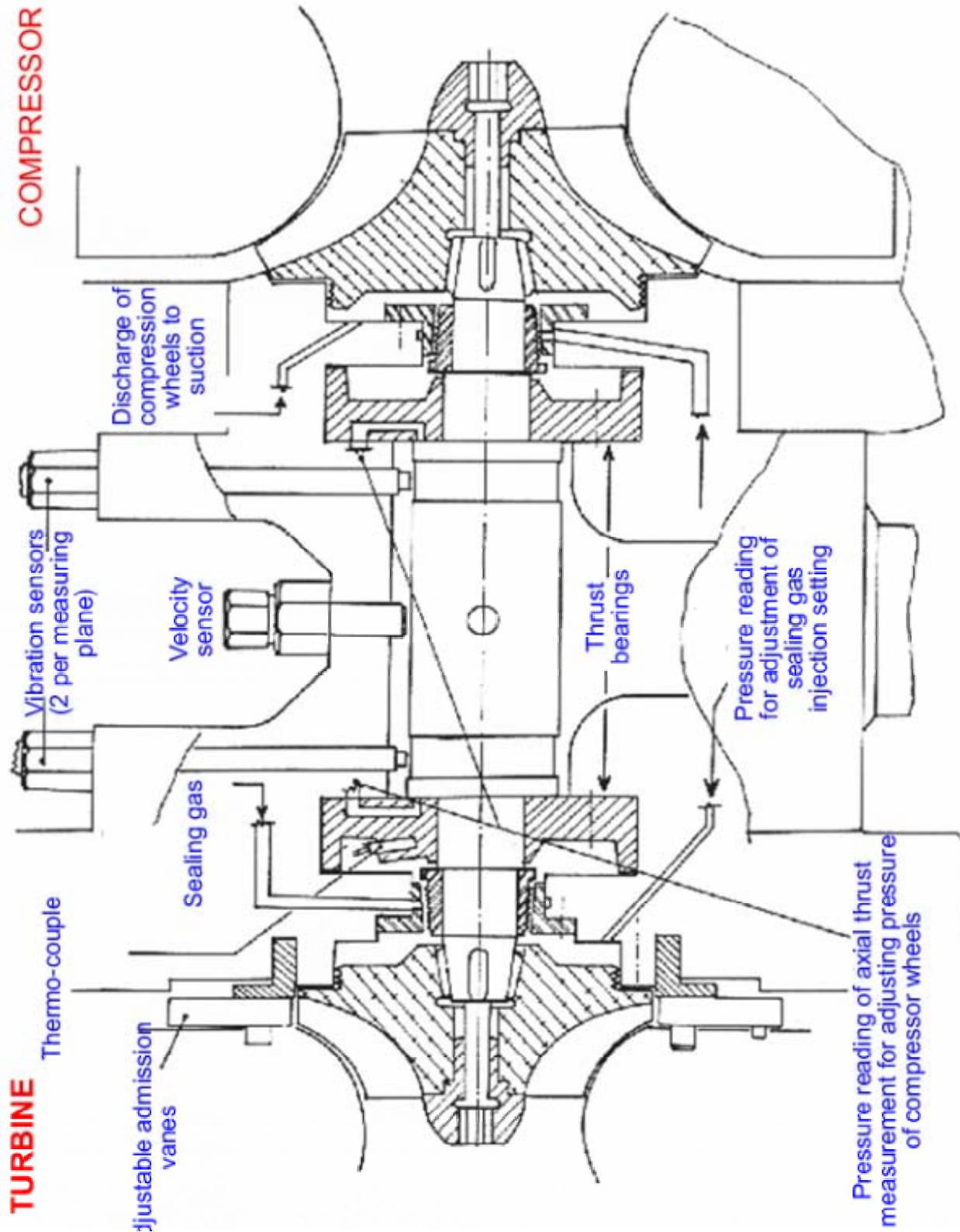


Figure 54: Turbo-expander

3.6. ADVANTAGES AND DISADVANTAGES OF THE VARIOUS TYPES

Type of compressor	Volumetric compressors		Dynamic compressors	
	Reciprocating	Rotary	Centrifugal	Axial
Advantages	<p>Well adapted to low flow-rates</p> <p>Can propel gases at all pressures</p> <p>Relatively flexible to operate</p>	<p>Can propel gases at a wide range of flow-rates</p> <p>Regular flow</p> <p>Satisfactory reliability</p>	<p>Well adapted to medium and high gas flow-rates</p> <p>Relatively flexible to operate</p> <p>Excellent reliability</p>	<p>Very high efficiency</p> <p>Well adapted to very high flow-rates and to moderate pressures</p> <p>Excellent reliability</p>
Disadvantages	<p>Pulsed flow</p> <p>Moderate reliability for the valves</p> <p>A back-up machine is necessary</p>	<p>Rarely used for high pressures</p>	<p>Not suitable for low flow-rates</p> <p>Surging phenomena at low flow-rates makes operation sensitive</p>	<p>Large rotors, delicate and costly to manufacture</p>

Table 2: Advantages and disadvantages of the various types of compressor

4. REPRESENTATION OF COMPRESSORS AND COMPRESSOR DATA



Description of the equipment

PID: Ao31440B (Appendix A)

Compressor: Centrifugal

Brand: Nuovo Pignone

Type: BCL 407

Operation settings

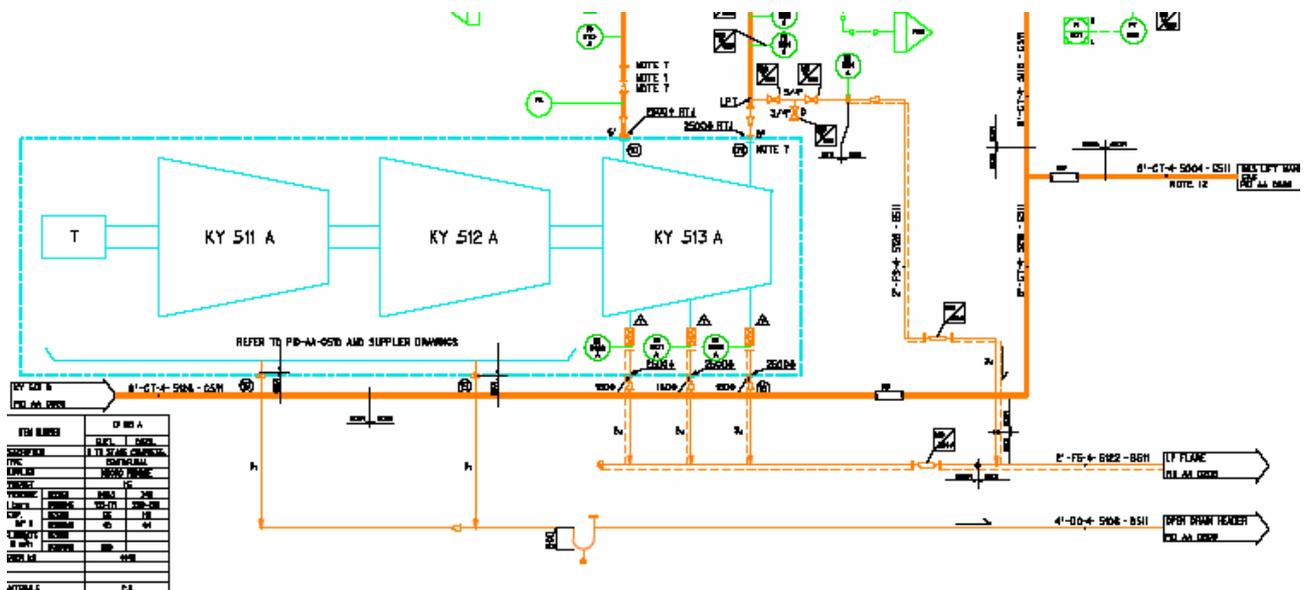
Fluid: gas

Suction T°: 40°C

Discharge T°: 160°C

Discharge pressure: 28.8 BARG

Suction rate: 7239 m³/h



5. COMPRESSORS IN THE PROCESS

5.1. LOCATION AND CRITICALITY

As we have seen previously, a compressor is used to transfer gas from one location to another:

- ✦ Transfer of gas from a platform to the onshore installations.
- ✦ Compression of air to supply the "instrument" and "utility" air systems.
- ✦ Injection of gas into the reservoir.

If this function stops, it is easy to understand that this will cause serious problems for the correct operation of the installation.

Take the example of compressors, located in the gas processing line and transferring the gas from a desulfurization unit to a dehydration unit. The criticality will be high because the shut-down of any of these compressors will result in halted production.

It is for this reason in particular that in some installations a backup compressor is installed, in case a problem occurs.

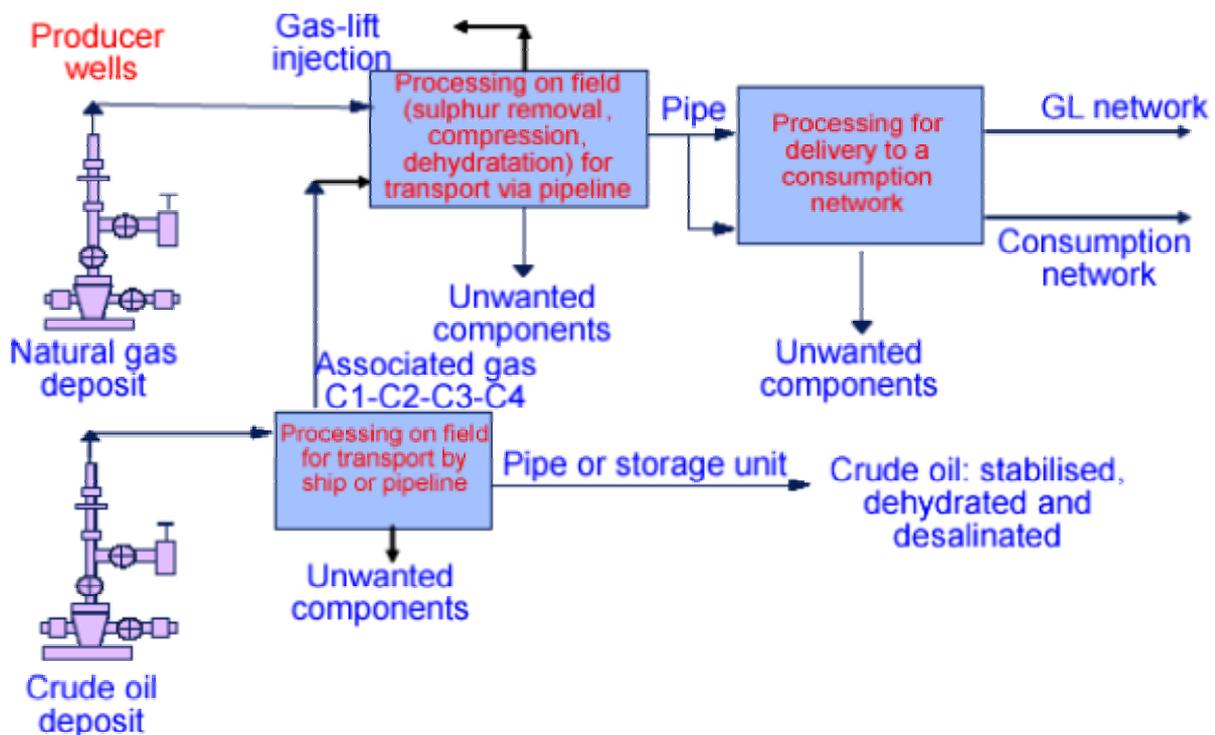
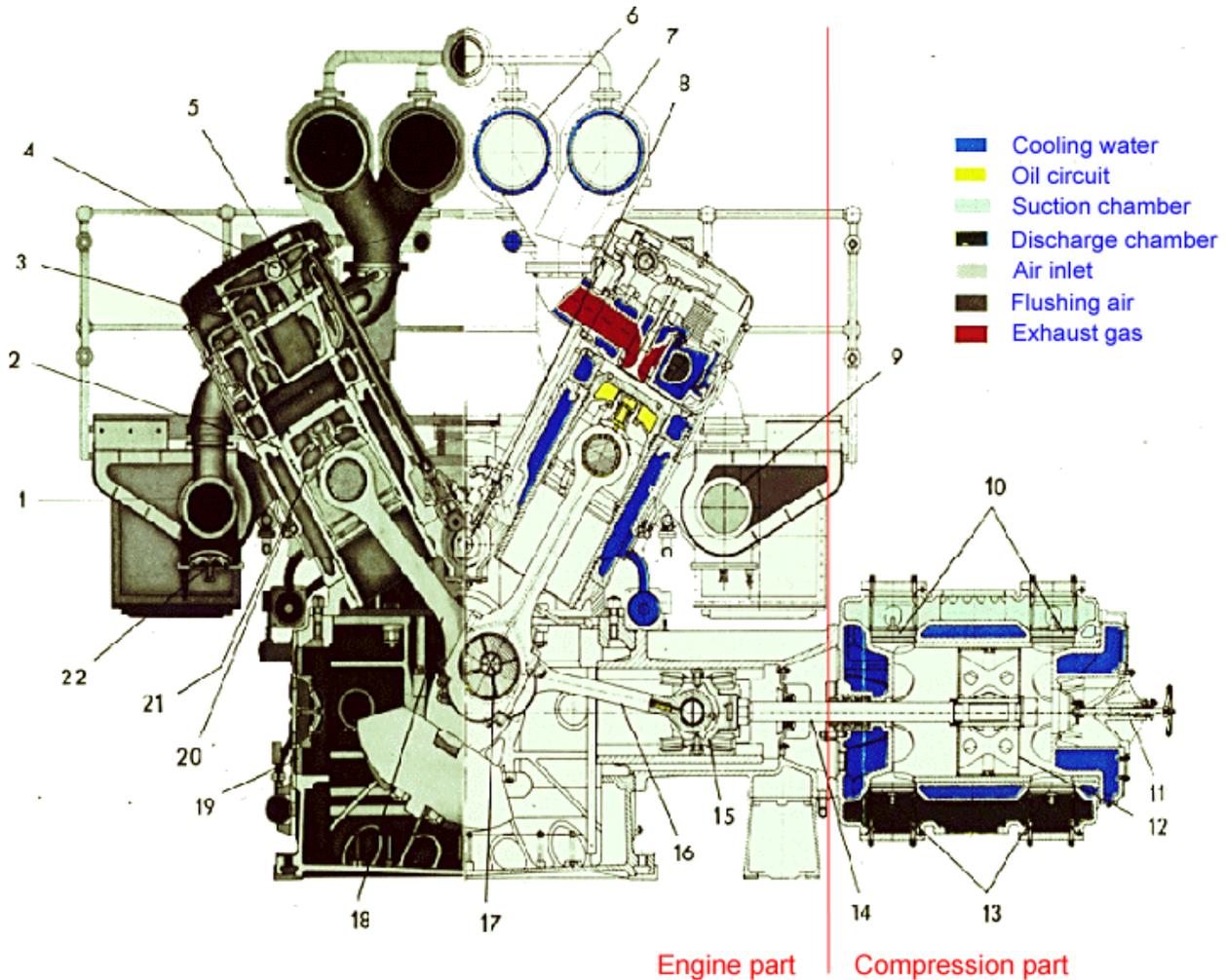


Figure 55: Location of the compressor in the process

6. AUXILIARY SYSTEMS

6.1. THE AUXILIARY SYSTEMS OF A RECIPROCATING COMPRESSOR



- | | | | |
|----|-------------------------------|----|------------------------------|
| 1 | Air intake manifold | 12 | Compressor piston |
| 2 | Drive cylinder | 13 | Cylinder discharge valves |
| 3 | Intake valve | 14 | Compressor piston rod |
| 4 | Intake valve rockers | 15 | Guide cross-head |
| 5 | Cylinder head | 16 | Compressor connecting rod |
| 6 | Exhaust manifolds | 17 | Crankshaft |
| 7 | Exhaust manifolds | 18 | Drive connecting rods |
| 8 | Camshaft | 19 | Casing |
| 9 | Air intake manifold | 20 | Cylinder envelope |
| 10 | Cylinder suction valves | 21 | Drive piston |
| 11 | Adjustable dead space control | 22 | Intake manifold safety valve |

Figure 56: View of a reciprocating compressor

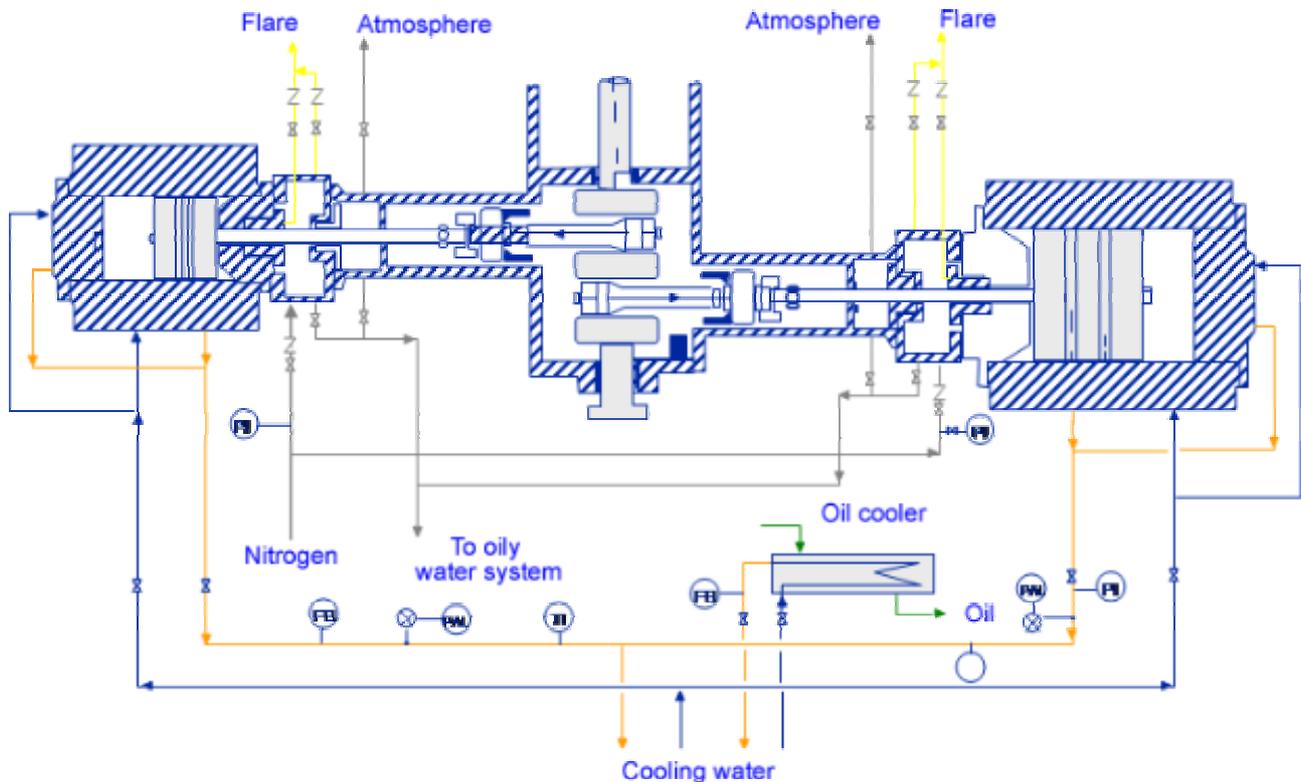


Figure 57: Diagram of the auxiliary systems of a reciprocating compressor

6.1.1. Cooling

When a gas is compressed, its temperature increases. This heat is dissipated in the various parts of the compressor.

When mechanical parts are in regular motion, their temperature increases.

It is therefore necessary to provide a cooling system. This system causes water to circulate around the cylinder of the compressor.

In order to ensure that this cooling water is always at a regular temperature, it is routed through refrigerants and heat exchanger type coolers of another type of temperature regulation system.

(Heat exchangers are covered in a different course).

6.1.2. Lubrication

The function of the lubrication system is to ensure lubrication during operation and prior to start-up, in other words to supply the shaft assembly with a **flow of oil which is constant** in terms of viscosity, pressure, temperature and filtration.

This function is usually provided by an **oil unit**, which may be shared with the sealing system.

The oil unit comprises:

- ⊕ the oil tank or reservoir,
- ⊕ the coolers,
- ⊕ the filters,
- ⊕ a pressure tank, if necessary,
- ⊕ the distribution pipes,
- ⊕ the oil return pipes,
- ⊕ the monitoring, warning and safety equipment.

6.1.3. Alarms and safety systems

The function of these auxiliary systems is to ensure:

- ⊕ The correct operation of the compressor throughout the range of characteristics required by the process.
- ⊕ the start-up of the plant without any incidents on the machine (drive, coupling, step-up gearbox) ...,
- ⊕ emergency shut-down: indication, deceleration and isolation of the compressor.
- ⊕ Temperature threshold and vibration sensors
- ⊕ Packing leaks

6.2. AUXILIARY SYSTEMS OF ROTARY VOLUMETRIC COMPRESSORS

6.2.1. The vane compressor

Operation with lubrication:

The vanes are usually made of composite material. The oil, in addition to reducing the friction between the vanes and the stator, also evacuates calories and improves the sealing at the points of contact between the vanes and the stator. In this configuration, the compressed gas is contaminated by the oil.

Cooling

Different methods can be used to eliminate the heat produced by compression and friction:

- ▶ Forced air circulation: in this case, the compressor is equipped with cooling fins.
- ▶ Water circulation in a double cooling envelope around the cylinder.

6.3. AUXILIARY SYSTEMS OF THE CENTRIFUGAL COMPRESSOR

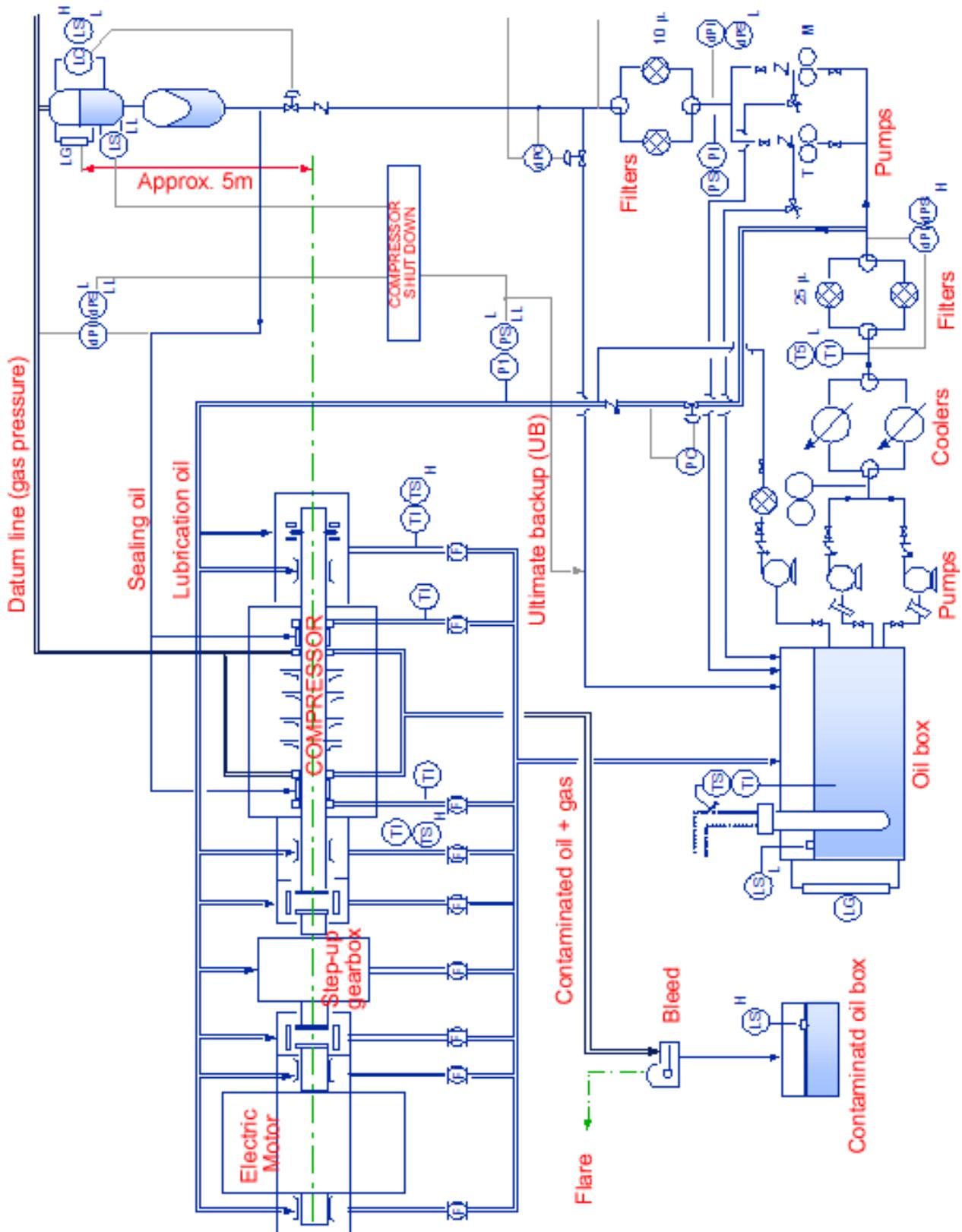


Figure 58: Diagram of the auxiliary systems of a centrifugal compressor

6.3.1. Lubrication

The operation of the pillow blocks and thrust bearings is dependent on the "hydrodynamic" principle, i.e. on the build-up and sustainment of an oil wedge.

Oil wedge: this is the very thin layer of oil that is found between two parts and prevents direct friction between them when they are moving.

The lubrication pressure does not contribute to the build-up of this oil wedge in any way, but simply enables the pillow block to be filled and the flow to be maintained, which in turn determines the temperature of the pillow block and therefore the viscosity of the oil in the pillow block and thrust bearing.

The oil temperature is maintained at a suitable level by the coolers (oil that is too cold and viscous) and by heaters (oil that is too hot is unusable) installed in the system. They ensure the removal of the calories introduced by:

- ⊕ the solid sections of the shaft (particularly at the discharge end),
- ⊕ the actual operation of the pillow blocks and thrust bearings.

The **pressure** measured at the discharge of the auxiliary oil pumps depends mainly on the connection pipes between the oil unit and the machine (lengths and diameters that determine the pressure loss as a function of the required flow-rate).

The flow-rate of the lubricant depends solely on the quantity of heat to be evacuated from the pillow block.

The viscosity of the oil required for the correct operation of the pillow block will determine the quality of the lubricant chosen according to the parameters of the machine: rotation speed, weight of rotor, specific load, type of pillow block, on-load operating temperature of the machine, material of which the rotor is made, etc.

The filtration depends on the operating clearances of the pillow block and on the type of pillow block.

Alarms and safety systems

The function of these auxiliary systems is to ensure:

- ⊕ the correct operation of the compressor throughout the range of characteristics required by the process: the equipment will inform the operator when the machine's surge and overload areas have almost been reached, and if necessary will operate the corresponding anti-surge or rpm limiting auxiliary systems,
- ⊕ the start-up of the unit without any negative effect on the mechanical condition of its components: compressor, drive machine, coupling, step-up gearbox, etc.,
- ⊕ emergency shut-down: indication, deceleration and isolation of the compressor.

The main function of the alarms is to enable the operators to complete the necessary operations for correcting operational anomalies, performing adjustments and carrying out routine maintenance in good time, without having to stop the machine.

Among these functions, the anti-surge system is an important safety device for the protection of the compressor.

7. OPERATING PARAMETERS

7.1. ANTI-SURGE SYSTEM

Surging is an extremely violent phenomenon which involves the entire mass of gas present in the machine.

The gas no longer flows regularly through the machine but is subject to alternating movements in all or part of the compressor.

It results in:

- ⊕ **vibrations** in the vanes of the compressor wheels,
- ⊕ **reversed axial thrust** on the rotor,
- ⊕ very low frequency **vibrations** in the compressor assembly (dull rumbling), which are obviously very detrimental to the mechanical strength of the machine.

The surge phenomenon occurs in the operating areas where the gas flow is slow.

It is therefore possible to show, in a compression ratio Vs flow-rate diagram, a prohibited operating area limited by a curve known as the surge limit curve.

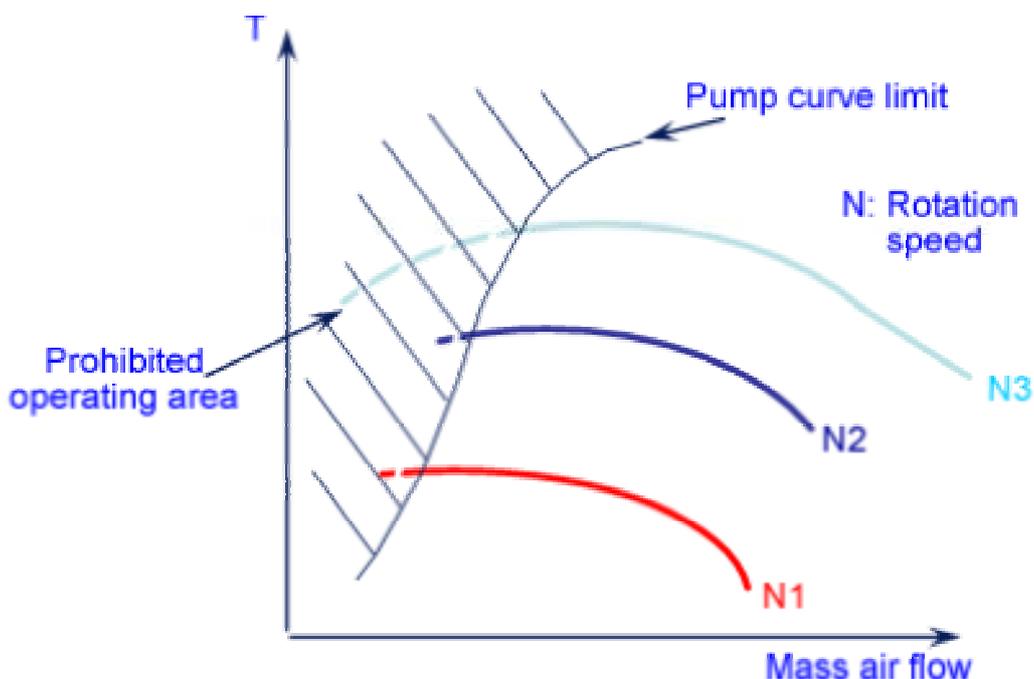


Figure 59: Prohibited operating area

It is therefore important to permanently ensure that there is a sufficient gas flow in the machine so that it is always working above the surge limit.

In practice, if the flow-rate required by the process **falls below the surge limit**, an anti-surge control system similar to the one shown in the above curve provides a means of ensuring a sufficiently high flow-rate in the compressor so that it operates in a stable zone: the excess gas flowing through the machine is cooled and recirculated to the suction end, or is vented to the atmosphere in the case of an air compressor.

For this reason, it is clear that the operation of a compressor needs to be monitored very carefully because the slightest problem can have very considerable consequences in terms of equipment safety and cost.

The operating parameters to be measured and monitored are listed in the following table. Some of these parameters are measured on the DCR displays in the control room, and are recorded in the system history. All the other parameters are measured directly on the machine by the operator. It is important to pay particular attention to the noise produced by the compressor, because certain variations in this noise indicate problems.

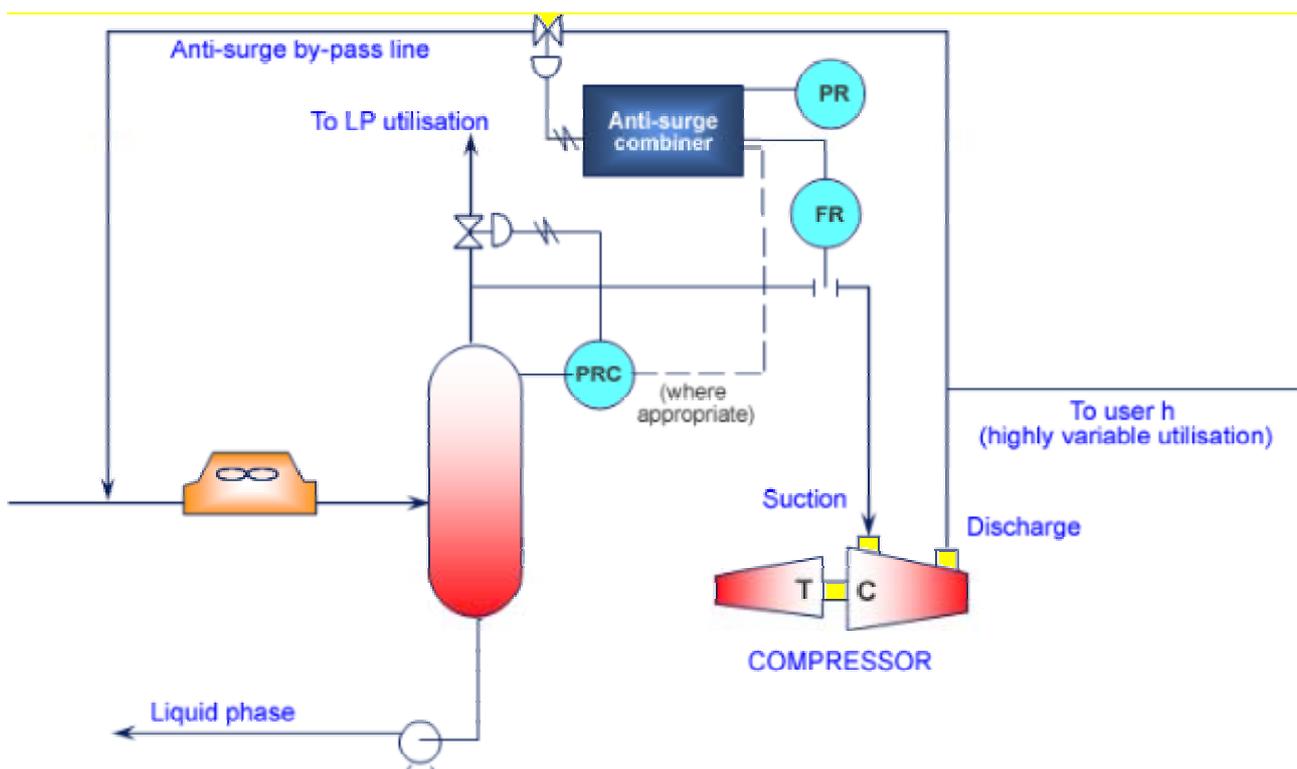


Figure 60: Example of a centrifugal compressor anti-surge control system

8. OPERATION OF COMPRESSORS

8.1. STARTING UP A RECIPROCATING COMPRESSOR

The following is a simplified standard start-up sequence. It contains the typical phases used on the machines installed on our sites. It will be necessary to obtain the "OPERGUID" procedures from the site corresponding to the machines installed. The latter procedures prevail over any procedures given herein.

8.1.1. Preparation of the auxiliary systems

- ▶ **Cooling water system:** start-up on the cylinders, on the oil cooler and on the intercoolers.
- ▶ **Lubrication system:** make sure that there is a sufficient quantity of oil in the frame and in the mechanical lubricator unit.
- ▶ Check the oil circulation to the cylinders and packings by manually operating the lubricators, after disconnecting the check valves screwed onto the cylinder cases and spacers.
- ▶ Configure and activate the lubrication systems.
- ▶ Bleed: the pulse dampers, the buffer tanks of each stage, the spacers.
- ▶ Instrument air: supply the suction valve control devices.
- ▶ Vent the piston rod packings.

Open the valves:

- ▶ to the LP torch,
- ▶ to the atmospheric vent,
- ▶ to the vacuum restart tank.

8.1.2. Preparation of the compressor

- ▶ Vacuum pumping of the compressor by locking the suction valves open, opening the bypass, or by opening additional dead spaces.
- ▶ Crank the compressor using a crank handle (if provided).
- ▶ Flush the gas systems and the compressor with inert gas.
- ▶ Configure the system to start according to the defined procedure.

8.1.3. Starting up the compressor

Safety chart: Reset the bars (reset of the alarms and safety systems)

Lubrication:

- ▶ Pre-lubricate the moving section by operating the manual or electric pump. Make sure that the lubrication operates correctly: at the correct pressure.
- ▶ By manually operating the mechanical lubricators, pre-lubricate the piston rod packings.

Start the drive machine

Compressors driven by electric motors accelerate off-load in about 10 seconds. They can begin compressing gas within less than 1/2 a minute.

Loading of the compressor and connection of the systems according to the current procedure.

Monitoring of the various points to be monitored on:

- ▶ the Process system,
- ▶ the lubrication systems,
- ▶ the cooling system,
- ▶ the separator chambers.

8.2. STARTING UP A CENTRIFUGAL COMPRESSOR

8.2.1. Preparation

- ⊕ Lubricating and sealing oil systems:
 - ▶ Check the levels in the tanks – Top up if necessary.
 - ▶ Bleed off the water from the bottom of the tanks.
 - ▶ Start up the heating system to a temperature of ~ 40 °C.
 - ▶ Check that the oil systems are open.
- ⊕ Safety system tests.
- ⊕ Start up the lubrication system.
- ⊕ Open the water supply to the coolers.
- ⊕ Check the pressures and temperatures.
- ⊕ Dp through the filters in service, inert gas pressure in the tanks.
- ⊕ Open the vapor and bleed systems.
- ⊕ Start up the sealing system.
- ⊕ Same operations as above.
- ⊕ On the lubrication system, check that a decrease in pressure initially causes the back-up pump to start, then causes the plant to shut down.
- ⊕ On the sealing system, check that a decrease in level in the upper tank initially causes the back-up pump to start, then causes the plant to shut down.
- ⊕ Process system:
 - ▶ Pressurize the compressor.
 - ▶ Bleed the low points of the compressor.
 - ▶ Check the process safety systems.
 - ▶ Configure the system to start up according to the defined procedure.

8.2.2. Starting up the compressor

- ▶ Request for authorization to start up.
- ▶ Reset the safety chart.
- ▶ **Bypass the low flow-rate safety systems if appropriate.**
- ▶ Start the drive machine or follow the recommended acceleration procedure (steam turbine).
- ▶ Load the compressor and connect the systems according to the current procedure.
- ▶ Set the oil temperature at the outlets of the coolers to approximately 50 °C.

8.2.3. Monitoring in operation

Process system:

- ▶ Suction pressure.
- ▶ Discharge pressure.
- ▶ Suction temperature.
- ▶ Flow discharge temperature.
- ▶ Anti-surge system.
- ▶ Buffer tank levels.

Auxiliary systems:

- ▶ Pressure, temperatures, oil circulation.
- ▶ Dp through filters.
- ▶ Gas/oil separation of contaminated sealing oil.
- ▶ Barrage gas pressure.
- ▶ Inert gas discharge pressure into the tanks.

Drive system:

- ▶ Temperature and vibrations of the step-up gearbox.
- ▶ Electric motor current.
- ▶ Steam systems: Pressures - Temperatures.

8.2.4. Monitoring in operation

- ▶ Lubrication and sealing systems.
- ▶ Levels in oil tanks.
- ▶ Pressure.
- ▶ Temperature.
- ▶ Dp through filters.

Process system

- ▶ Buffer tank levels.
- ▶ Suction and discharge pressures.
- ▶ Suction and discharge temperature.
- ▶ Gas flow-rate, stability.

8.3. 1st LEVEL MAINTENANCE

1st level maintenance (also called servicing) includes:

- ⊕ Cleanliness: cleanliness is essential to good health and makes leak detection easier, for example.
- ⊕ Levels: topping up.
- ⊕ Fuels: filling, filters.
- ⊕ Lubrication, samples, checks.*
- ⊕ Manual lubrication

9. TROUBLESHOOTING

9.1. POSSIBLE CAUSES OF OPERATIONAL ANOMALIES

Increase leakage due to:

- ⊕ destruction of the inter-stage labyrinths,
- ⊕ fouling of the ducts and wheels of a centrifugal compressor,
- ⊕ early signs of seizure of a packing, a pillow block or a thrust bearing.

By monitoring the performance of a machine, and particularly its efficiency data, it is possible to monitor the condition of the internal parts of the machine while it is in operation. Other measurements and other information are obviously essential (vibration level, axial displacements, oil overheating, results of oil analyses, etc.), in order to determine the mechanical condition of the compressor.

Caution, leaks that are presumed to be internal may in fact be caused by poor sealing of process valves or improper positioning.

TROUBLE	PROBABLE CAUSE(S)	TROUBLE	PROBABLE CAUSE(S)
Low Discharge Pressure	<ol style="list-style-type: none"> 1. Compressor not up to speed 2. Excessive compressor inlet temperature. 3. Low inlet pressure. 4. Leak in discharge piping. 5. Excessive system demand from compressor. 	High Bearing Oil Temperature Note: Lube oil temperature leaving bearings should never be permitted to exceed 82°C.	<ol style="list-style-type: none"> 1. Inadequate or restricted flow of lube oil to bearings. 2. Poor conditions of lube oil or dirt or gummy deposits in bearings. 3. Inadequate cooling water flow lube oil cooler.
Compressor Surge	<ol style="list-style-type: none"> 1. Inadequate flow through the compressor. 2. Change in system resistance due to obstruction in the discharge piping or improper valve position. 3. Deposit buildup on rotor or diffusers restricting gas flow. 		<ol style="list-style-type: none"> 4. Fouled lube oil cooler. 5. Wiped bearing. 6. High oil viscosity. 7. Excessive vibration. 8. Water in lube oil. 9. Rough journal surface.
Low Lube Oil Pressure	<ol style="list-style-type: none"> 1. Faulty lube oil pressure gauge or switch. 2. Low level in oil reservoir. 3. Oil pump suction plugged. 4. Leak in oil pump suction piping. 5. Clogged oil strainers or filters. 6. Failure of both main and auxiliary oil pumps. 7. Operation at a low speed without the auxiliary oil pump running (if main oil pump is shaft-driven). 8. Relief valve improperly set or stuck open. 9. Leaks in the oil system. 10. Incorrect pressure control valve setting or operation. 11. Bearing lube oil orifices missing or plugged. 	Excessive Vibration Note: Vibration may be transmitted from the coupled machine. To localize vibration, disconnect coupling and operate driver alone. This should help to indicate whether driver is causing vibrations	<ol style="list-style-type: none"> 1. Improperly assembled parts. 2. Loose or broken bolting. 3. Piping strain. 4. Shaft misalignment. 5. Worn or damaged coupling. 6. Dry coupling (if continuously lubricated type is used). 7. Warped shaft caused by uneven heating or cooling. 8. Damaged rotor or bent shaft. 9. Unbalanced rotor or warped shaft due to severe rubbing. 10. Excessive bearing clearance. 11. Operating near critical speed
Shaft Misalignment	<ol style="list-style-type: none"> 1. Piping strain. 2. Warped bed-plate compressor or, driver. 3. Warped foundation. 4. Loose or broken foundation bolts. 5. Defective grouting 	Water In Lube Oil	<ol style="list-style-type: none"> 1. Condensation in oil reservoir. 2. Leak in lube oil cooler tubes or tube-sheet.

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