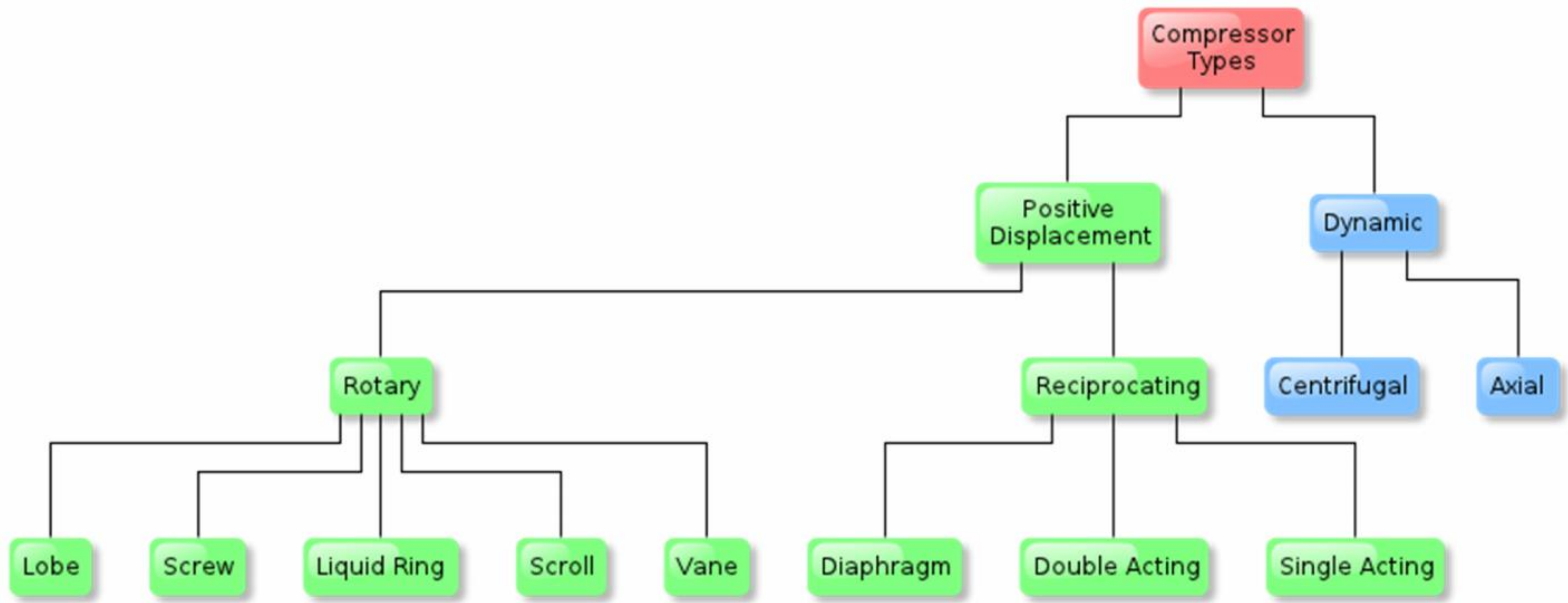
EFRC Training Workshop
Design and operation of reciprocating compressors

Design and Construction of Reciprocating Compressors

Massimo Maffeis

COMPRESSOR CLASSIFICATION



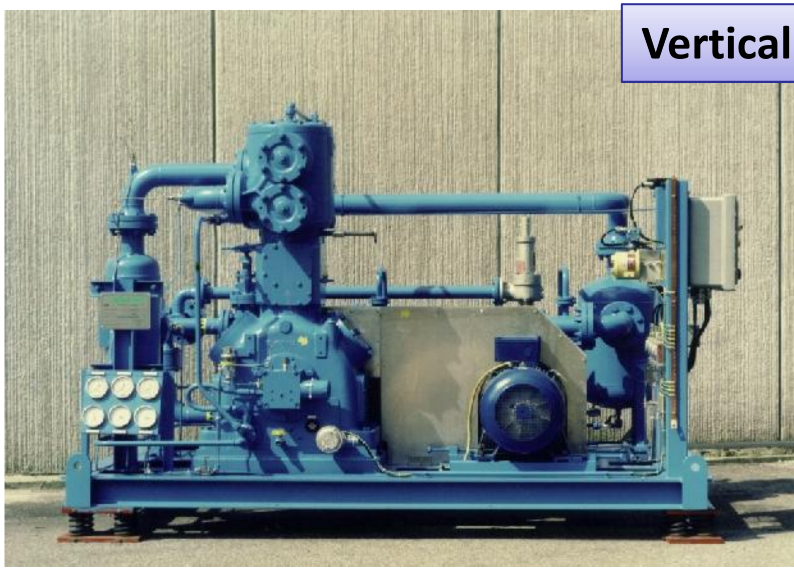
CONFIGURATIONS

Horizontal balanced opposed

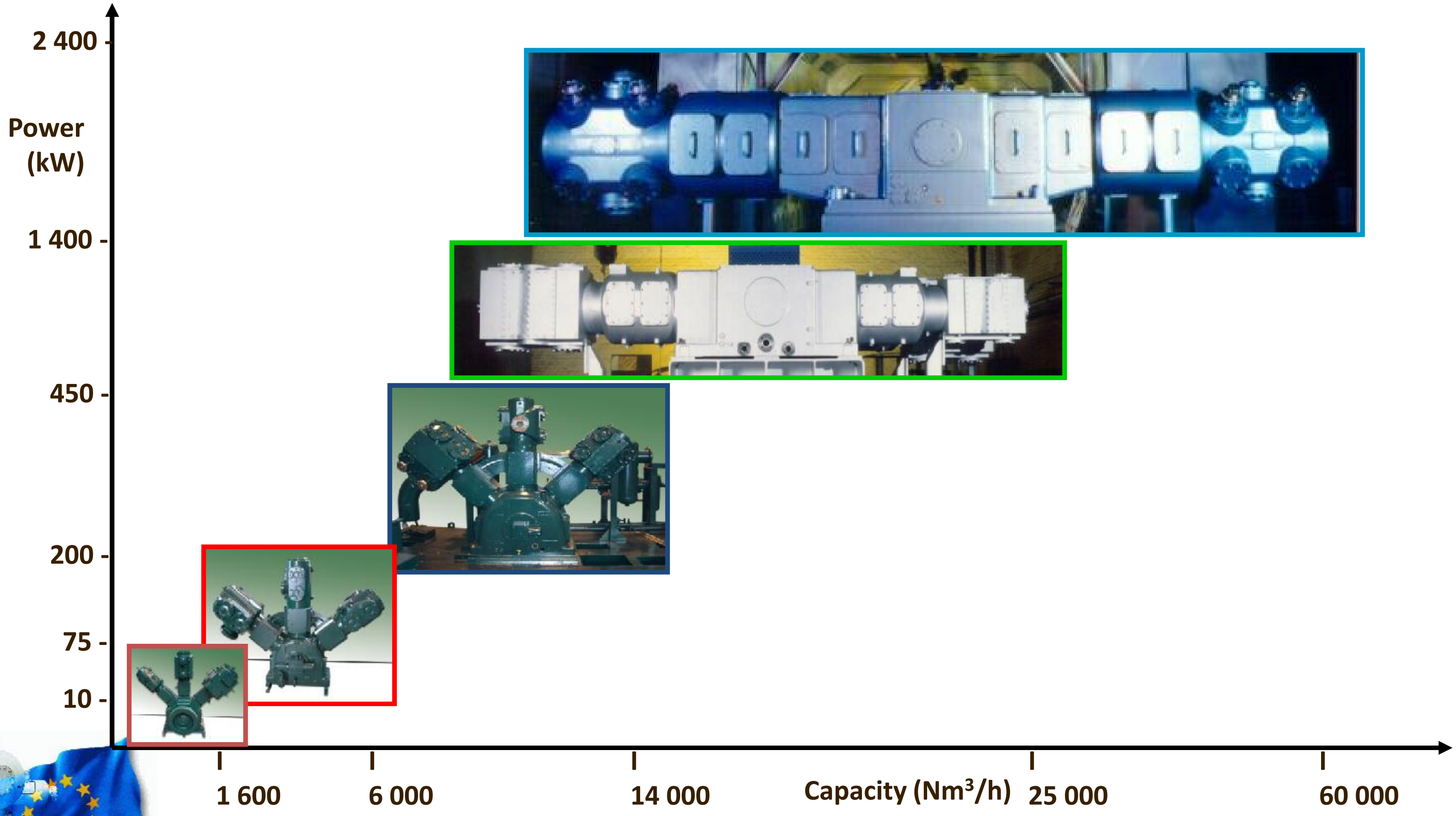
W type

L type

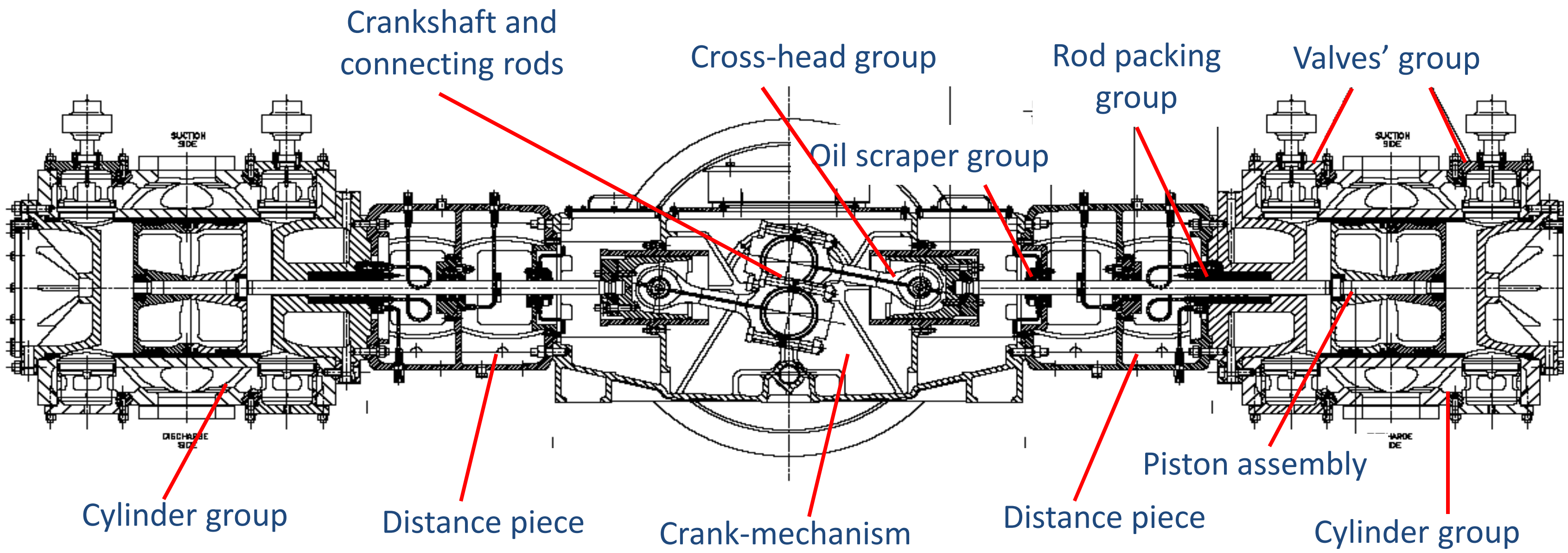
Vertical type



TYPICAL FRAME CHART



GLOSSARY

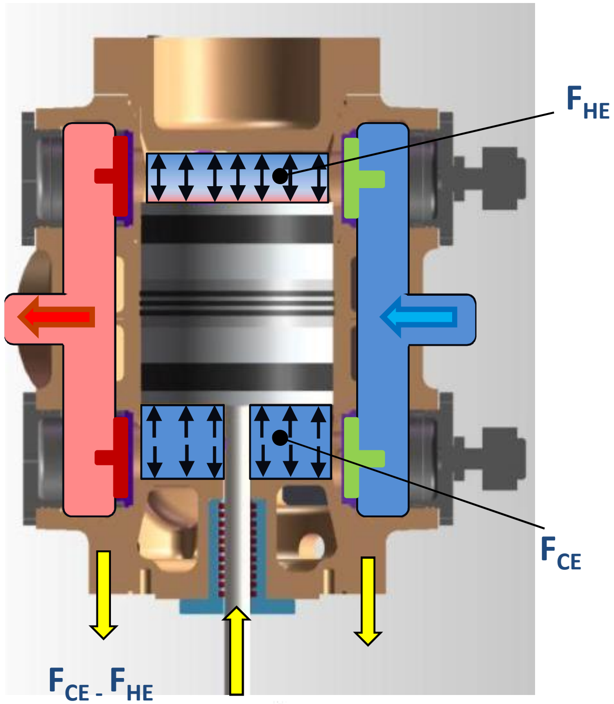


Crankshaft and connecting rods
Cross-head group
Rod packing group
Valves' group
Oil scraper group
SUCTION SIDE
DISCHARGE SIDE
Piston assembly
Cylinder group
Distance piece
Crank-mechanism
Distance piece
Cylinder group

INTERNAL/EXTERNAL FORCES GENERATED BY THE COMPRESSOR

Gas force: it is generated by the pressure acting on the piston and internally to the compressor chamber of the cylinders.

It is completely balanced by the cylinder and crank-case.

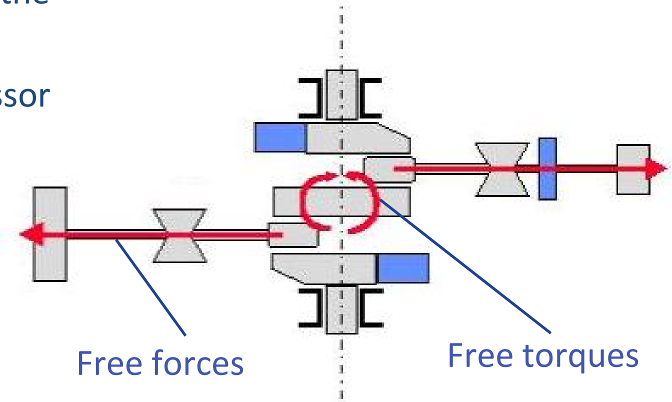


Driving torque: it is transferred by the crankshaft, and it is an external torque that is transferred to the compressor foundation.

Free inertia forces & moments:

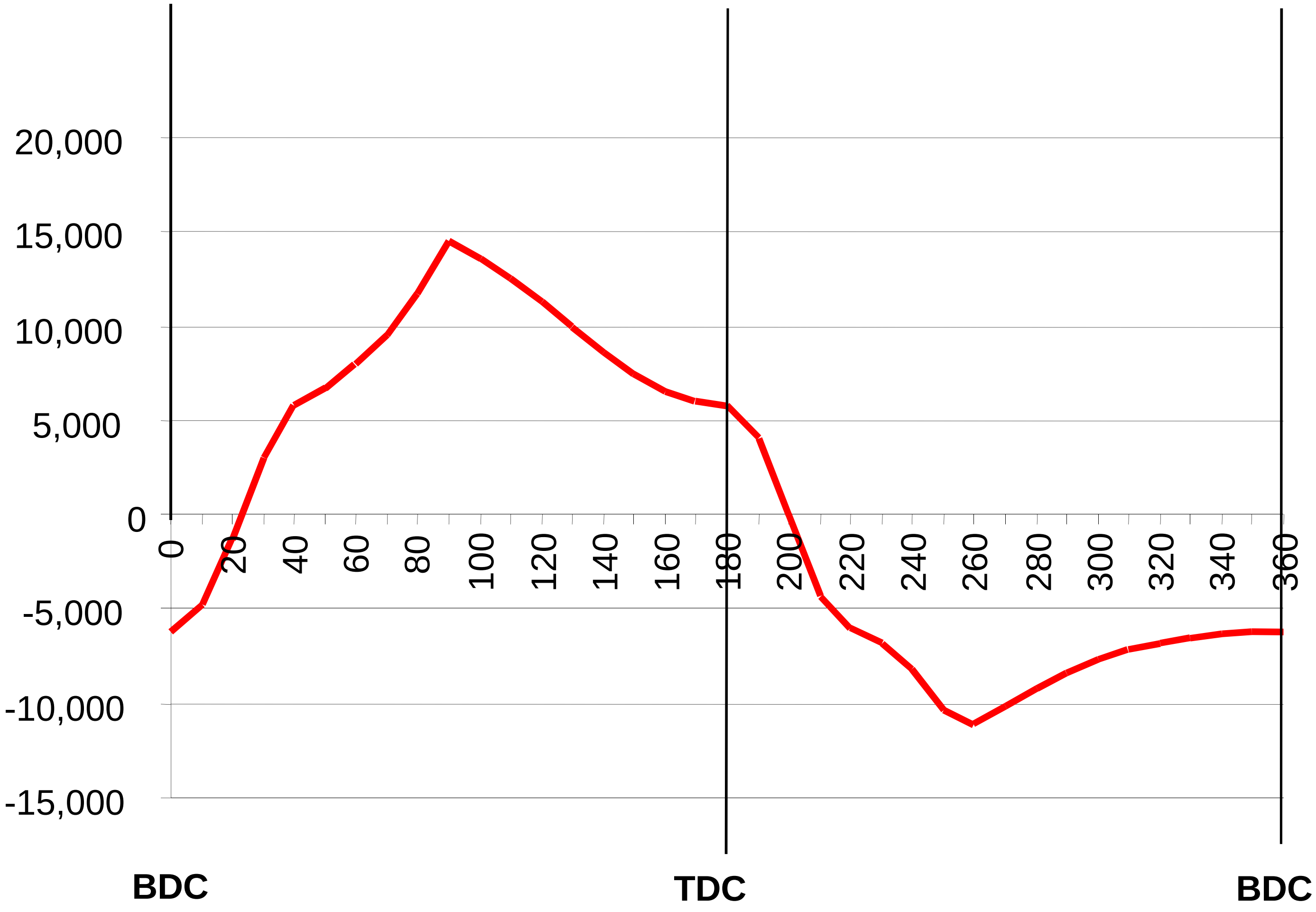
they are generated by the acceleration of the reciprocating and rotating masses.

These forces are transferred to the compressor foundation.



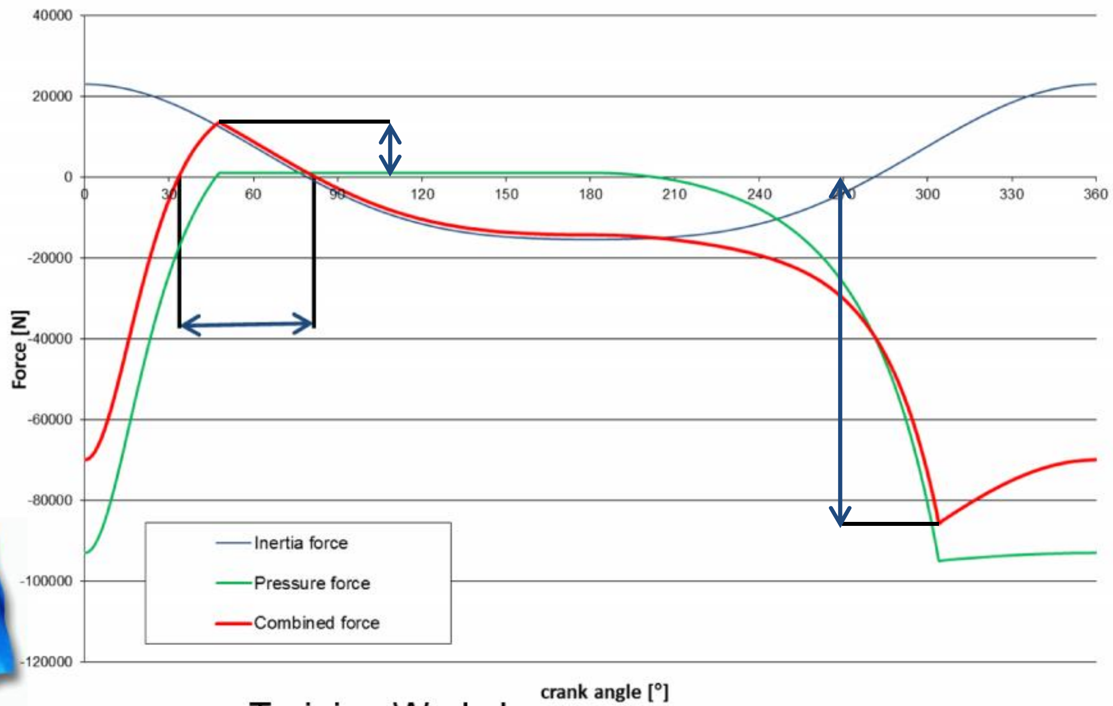
TOTAL FORCES ON THE CROSSHEAD PIN

The resultant force (combined) is the arithmetical sum of the gas forces and inertia forces.



REVERSAL OF THE LOAD

- It is necessary the reversal of the load on crosshead pin to guarantee a correct hydrodynamic lubrication because the small end bearing has an oscillating movement.
- The combined load (gas + inertia) has to change its direction during a crank rotation, with a minimum amplitude and a minimum angle.
- The higher the rotating speed, the lower the allowable value for the min. amplitude and min. angle.
- The inversion of the load has to be verified for each running condition and for the no-load running.

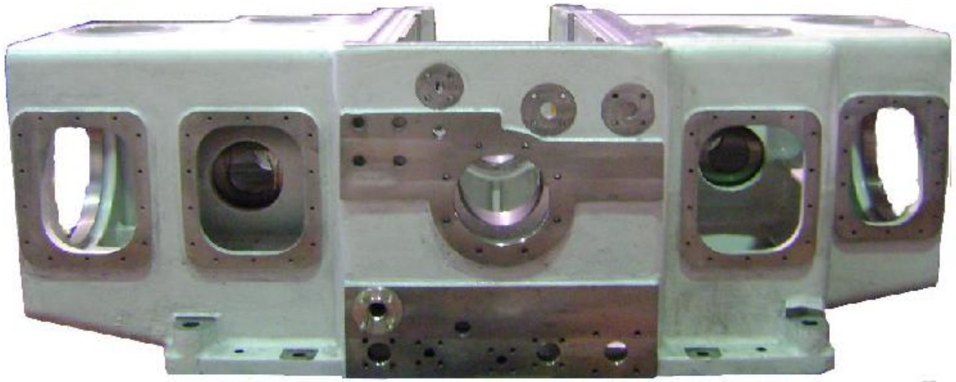


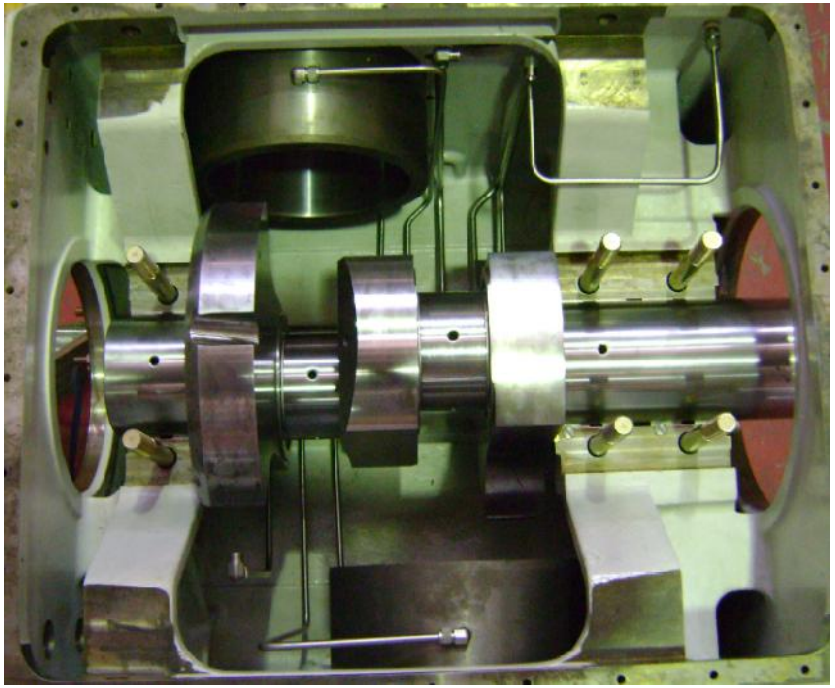
➢ The duration of the reversal shall not be less than 15° of crank angle

➢ The magnitude of the peak combined reversed load shall be at least 3% of the actual combined load in the opposite direction

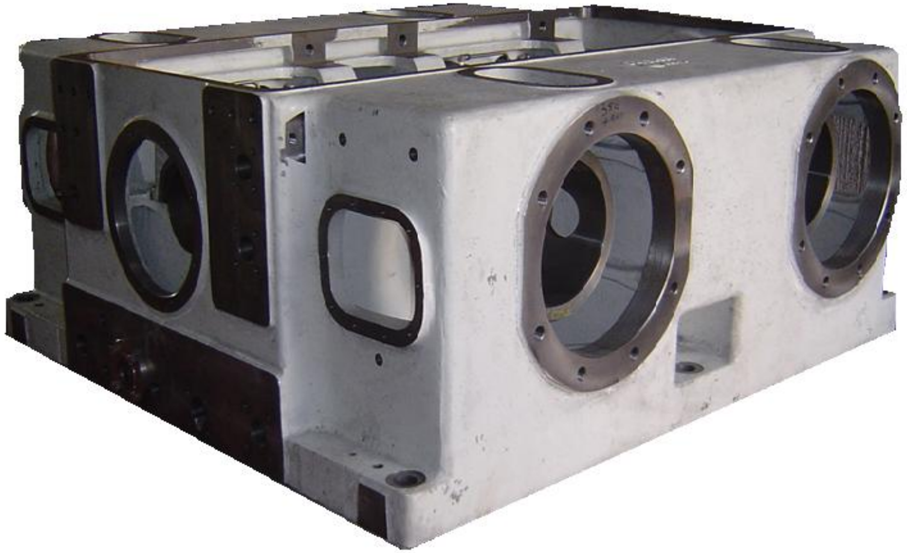
PURPOSES OF THE CRANKCASE

- Supports the different parts of the compressor and the forces acting on the crank mechanism
- Tranfers the forces and the torques to the foundations
- Keeps the different components (main bearing, connecting rod crankshaft) aligned
- Collects and distributes the crank mechanism lubrication oil





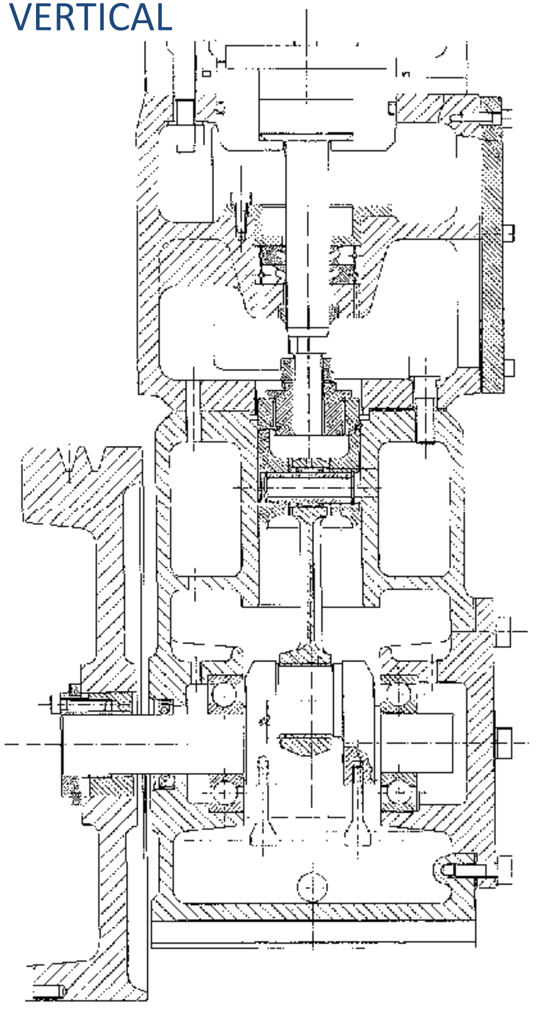
CRANKCASE - CONSTRUCTION



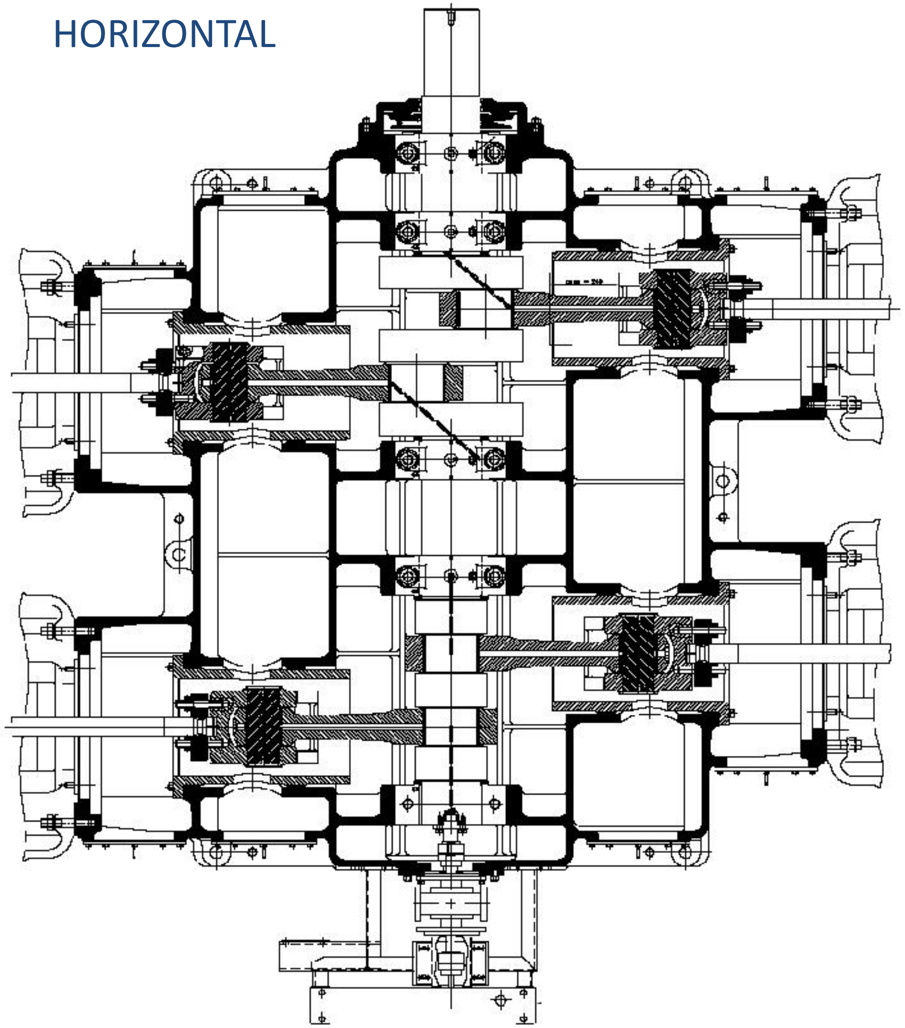
- It is normally made in cast iron, strongly ribbed
- There are large inspection doors for easy maintenance
- It includes the oil sump for the lubrication of the crankmechanism
- There are side doors for inspection and maintenance
- The crosshead guides might be integral or it bears the crosshead liner

CRANKCASE EXEMPLES: VERTICAL AND HORIZONTAL

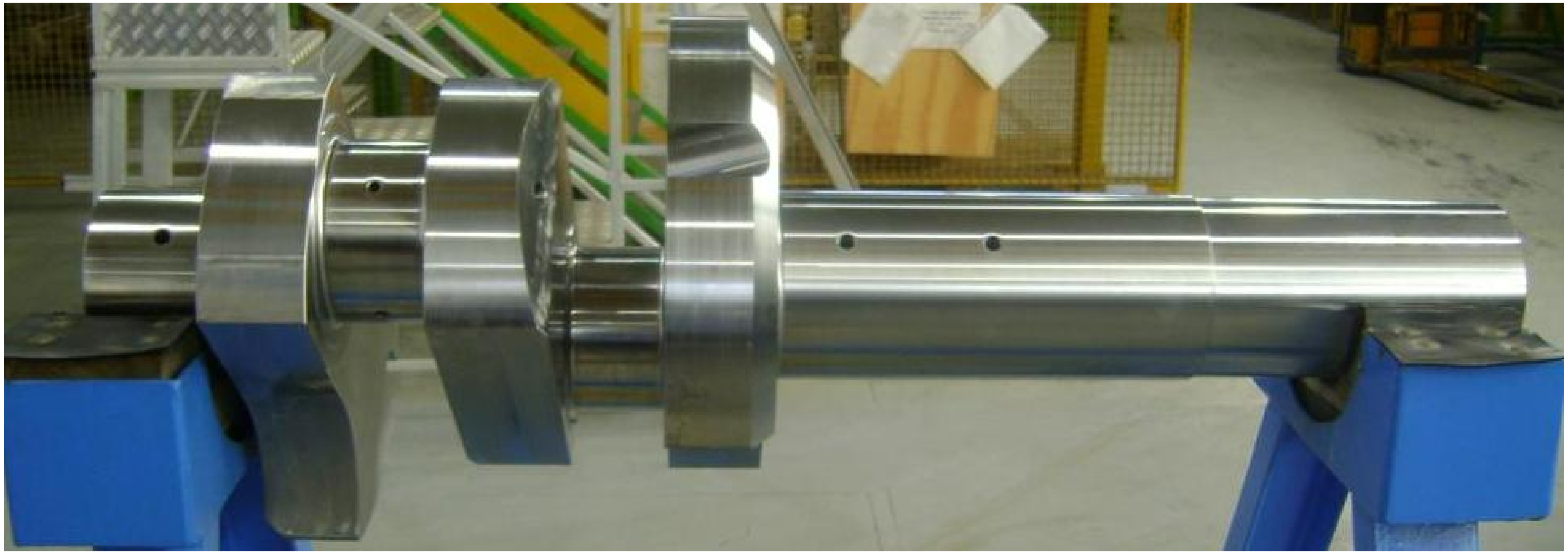
VERTICAL



HORIZONTAL

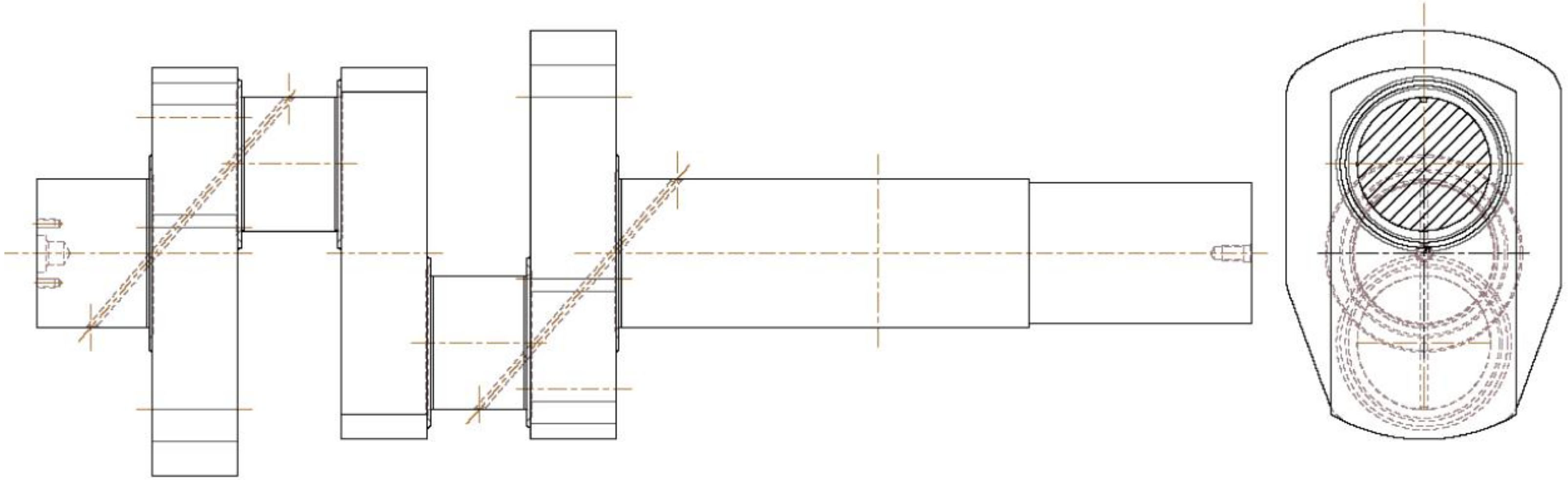


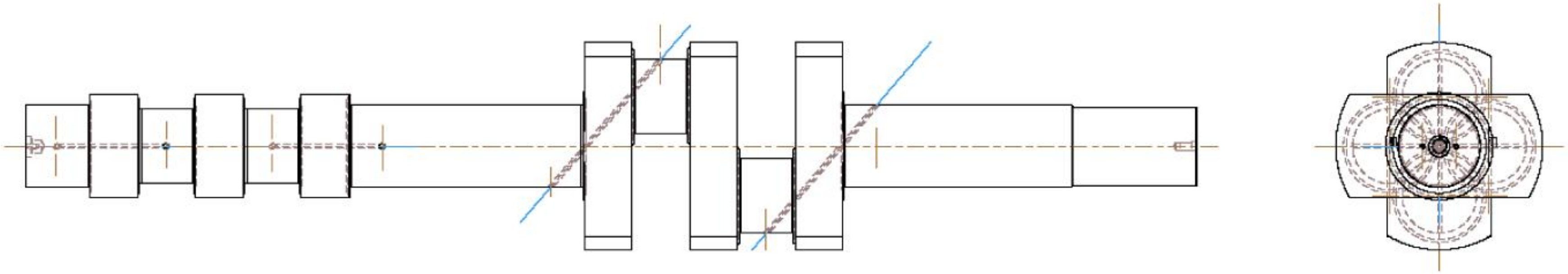
CRANKSHAFT



- ➢Transfers the power from the drive motor to the pistons
- ➢Transforms the rotary motion into alternating motion via the connecting rod
- ➢Restrains the dynamic forces and torques of the crank mechanism

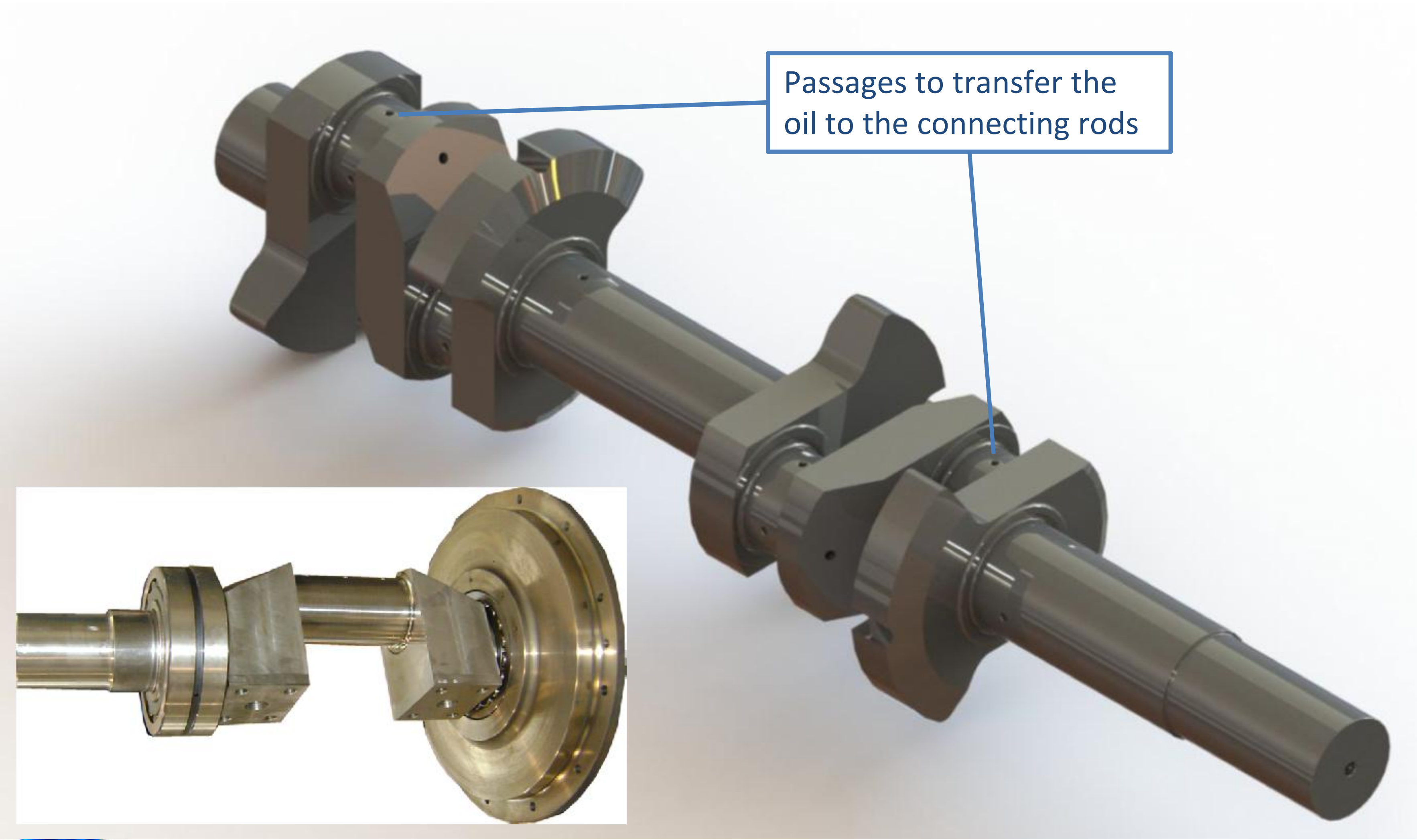
CRANKSHAFT - CONSTRUCTION





- Material is forged steel, with 2 elbows at 180°
- Passages for lubricating oil that goes to the bearings and to the mechanical sealing
- The main lubrication (gear) pump is usually directly coupled to the crankshaft

CRANKSHAFT - EXAMPLES



CONNECTING ROD: GLOSSARY

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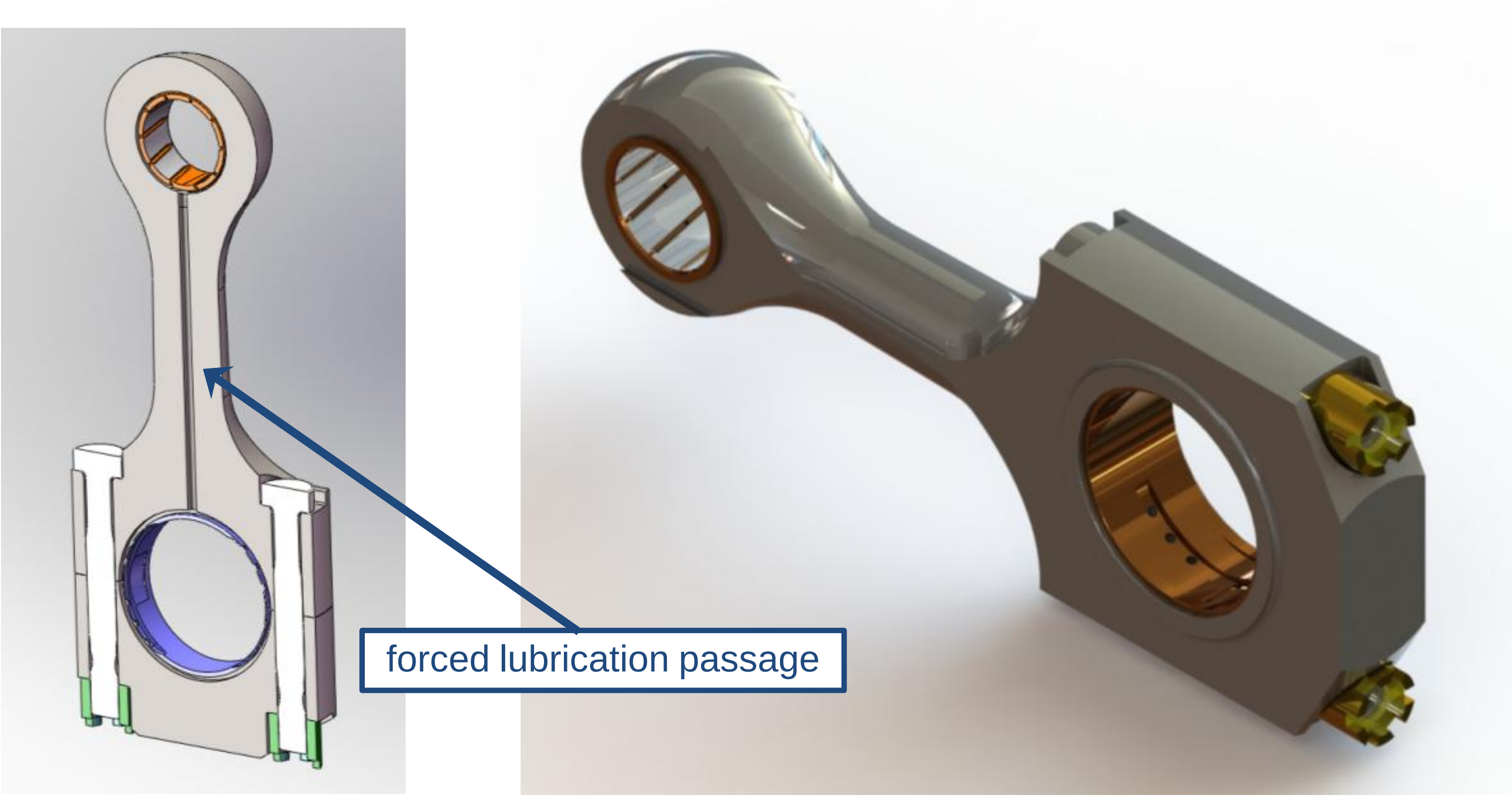
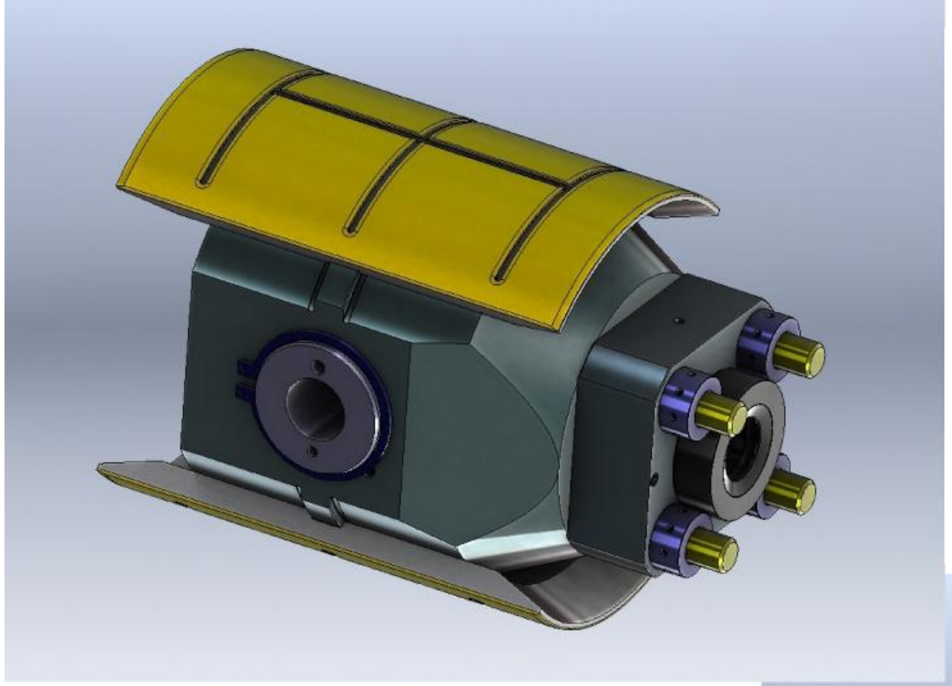
CONNECTING ROD

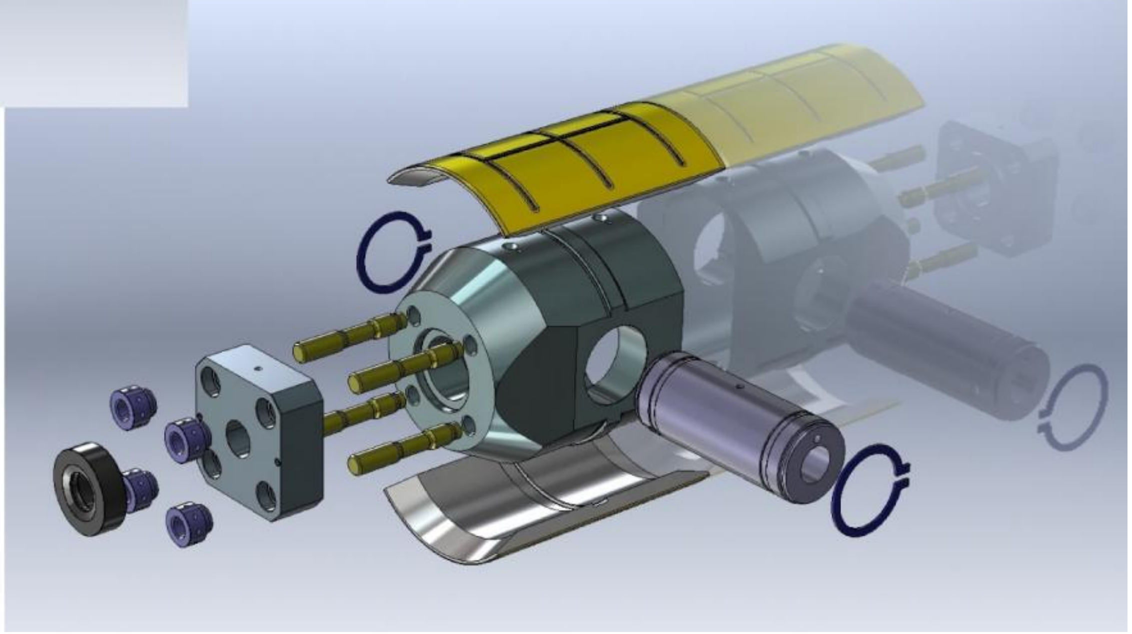
- Usually the big end is split into two parts with a removable cap, while the small end is integral with the connecting rod body.
- Normally they are realized in forged steel to get:
    - continuity of the fibers
    - high stiffness to avoid any bending



CROSSHEAD

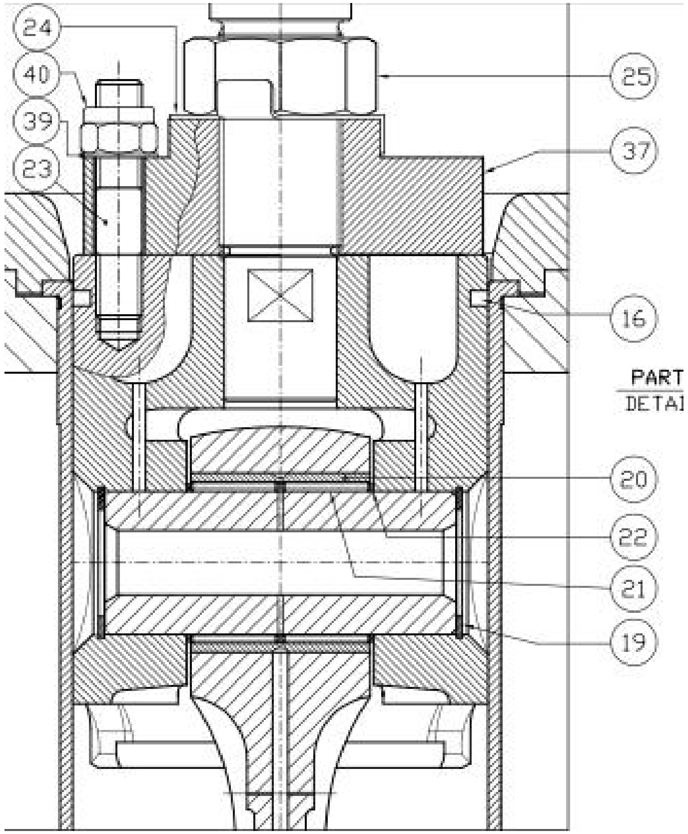


- It connects the piston rod to the connecting rod
- It guides the piston rod avoiding sideways pressure and lateral vibrations
- It is normally a steel casting
- The shoes maybe integral with an anti-friction coating or replaceable and shim-adjustable (API618 requirement)



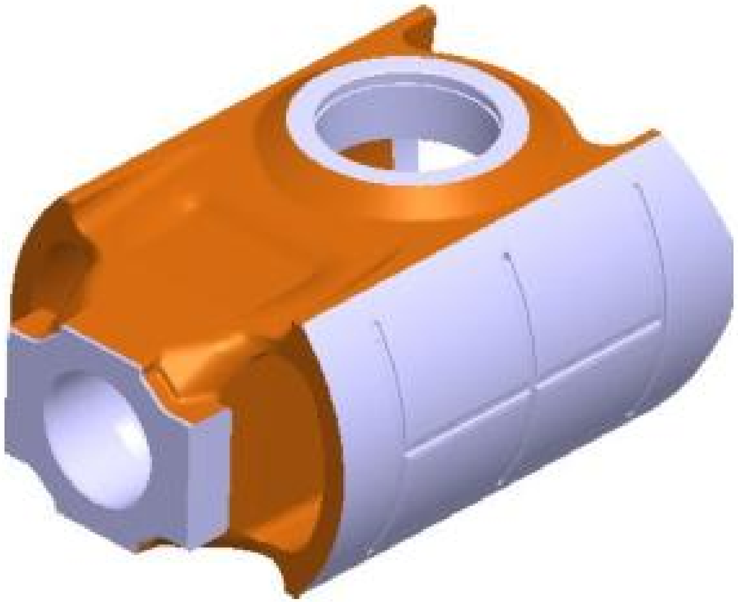
- It has to be lubricated
- Side clearances need to be verified during maintenance operations

CROSSHEAD

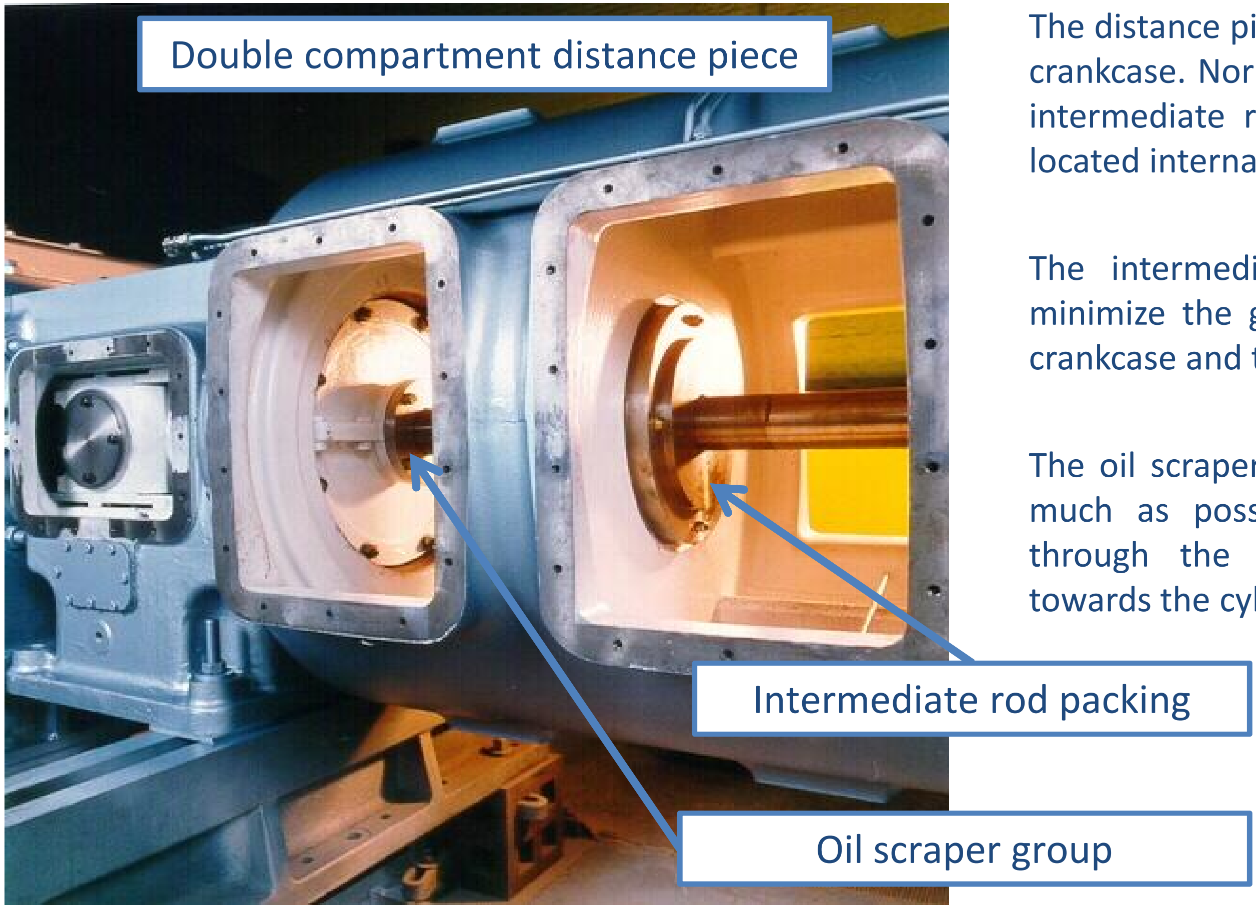


The connection crosshead / piston rod is a design challange: the rod has to be positively locked to the crosshead to prevent rotation.

The connection can be realized through a counter-nut at specified tightening torque or, more often for larger compressors, through an hydraulic tightening of the nuts.



DISTANCE PIECE



The distance piece separates the cylinder from the crankcase. Normally the oil scraper group and the intermediate rod packing group (if present) are located internally to the distance piece.

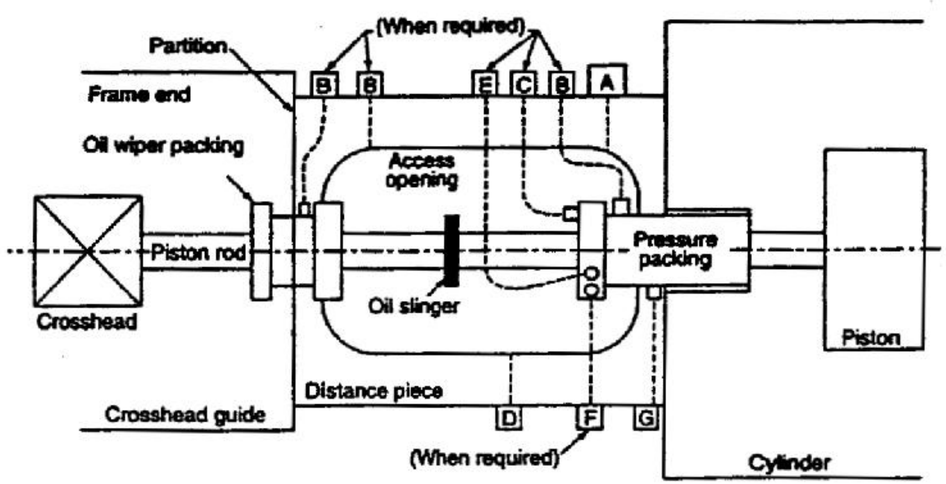
The intermediate rod packing is intended to minimize the gas leaks from the cylinder to the crankcase and to the external environment.

The oil scraper group is intended to minimize as much as possible (or eliminate) the oil leaks through the piston rod from the crankcase towards the cylinder.

DISTANCE PIECE - API 618

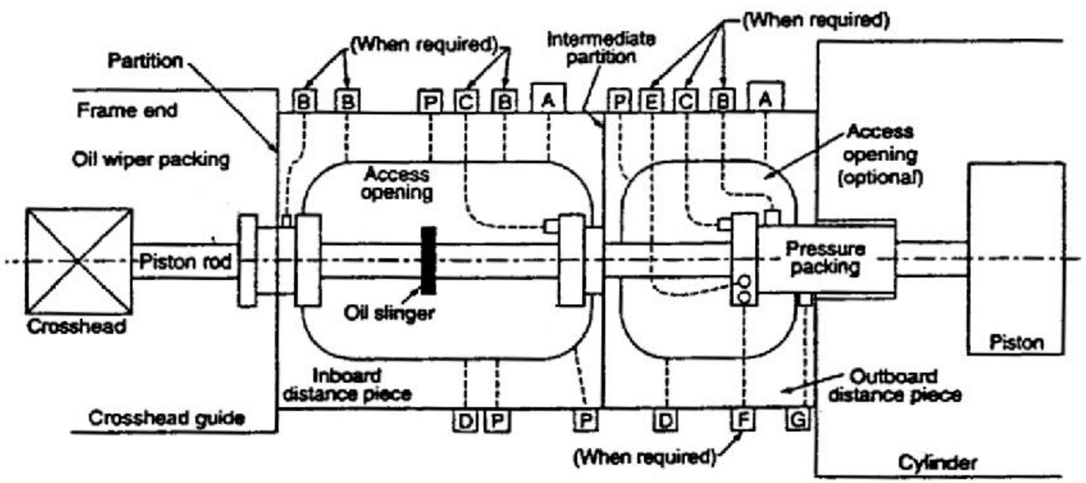
Type B

Long single-compartment



Legend:

A	vent, distance piece
B	purge, buffer or pressure packing or distance piece
C	lube pressure packing
D	drain distance piece
E	coolant out, pressur packing
F	coolant in, pressur packing
G	common vent and drain, pressure packing
P	plugged connection

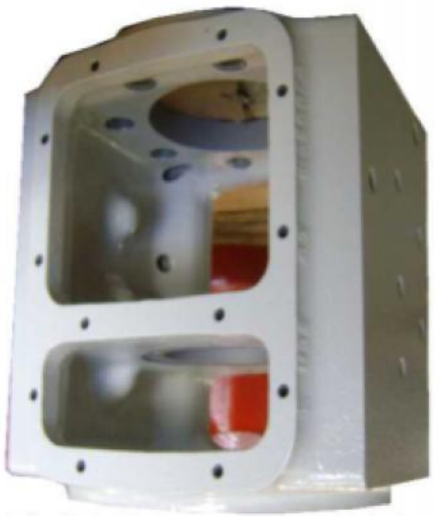


Type D

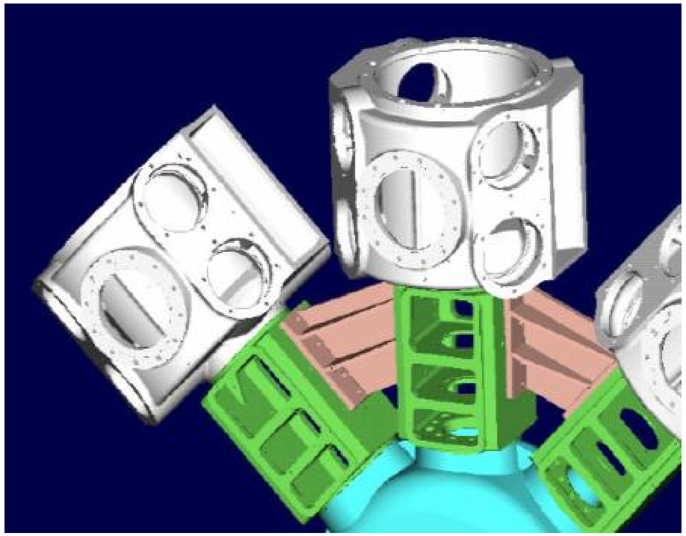
Short two-compartment

DISTANCE PIECE - EXAMPLES

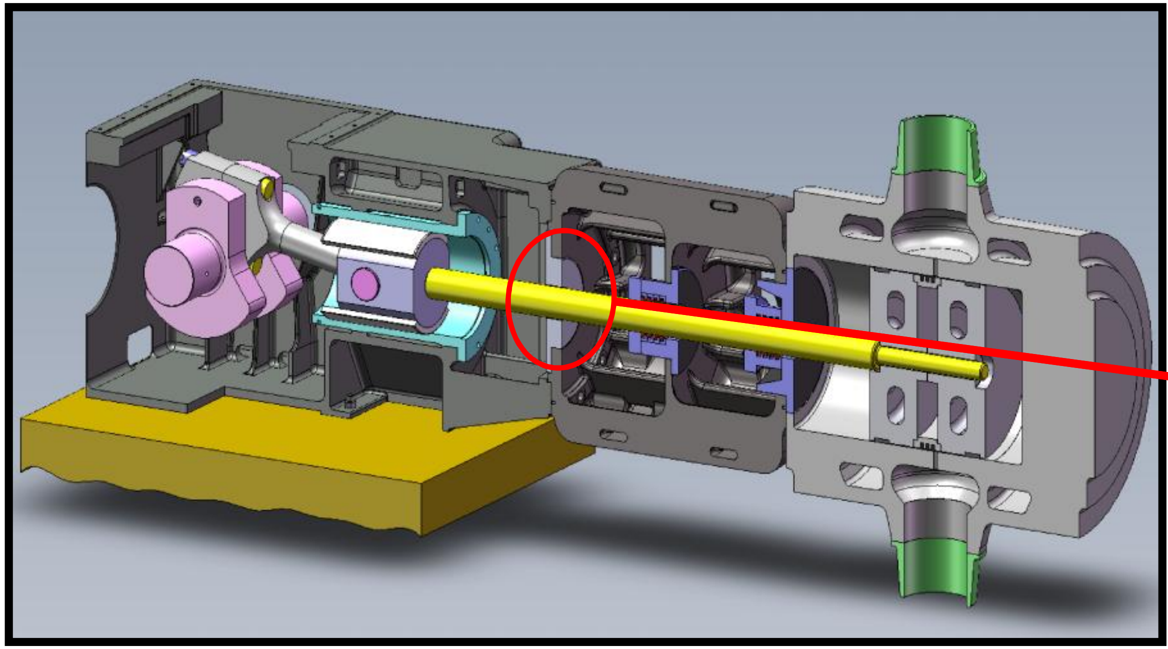
type "B"

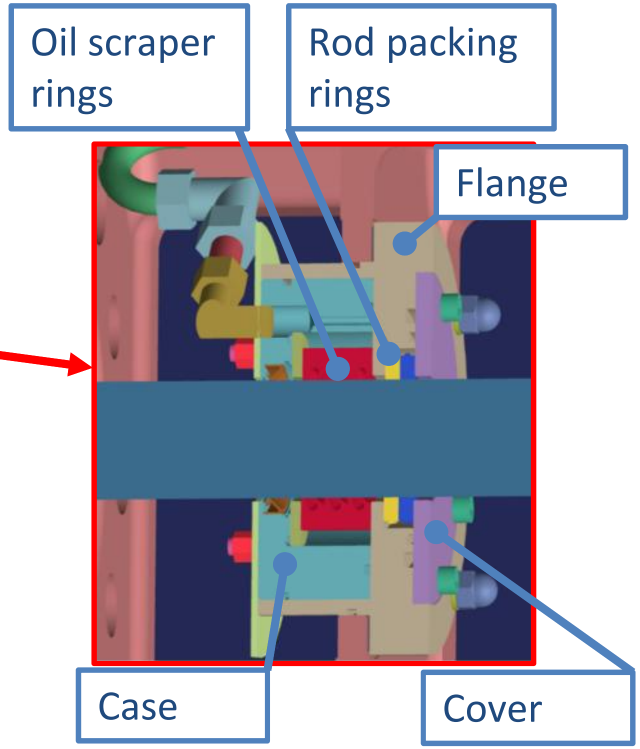


type "D"



OIL WIPER PACKING





The oil wiper packing is located between the distance piece and the crankcase, or the crosshead guide in some cases, and it is typically composed by the following items:

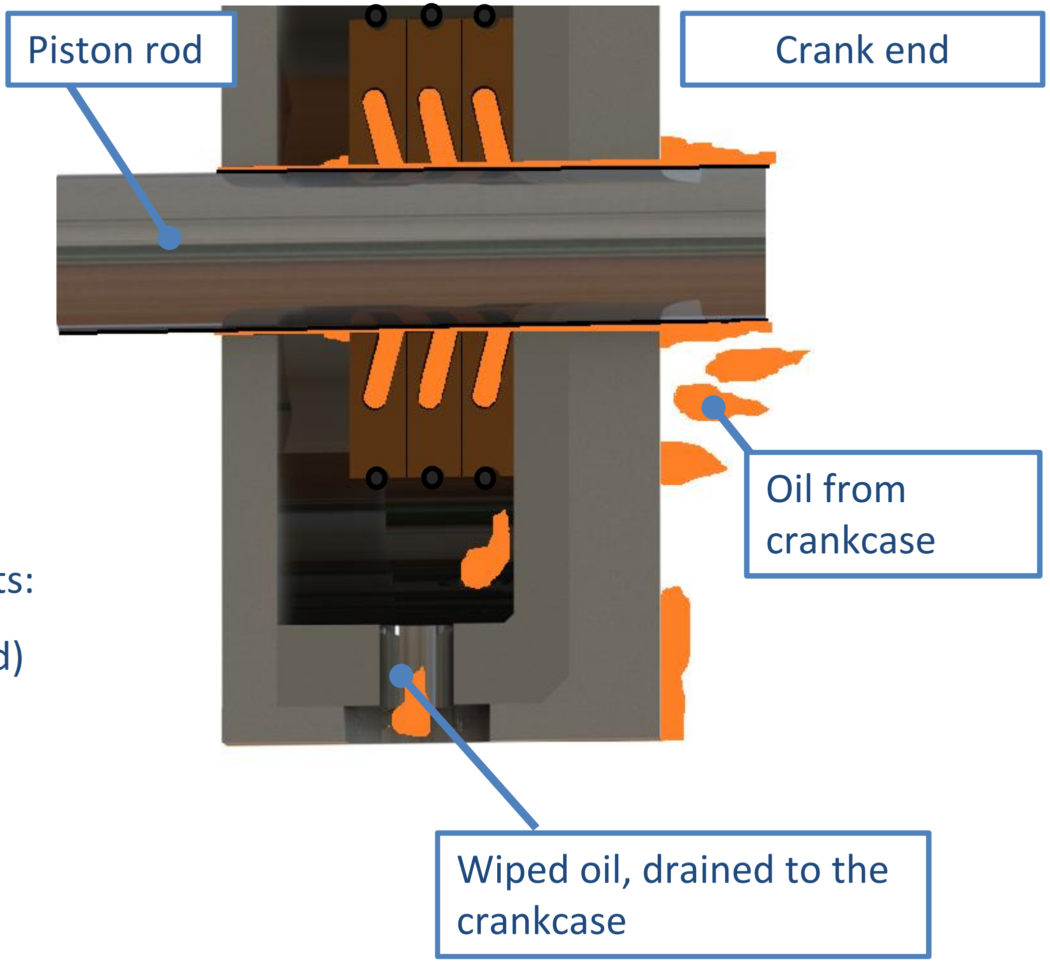
- flange
- one or more packing cases
- oil scraper rings
- rod packing rings

HOW THE OIL WIPER WORKS

The oil wiper rings are typically made in bronze, white metal or aluminum. They have a sharp edge to wipe the oil and radial grooves for draining.

The wiped oil is removed from the rings and drained into the crankcase through passages realized in the case.

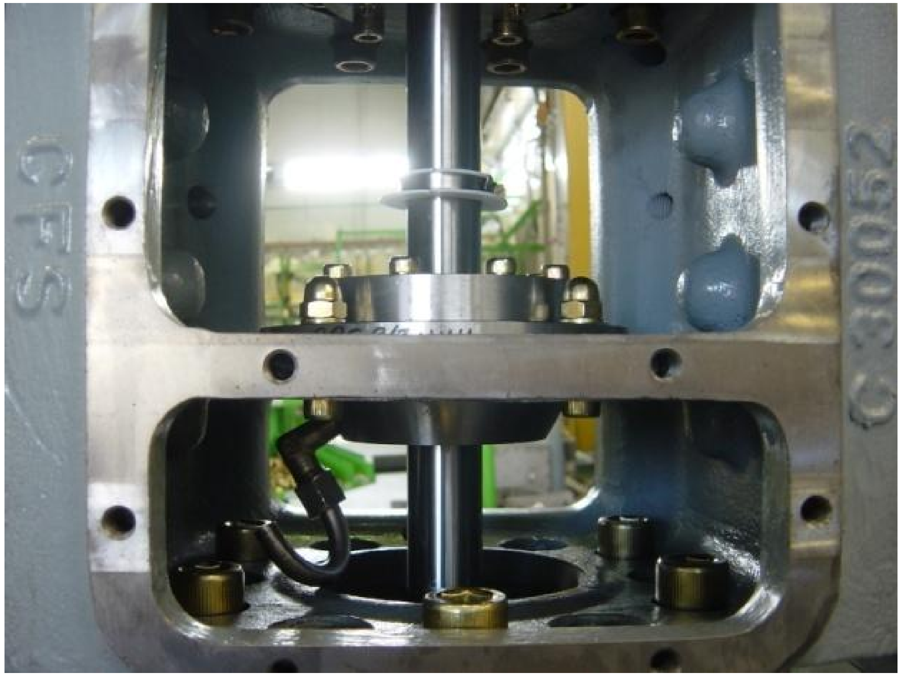
The quantity of oil to be wiped and drained is proportional to the piston rod diameter and compressor speed.



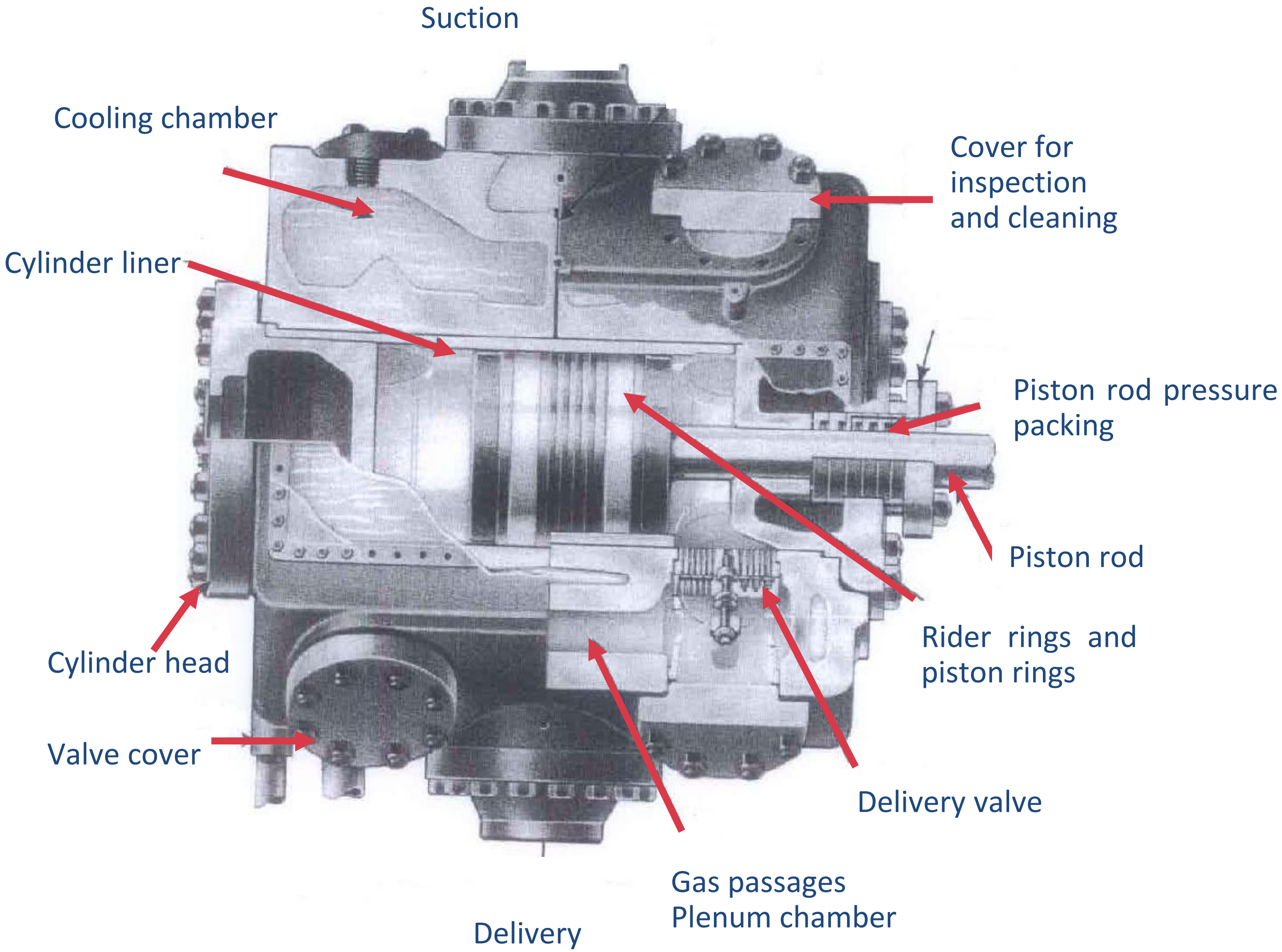
The effiency is reduced by the following aspects:

- damaged surface of the piston rod (scratched)
- high run-out of the piston rod
- high vibrations
- damaged edge of the oil scraper ring

OIL SCRAPER RINGS - EXAMPLES



MAIN ITEMS OF THE CYLINDER



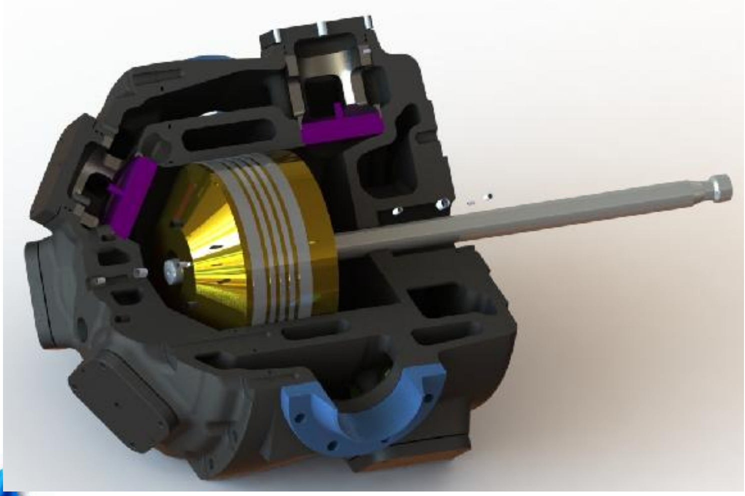
CYLINDERS - CONSTRUCTION

There are several types of cylinders depending from the application and working pressure. Typically they are:

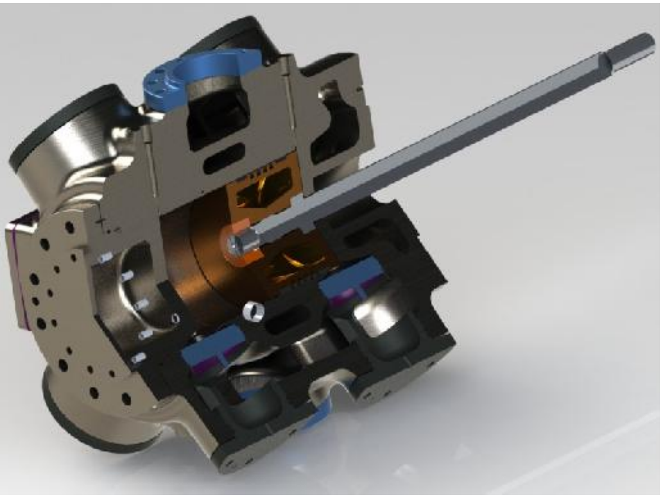
- made in grey cast iron or nodular cast iron for low pressure
- made in steel, casted or forged, for higher pressures

There is often a liner where the piston slides. The liner can be fitted by interference or free. The valves' locations and cooling passages are realized inside the cylinder.

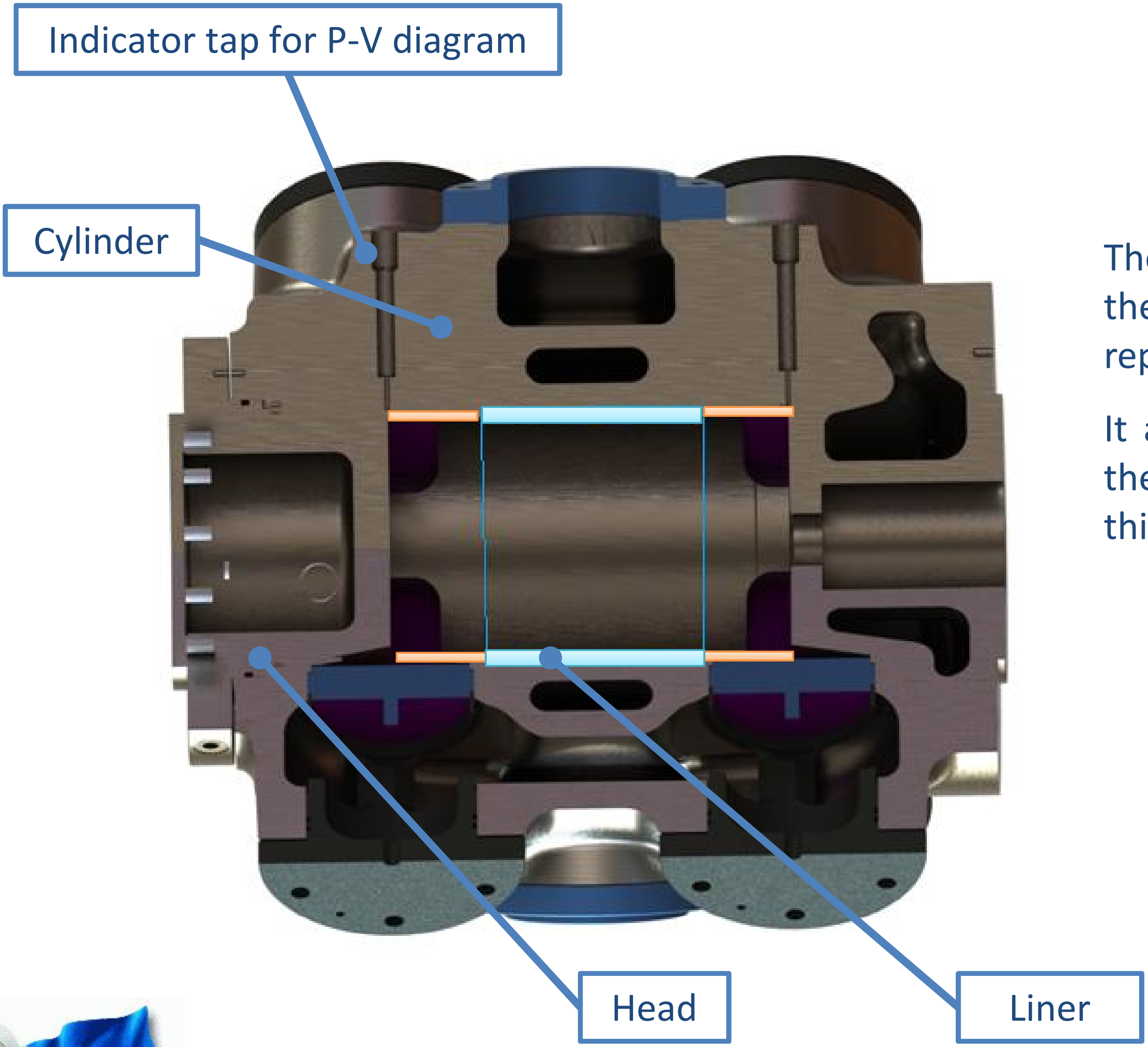
Low pressure cylinder



High pressure cylinder



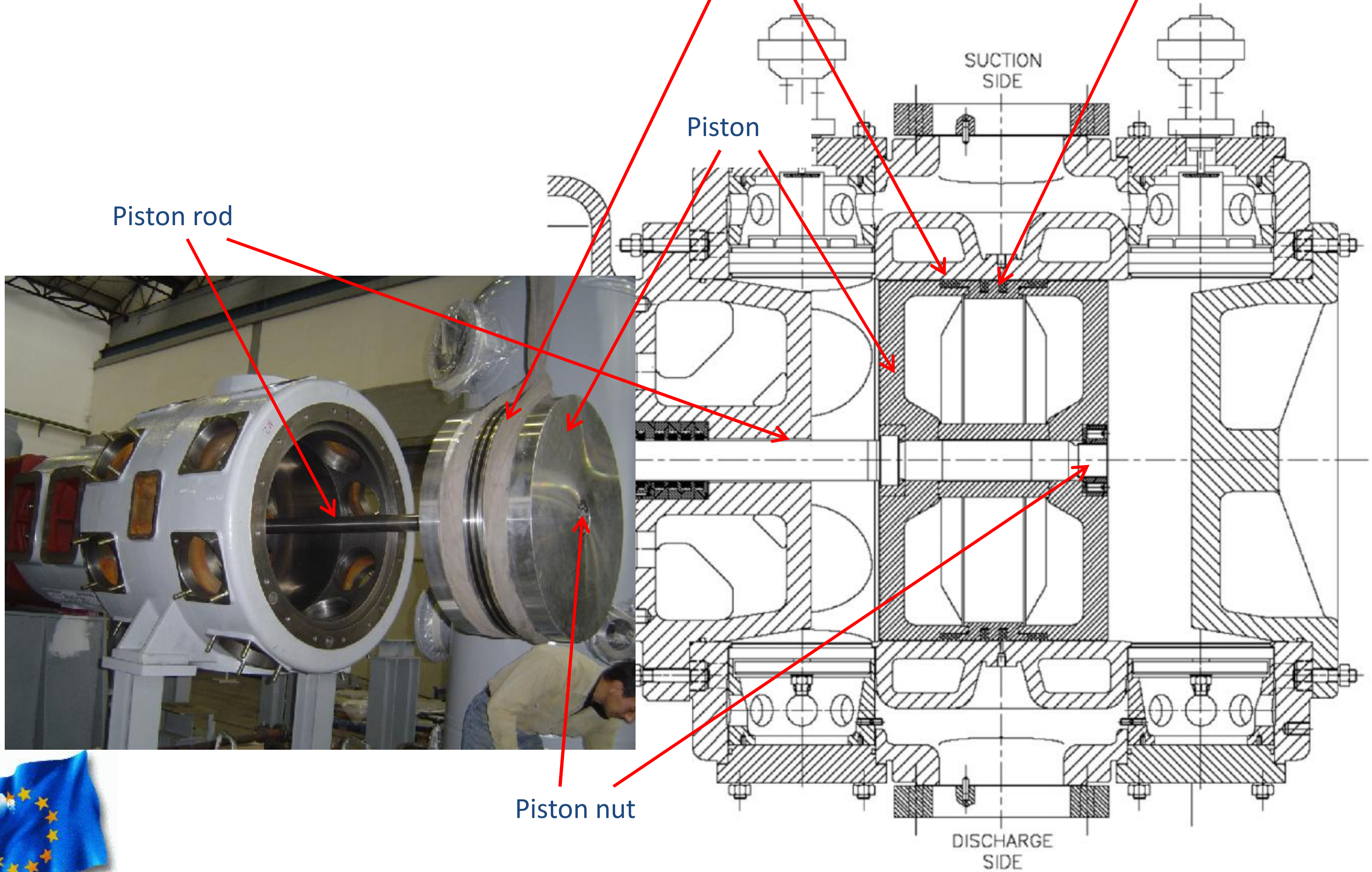
CYLINDER WITH LINER



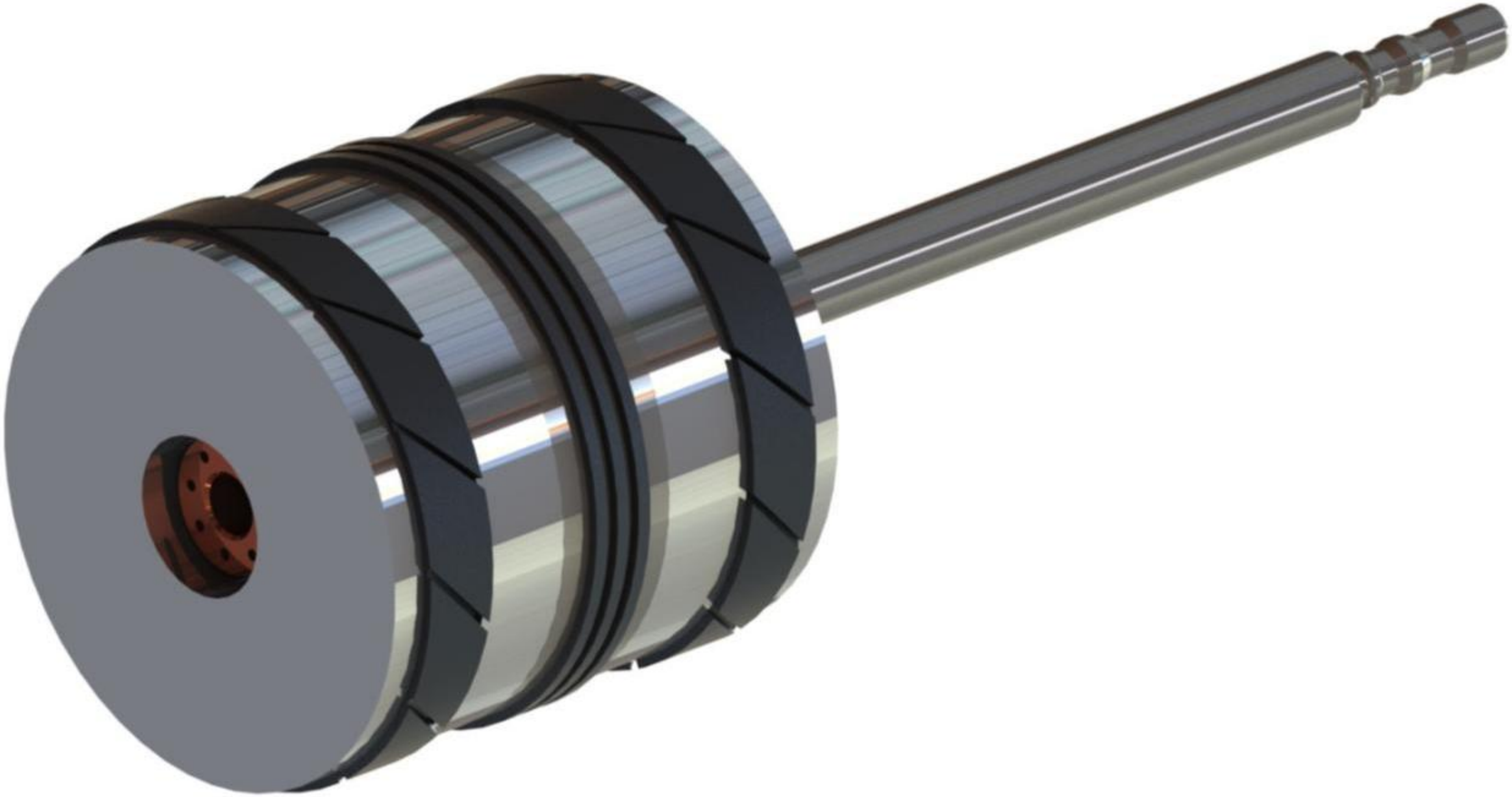
The liner allows to increase the life of the cylinder because it can be replaced when it is worn out.

It allows to get different bores from the same cylinder changing the liner’s thickness.

PISTON ASSEMBLY

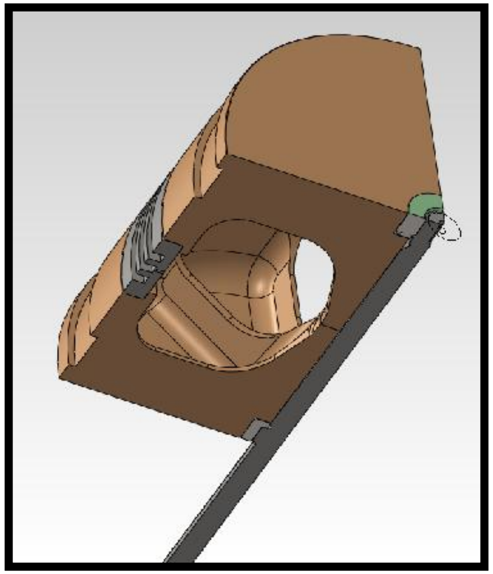


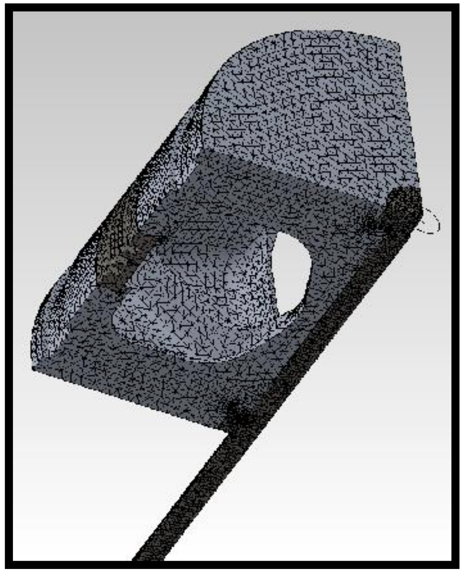
PISTON ASSEMBLY

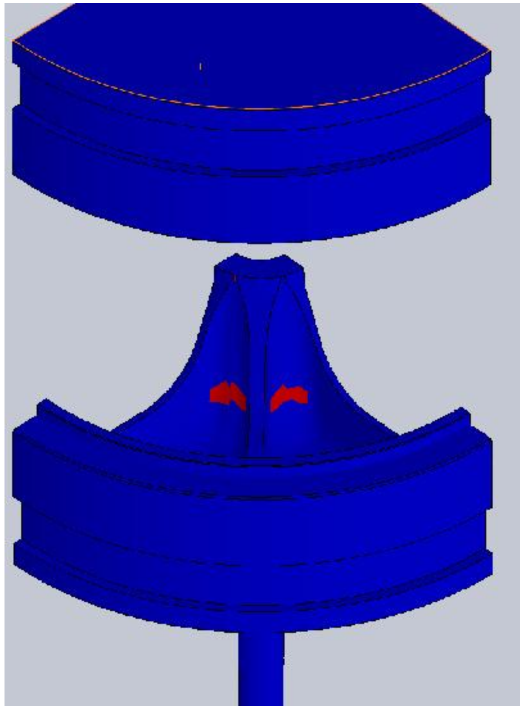


It is designed to balance the rod loads.
The material has to be suitable with the process gas.

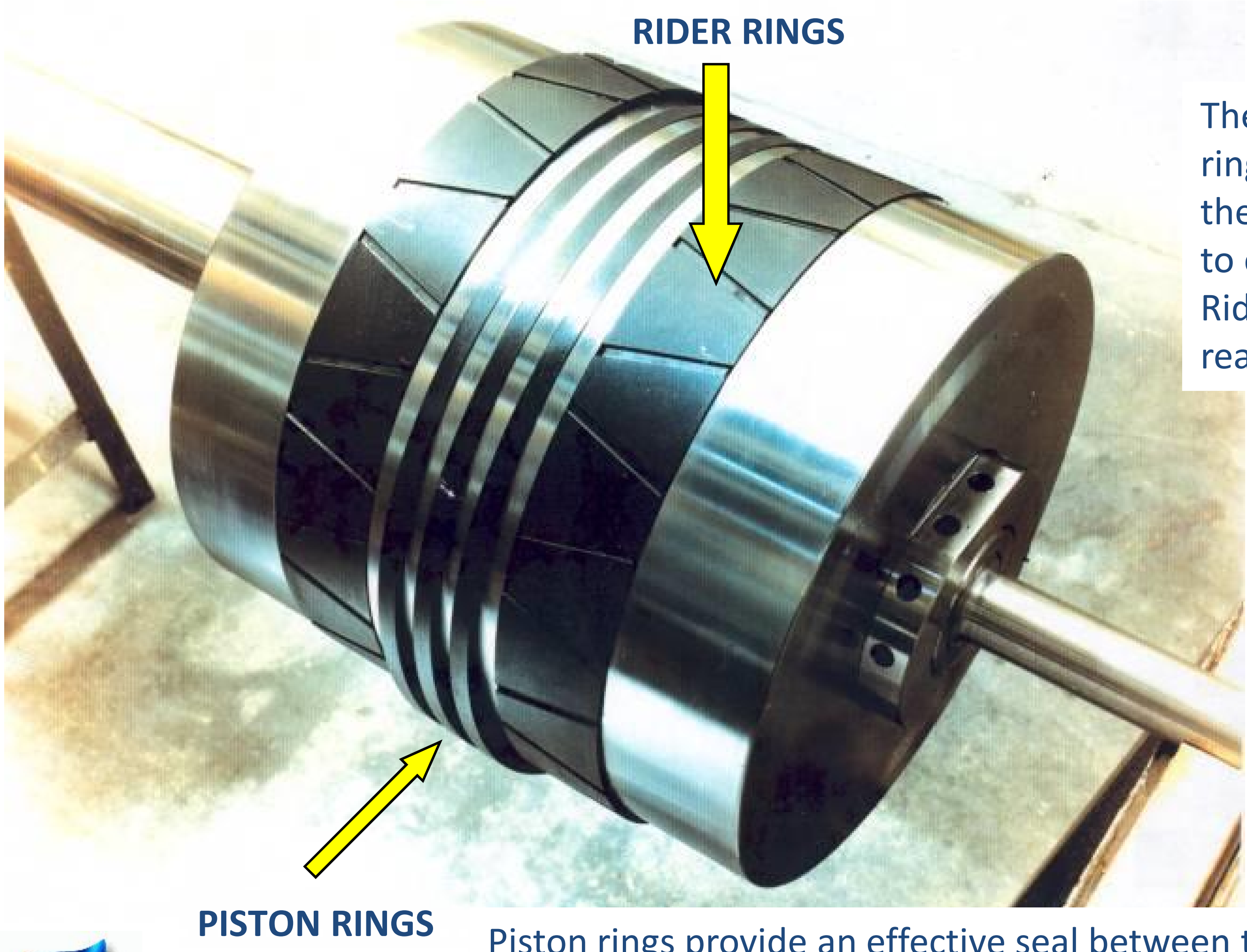
PISTON DESIGN WITH FEM ANALYSIS







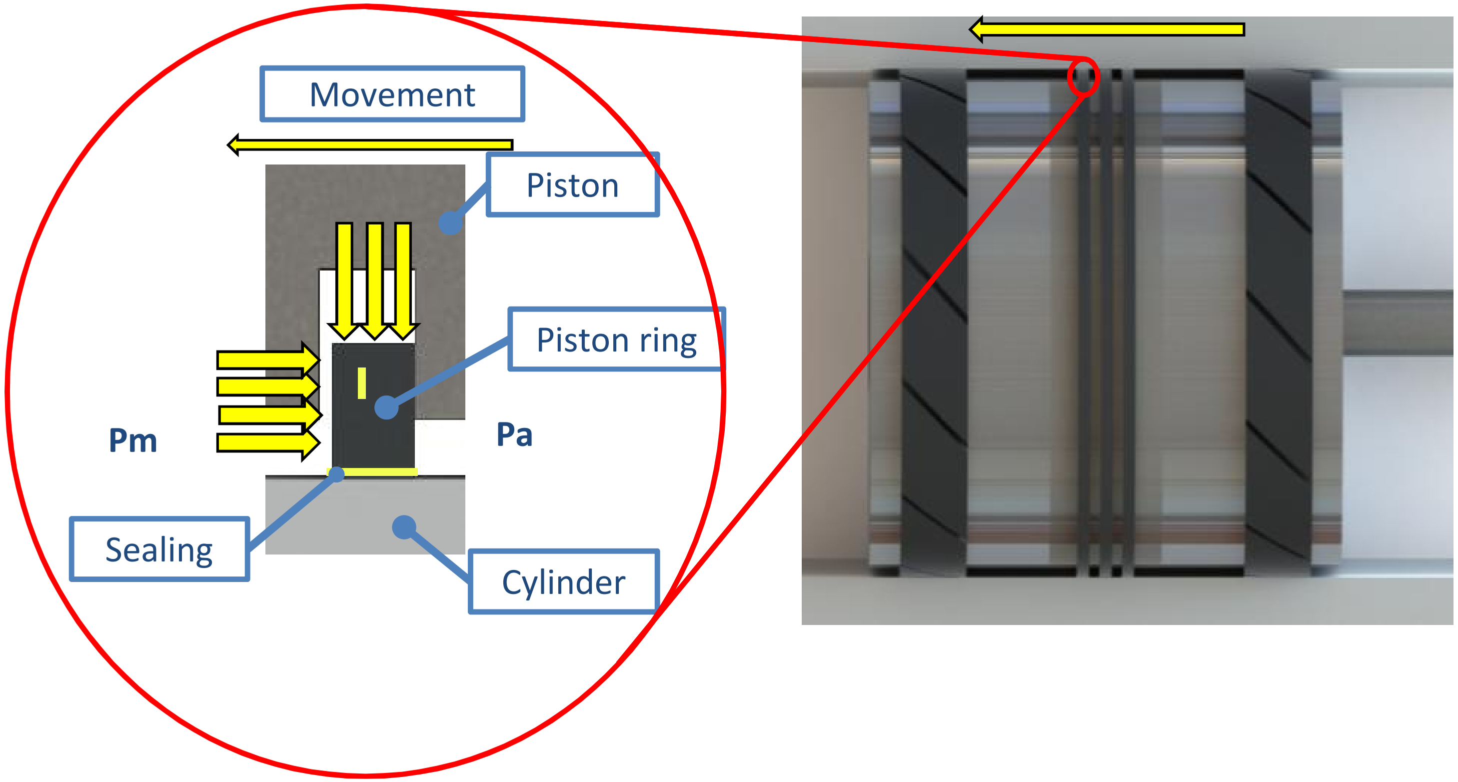
PISTON RINGS AND RIDER RINGS



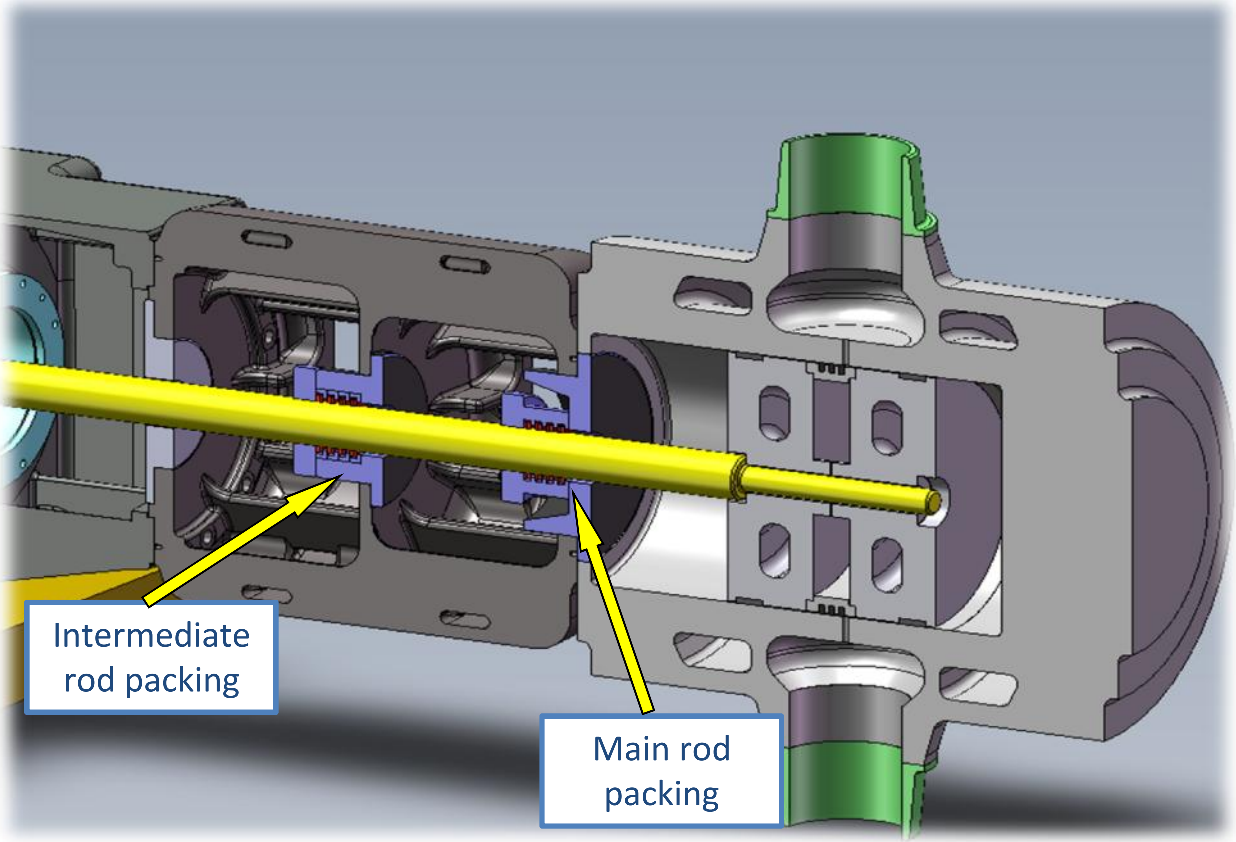
The function of the rider ring is to support and guide the piston to prevent piston to cylinder bore contact. Rider ring should not seal, reason for relieve grooves.

Piston rings provide an effective seal between the piston and cylinder bore for an acceptable service life.

HOW THE PISTON RINGS WORK

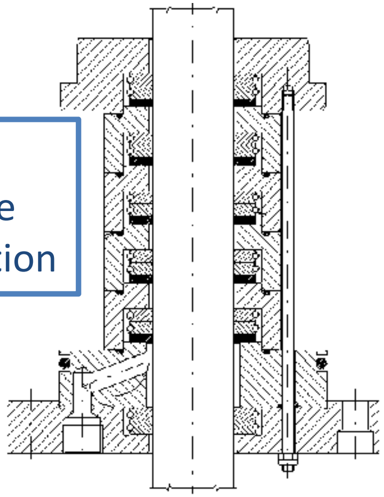


POSITION OF THE PRESSURE ROD PACKING

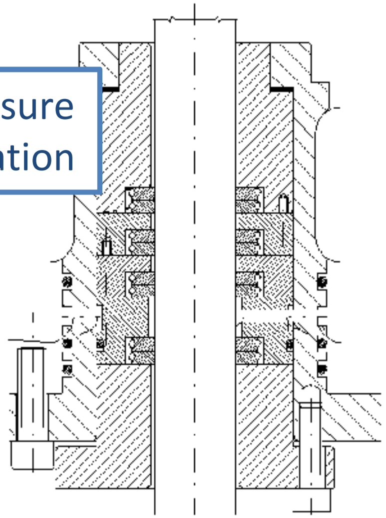


ROD PACKING GROUP

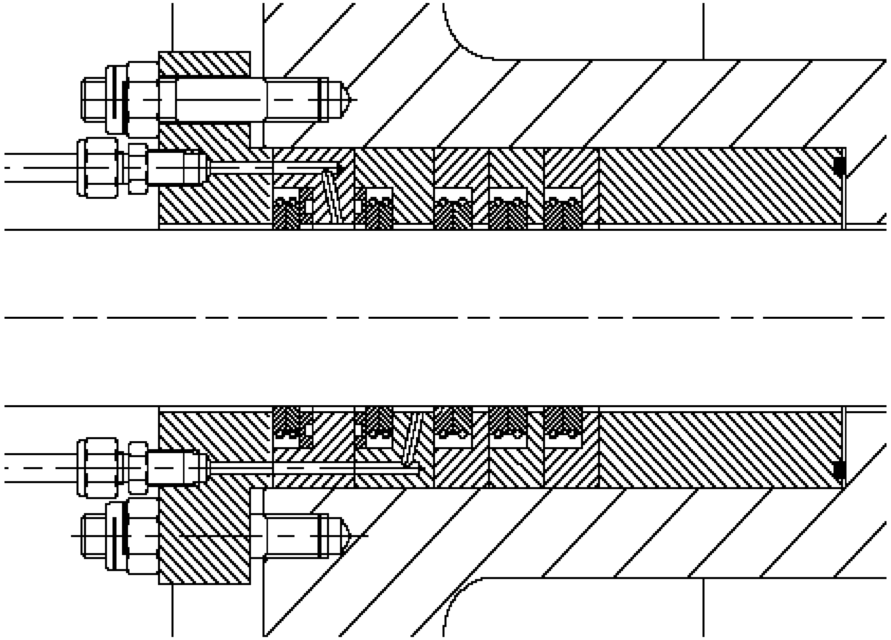
High pressure configuration



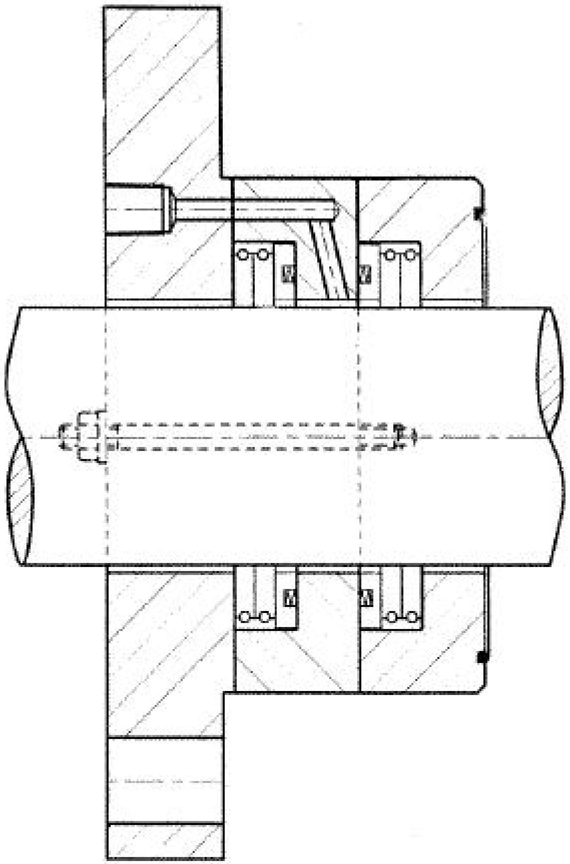
Low pressure configuration



MAIN ROD PACKING (PRESSURE) AND INTERMEDIATE PACK.

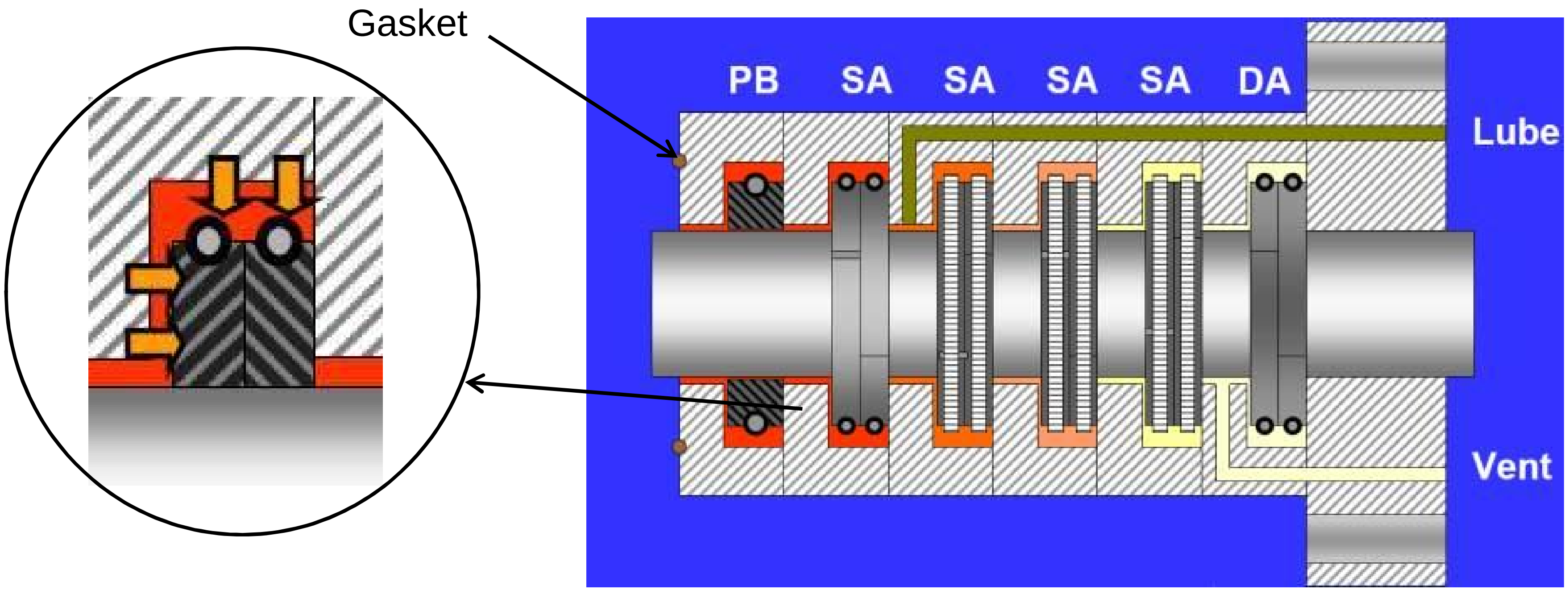


Main rod packing



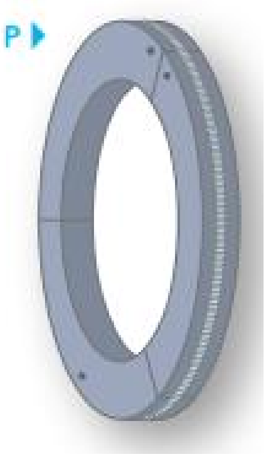
Intermediate rod packing

HOW THE ROD PACKING RINGS WORK

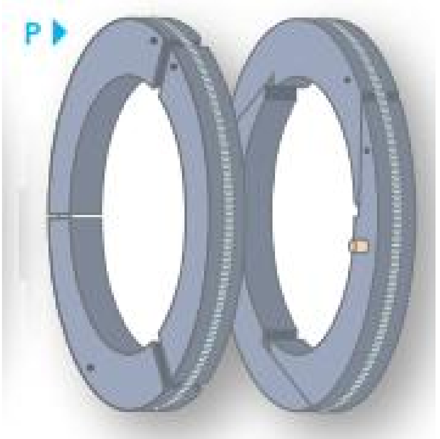


- The rings segments are held together by garter springs until the gas pressure is such that they are forced on to the rod to create the seal.
- Sealing rings are doweled together so that the gaps between the ring segments of one ring are covered by the ring segments of the other to reduce leakage.
- Rings can float axially and radially in the grooves of the cups to compensate for rod movement (full floating).

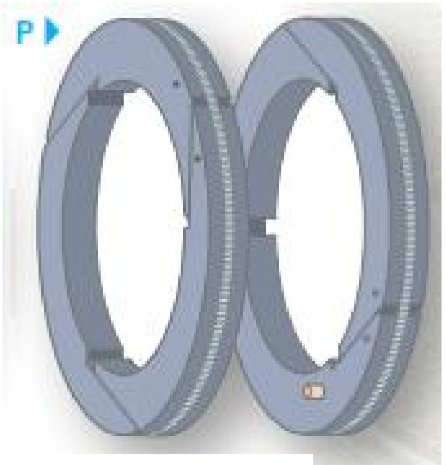
ROD PACKING RINGS - CONFIGURATIONS



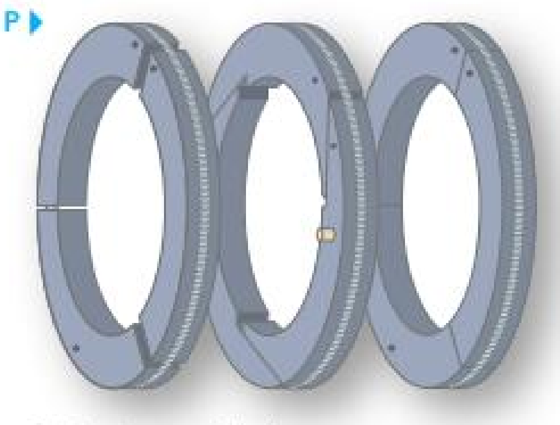
Pressure breaker



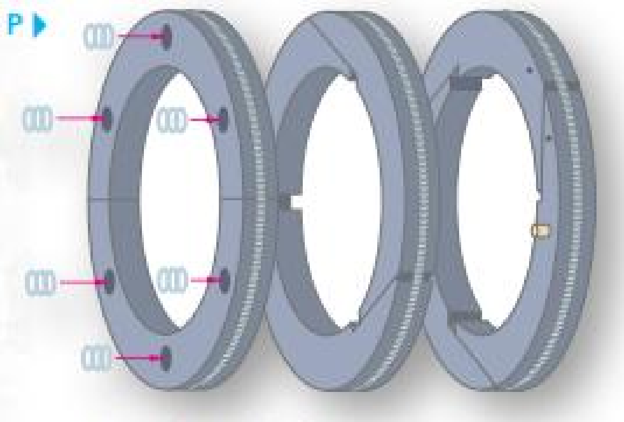
Radial + tangent



Double tangent

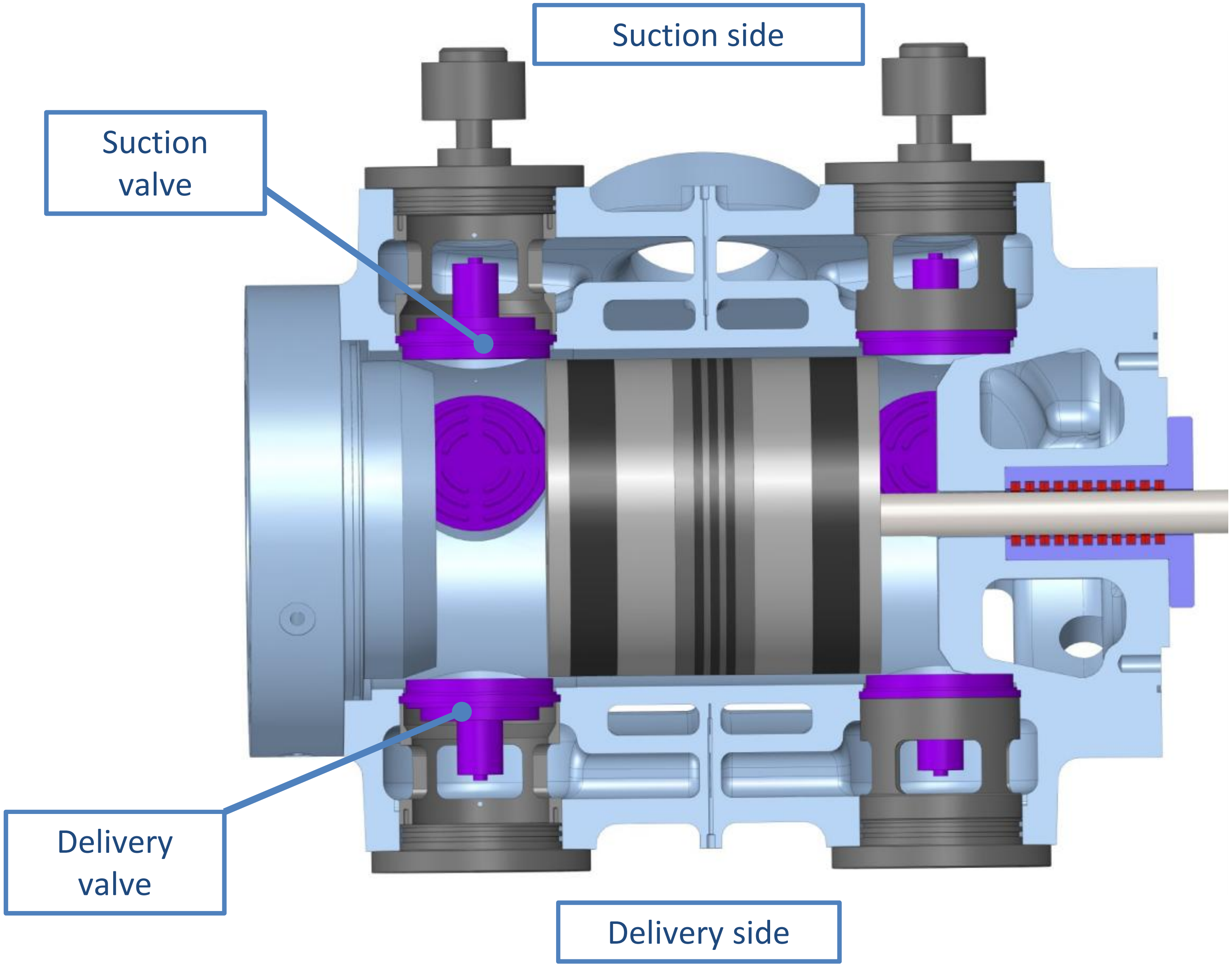


Radial + tangent + back-up

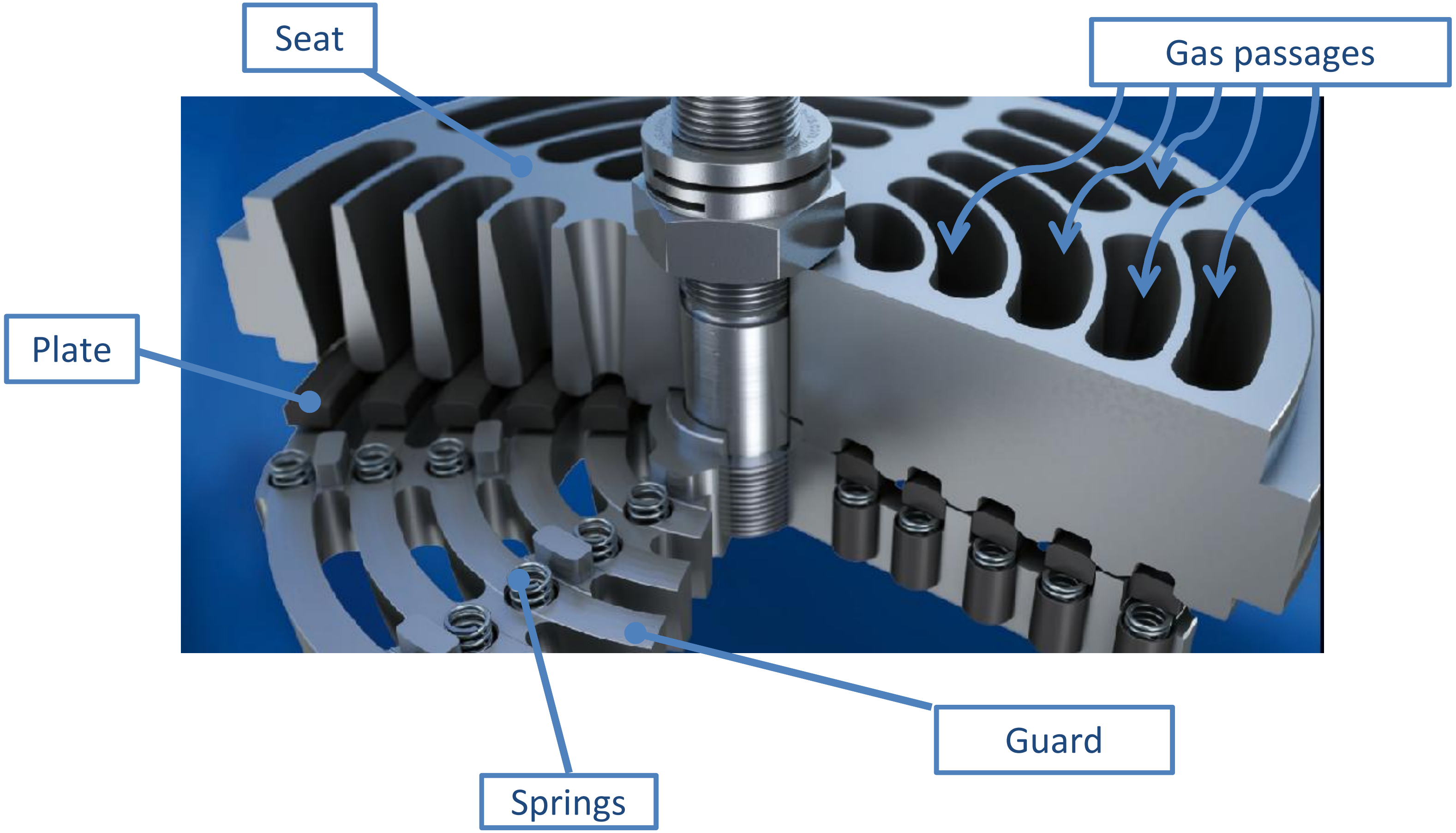


Axial loaded ring with double tangent

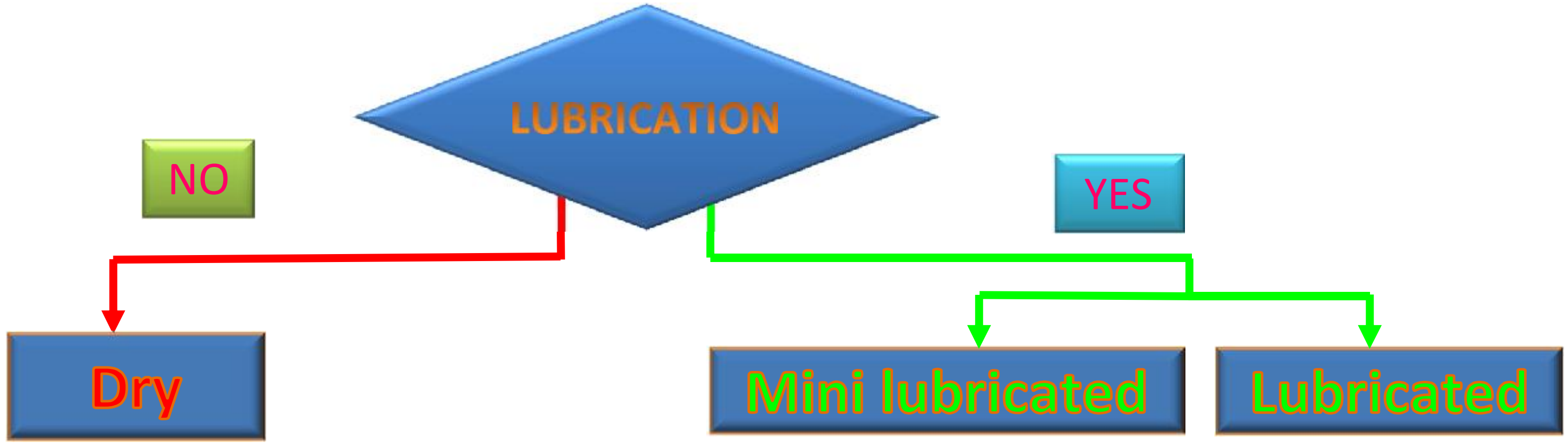
VALVE POSITION



SUCTION VALVE



OPTIONS FOR CYLINDER LUBRICATION



Depends on:

- Toleration with the process
- Economical evaluation
- Required reliability
- Delivery pressure

LUBRICATION RATE FOR CYLINDERS AND ROD PACKING

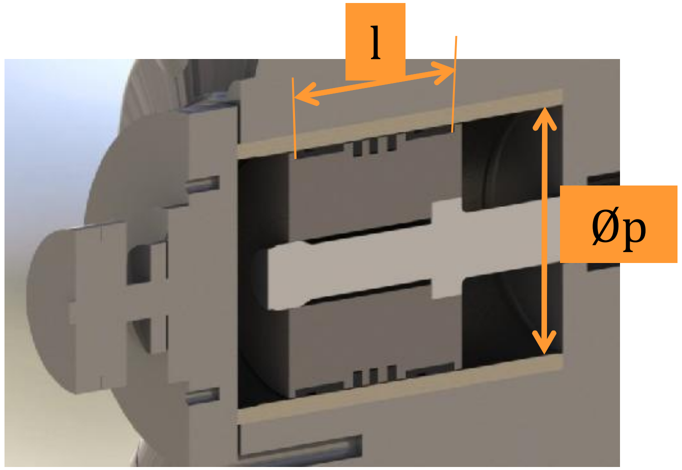
Cylinder nominal lube rate = Cx · SSPp

Cx = specific requirement (consumption)

Surface swept by the piston

$$SSP_p = \pi \cdot Øp \cdot (c + l) \cdot n \cdot 2$$

c = piston stroke
n = compressor speed



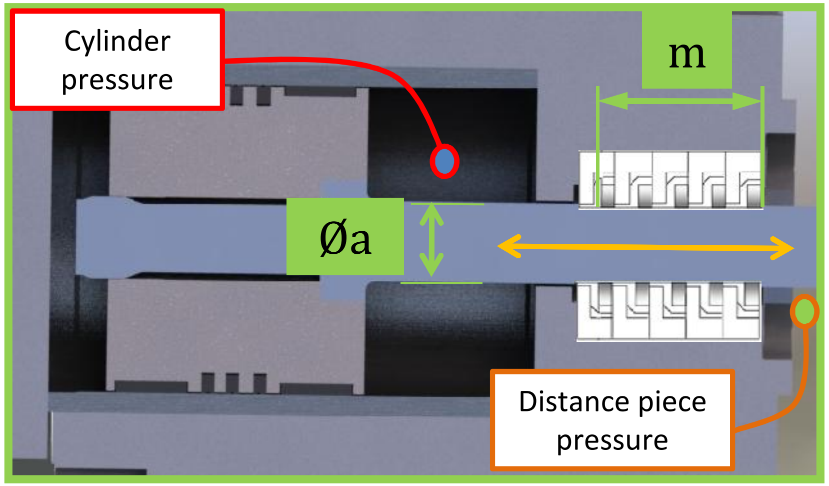
Rod packing nominal lube rate = Cy · SSPa

Cy = specific requirement (consumption)

Surface swept by the pist. rod

$$SSP_a = \pi \cdot Øa \cdot (2c + m) \cdot n$$

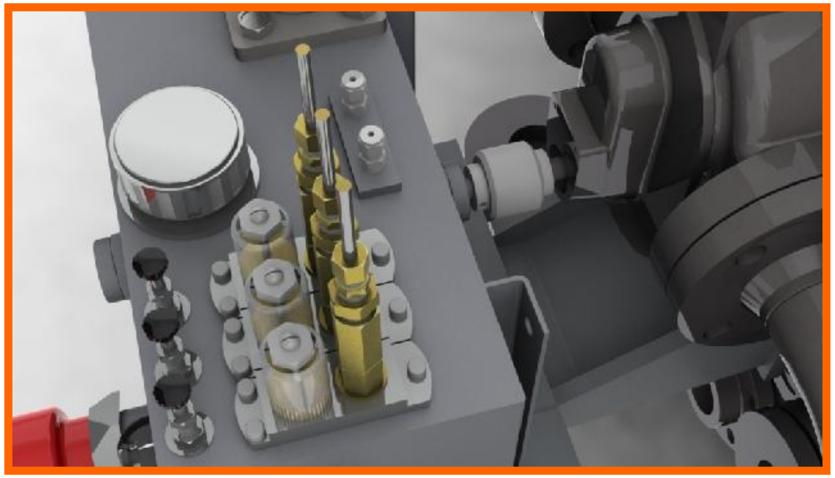
c = piston stroke
n = compressor speed

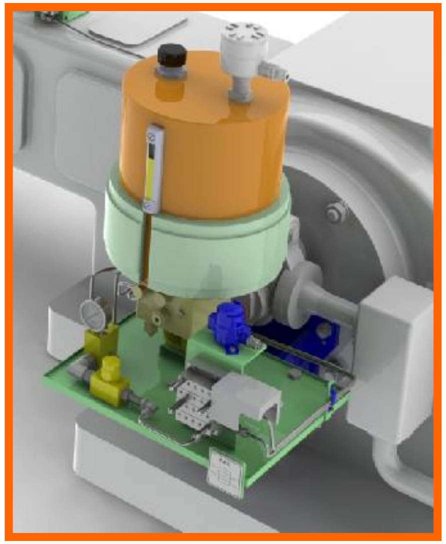


API618 requires a system able to provide a lubrication rate in the range from 75% to 200% of the nominal rate calculated

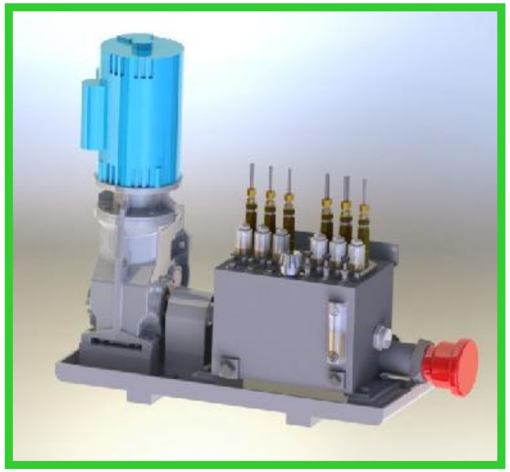
DRIVES FOR CYLINDER LUBE PUMPS

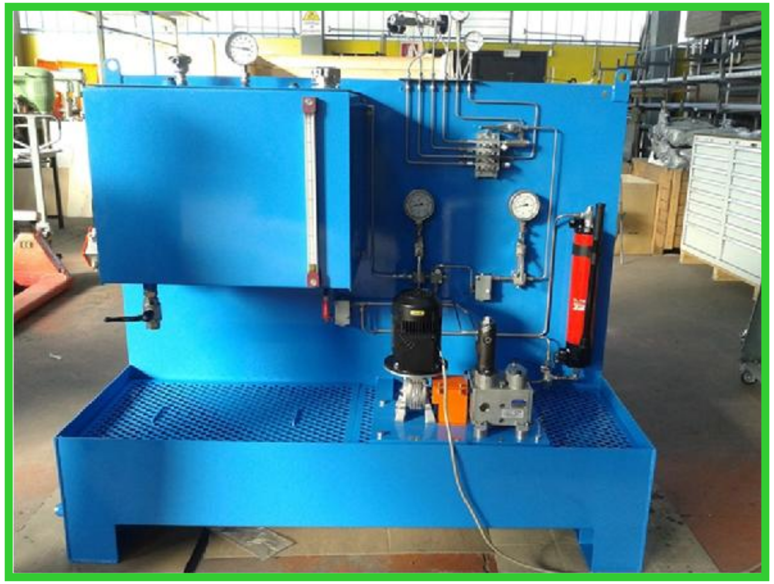
Crankshaft driven





Electrical motor driven





COOLING SYSTEMS

The cooling systems may use the following fluids:

- water or other liquids (glycol, ….)
- air

Normally the cooling system is intended for:

- Process gas
  - at compressor suction (not often)
  - to cool down the gas between the compression stages
  - downstream the compressor
- Cylinders
  - Heads
  - Liners
  - Rod packing group
- Lubricating oil for the crank-mechanism

The cooling system may be:

- Open loop with water
- Closed loop (in this case the heat is removed through and air or water cooler)

DRIVE MOTORS

- **Drive motors**
  - **Fixed speed**
    - Asyncronous motors (1 or 2 bearings)
    - Syncronous motors (1 bearing)
  - **Variable speed**
    - Electrical motors (asyncronous) with inverter
    - Endothermic engines (2 or 4 strokes)

DRIVE SYSTEM SELECTION

- The most common is the electric motor at fixed speed. Magnetic poles or a gear reducer are used to match the compressor speed with the motor speed.
- Synchronous motors are generally used for high power and low speed because it allows to adjust the power factor (cos ϕ).
- Motors suitable for a variable speed drive (VSD) are generally more expensive but they allow to regulate the flow rate reaching the highest efficiency.
- Gas engines are typically used for natural gas applications with high speed compressors (750-1800 rpm), particularly in remote sites where the electric supply is not available or much more expensive than gas.
- It is highly recommended to perform a torsional analysis of the complete drive train (driver, coupling, flywheel, crankshaft) to avoid mechanical intergrity issues.

ASYNCHRONOUS MOTOR

The most common for low-medium power (up to 1000 ÷ 2000 kW).

- Good efficiency (93 ÷ 97%)
- Excellent starting torque
- Accepts voltage drops
- High starting intensity (Amps)
- Low power factor (cosφ)

$$n = \frac{2 \cdot f \cdot 60}{np} \cdot (1 - s)$$

n = rotating speed (rpm)

f = frequency of the feeding line (Hz)

np = magnetic poles

s = sliding (1÷3 %)

SYNCHRONOUS MOTOR

It is generally used for high power and low speed.

- High efficiency (94 ÷98 %)
- Low starting intensity (Amps)
- It allows to modify the power factor (cosφ),
- It does not accept voltage drops

$$n = \frac{2 \cdot f \cdot 60}{np}$$

n = rotating speed (rpm)

f = frequency of the feeding line (Hz)

np = magnetic poles

ENDOTHERMIC ENGINE

It can be 2 or 4 strokes and with different kinds of fuels.

- It does not require electricity
- The speed is variable
- Lower reliability in comparison to electrical motors
- High cost
- It requires periodic maintenance (more frequent than electrical motors)
- It requires auxiliary circuits

CONCLUSIONS

- The reciprocating compressor technology is well proven and dated
- The reciprocating compressors are well known for:
    - high efficiency in many different operating conditions, flexibility
    - easy regulation possibilities
    - suitability for light gases
    - capability to handle high compression ratios and high pressures
- New challanges are:
    - higher efficiencies leading to energy savings
    - increasing the availability with longer MTBO (mean time between overhaul)
    - handling harsh process conditions
- It is a very reliable equipment if carefully designed, constructed and maintained

THANKS!!