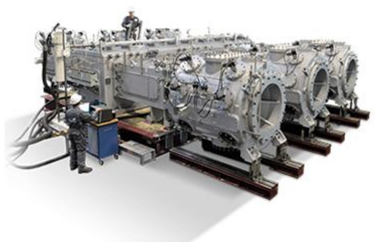
EFRC Training Workshop
Basic training

Design & Construction

Niek Albers – Howden Thomassen Compressors B.V.

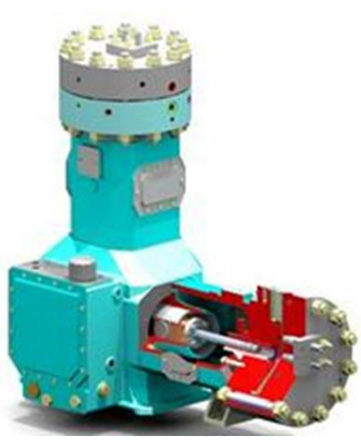
Compressor configurations

Horizontal



Vertical

L-type

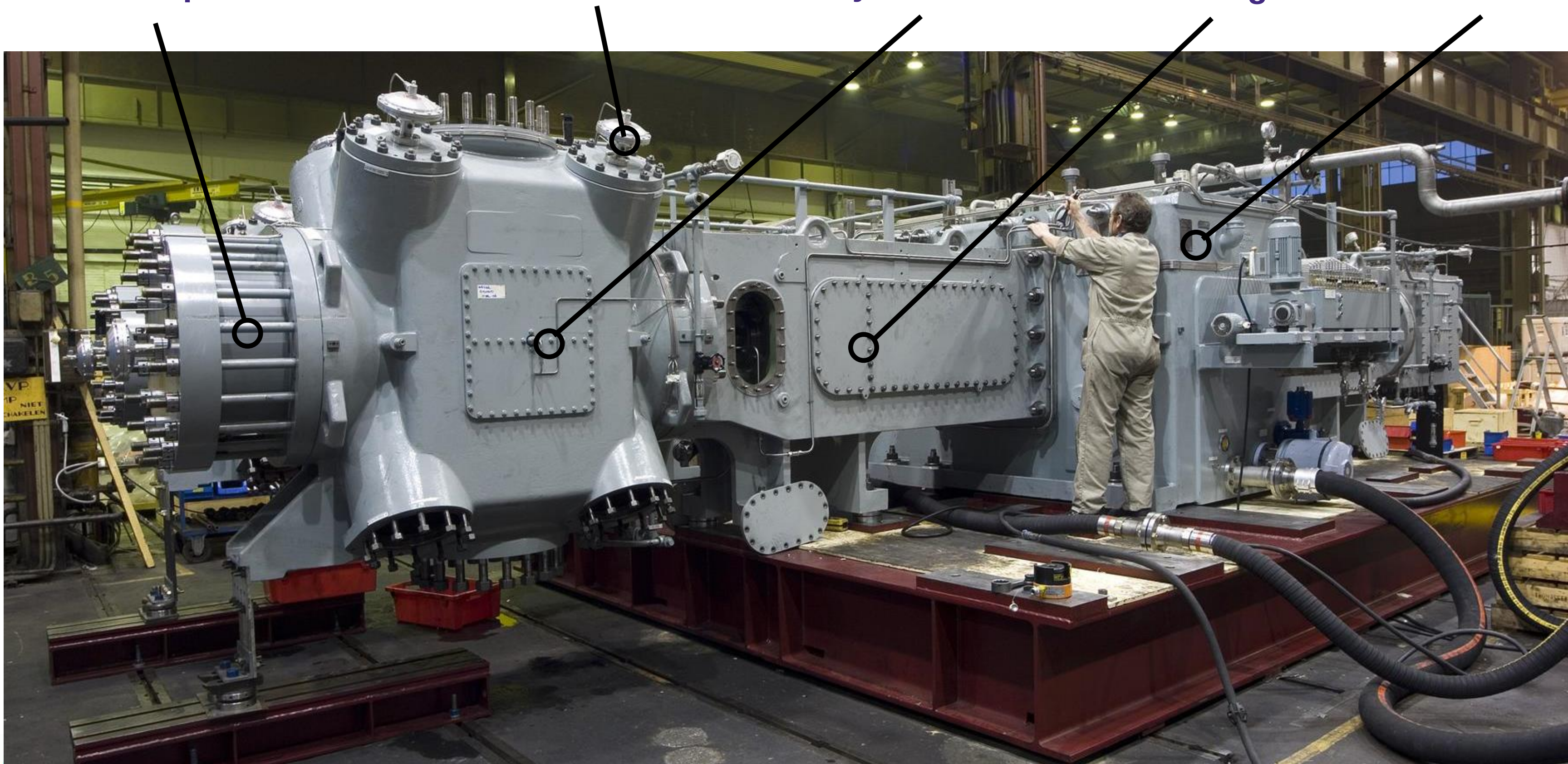


V-type

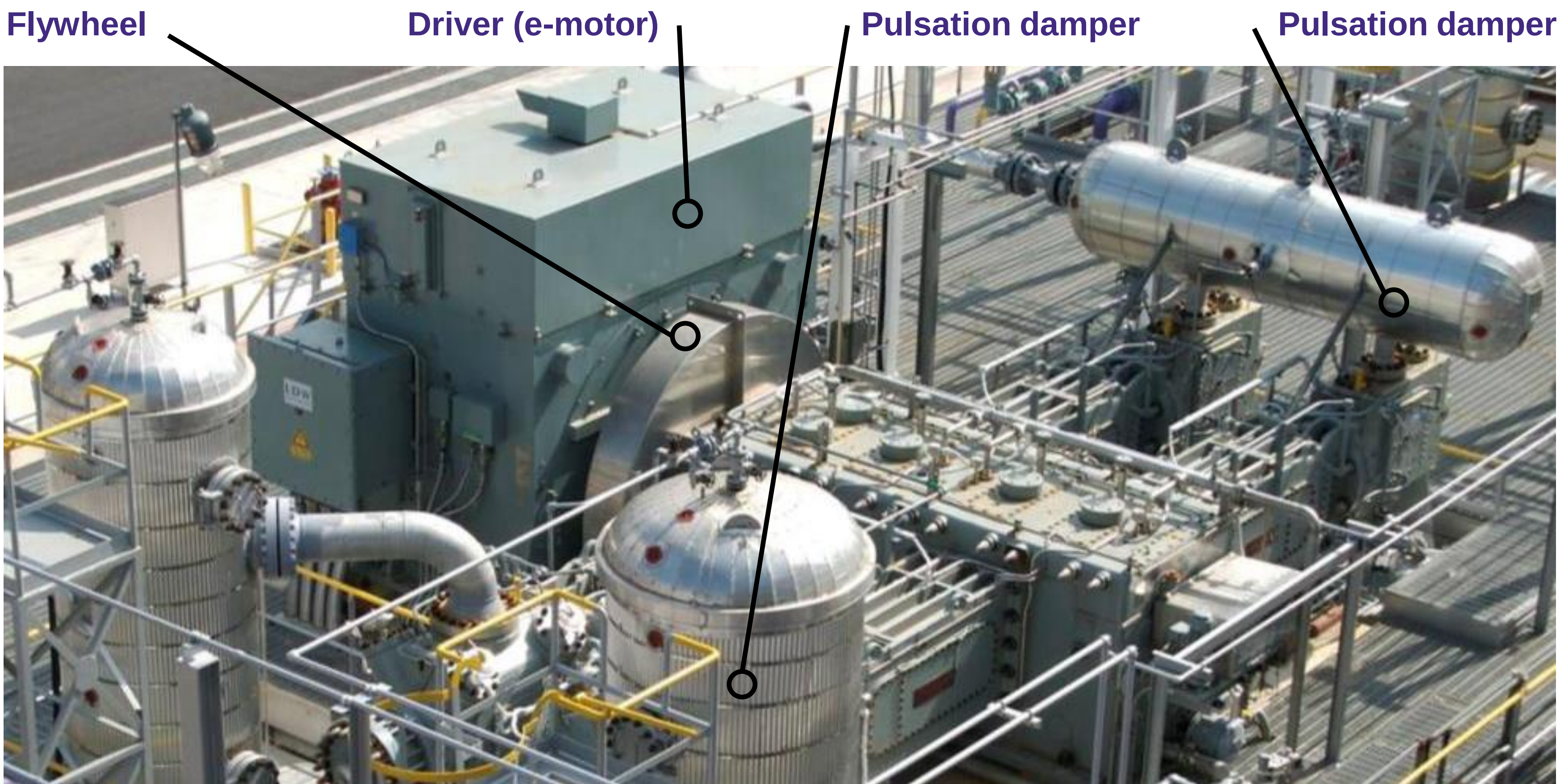
W-type

Image source: Howden, SIAD MI (V), GEA Grasso (W)

Main components



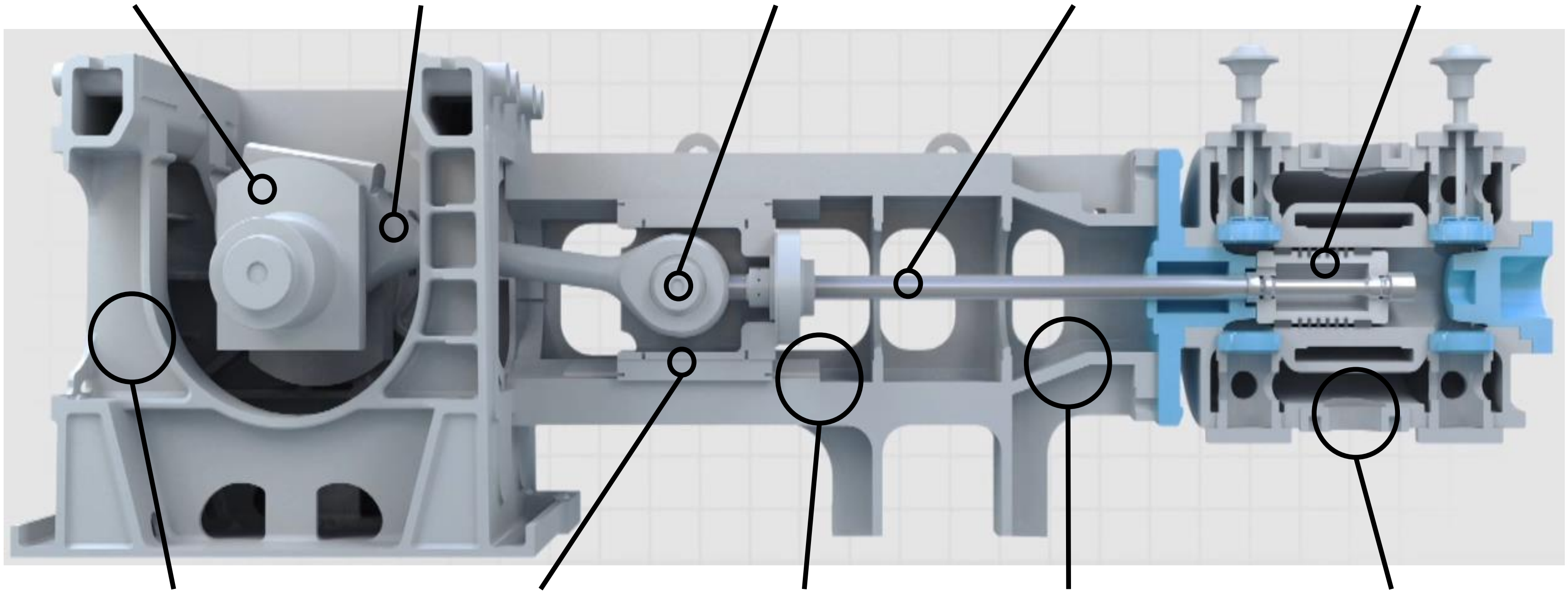
Main components



Standards

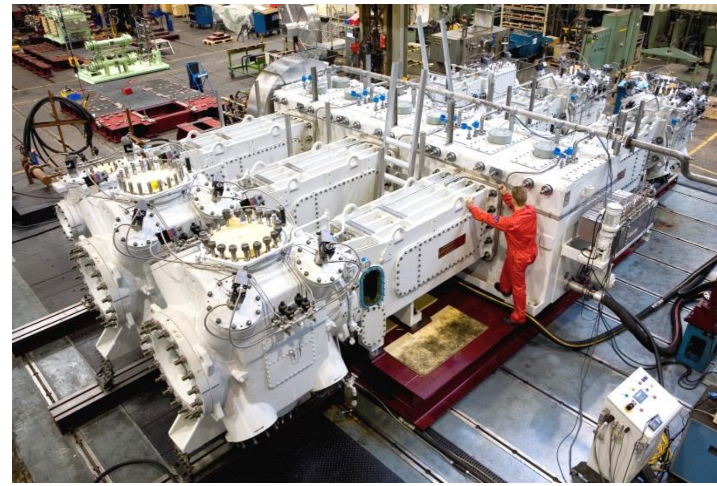
- API
  - 618: Reciprocating Compressors
  - 614: Lubrication, shaft-sealing and control-oil systems and auxiliaries
  - RP 686: Recommended practices for machinery installation and installation design
  - RP 684: Standard paragraphs rotordynamic tutorial
  - RP 688: Pulsation and vibration control in positive displacement machinery systems
- Customer & project specifications

Construction

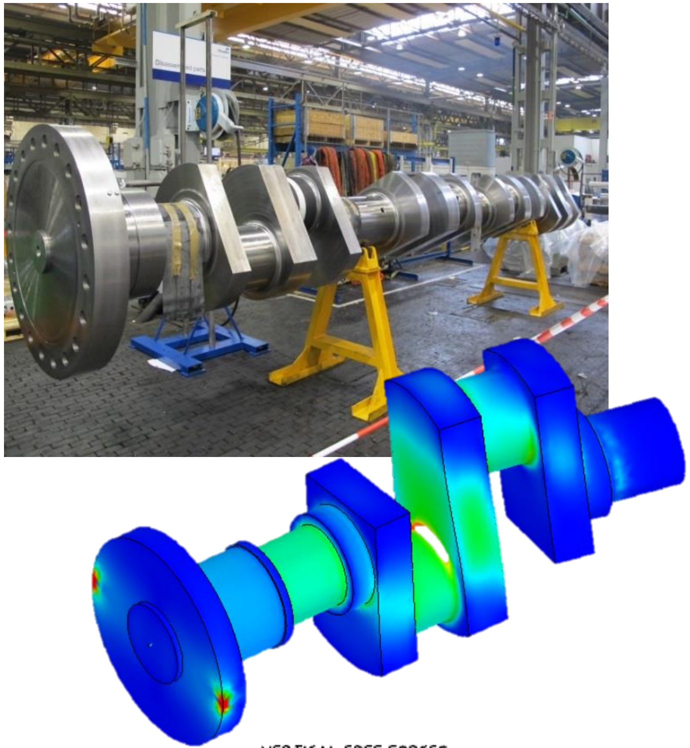


Crankcase

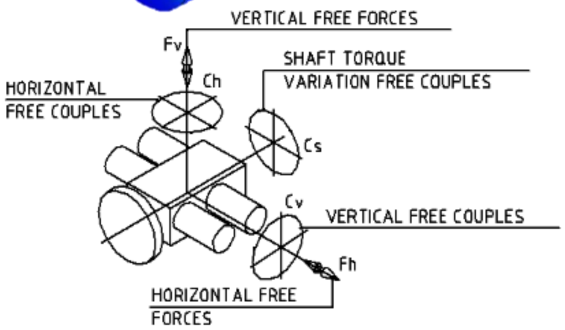
- Function
  - Contain and support parts
  - Transfer forces and moments to foundation
  - Oil reservoir
- Design
  - Cast iron
  - Ribbed construction for force transfer



Crankshaft

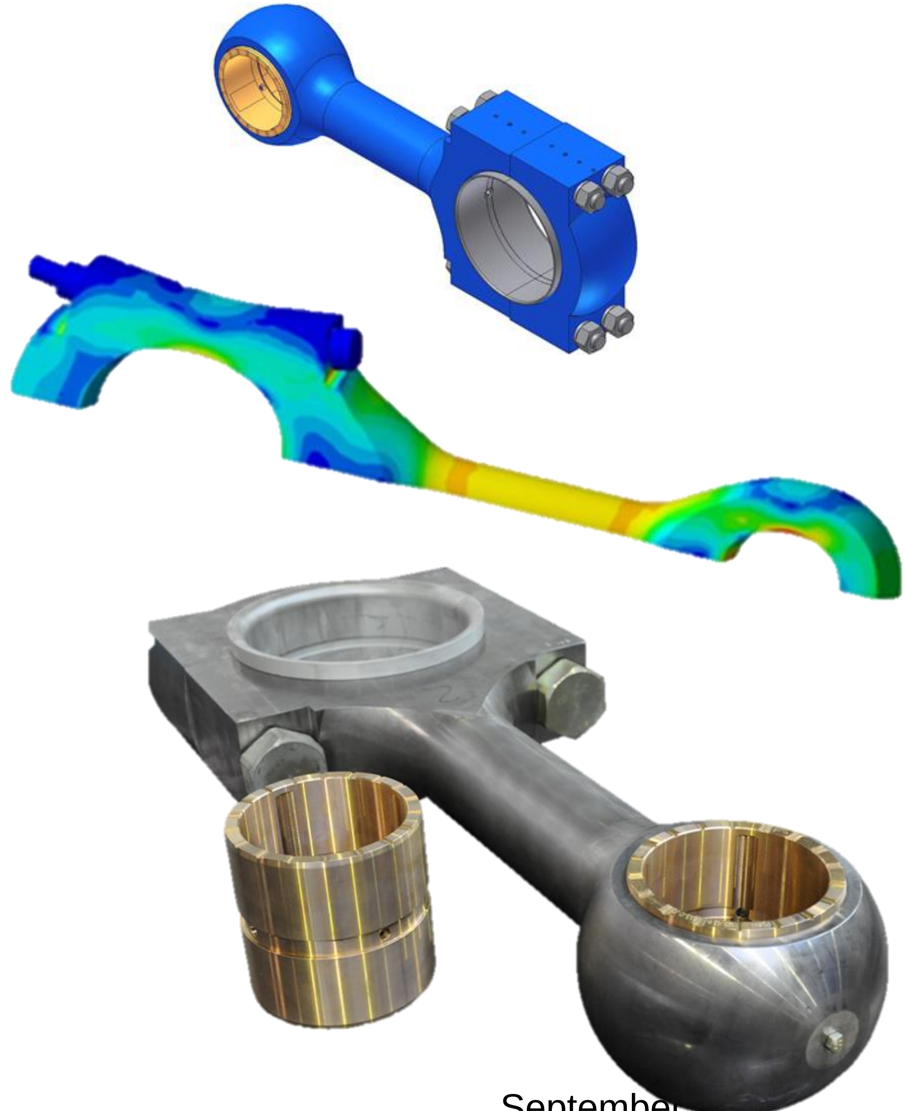


- Function
  - Transfer rotating motion from driver to connecting rod big end bearing
- Design
  - Forged steel
  - Drilled passages for lube oil distribution to connecting rod
  - Flanged or shaft end



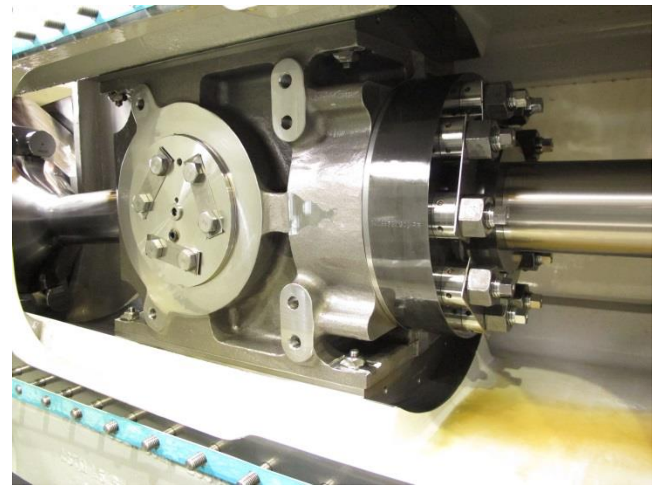
Connecting Rod

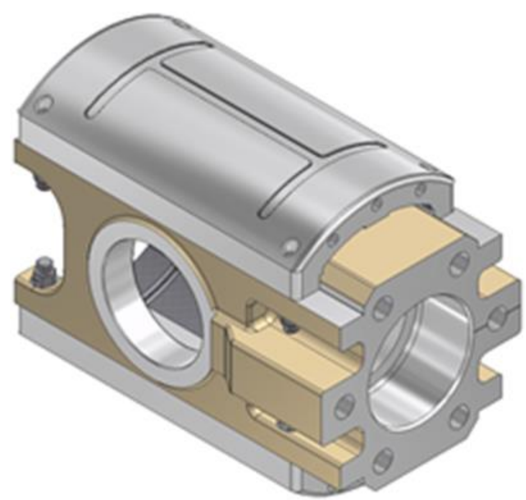
- Function
  - Connect crankshaft to crosshead
  - Transfer rotating to reciprocating motion
- Design
  - Forged steel
  - Big end bearing cap
  - Houses big and small end bearings



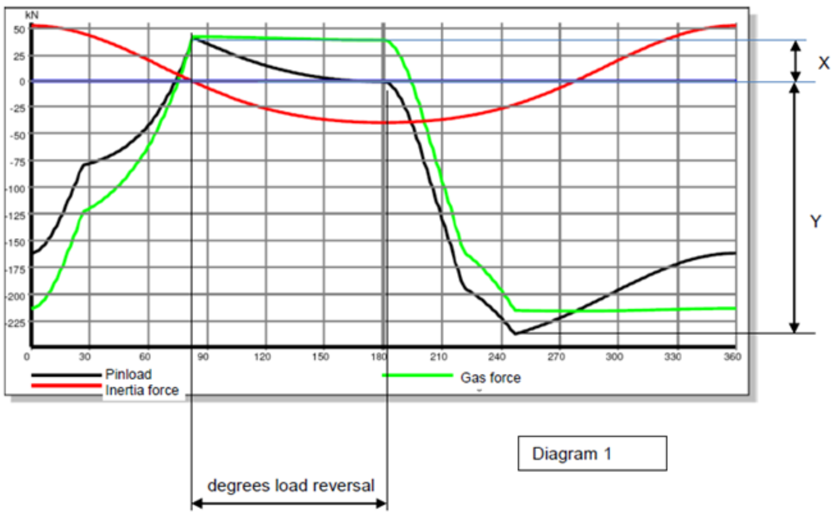
Crosshead

- Function
  - Connect piston rod to connecting rod
- Design
  - Cast steel
  - Replaceable shoes
  - Floating or fixed crosshead pin
  - Crosshead pin bushings





Pin load and reversal

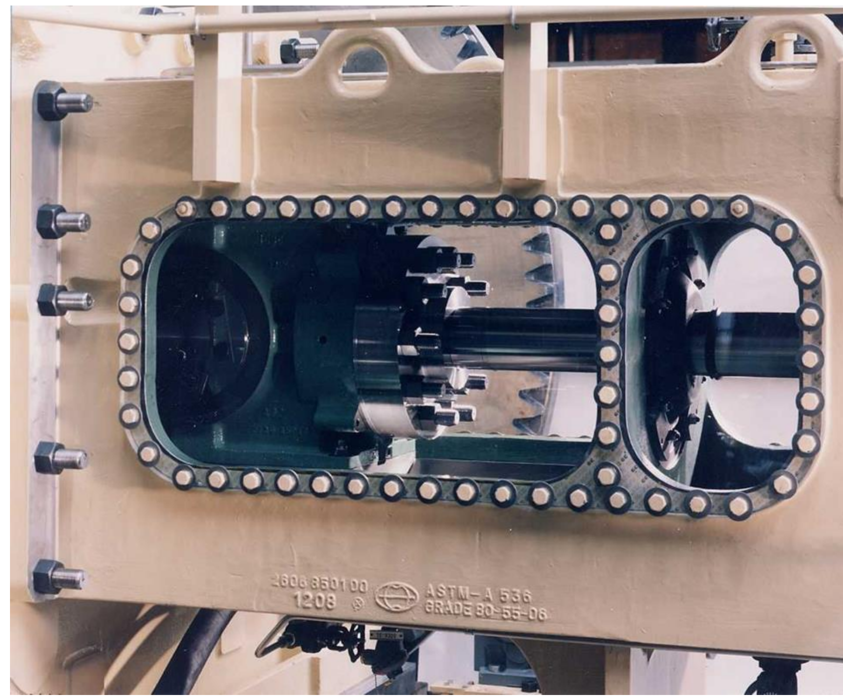


Amount of crosshead pin load reversal is "X"/"Y"

- Combined rod load/pin load is the sum of gas load and inertia forces on the crosshead pin
- Load shall fully reverse between pin and bushing
- Duration (°) and magnitude (%) shall be sufficient to maintain proper lubrication

Crosshead Guide

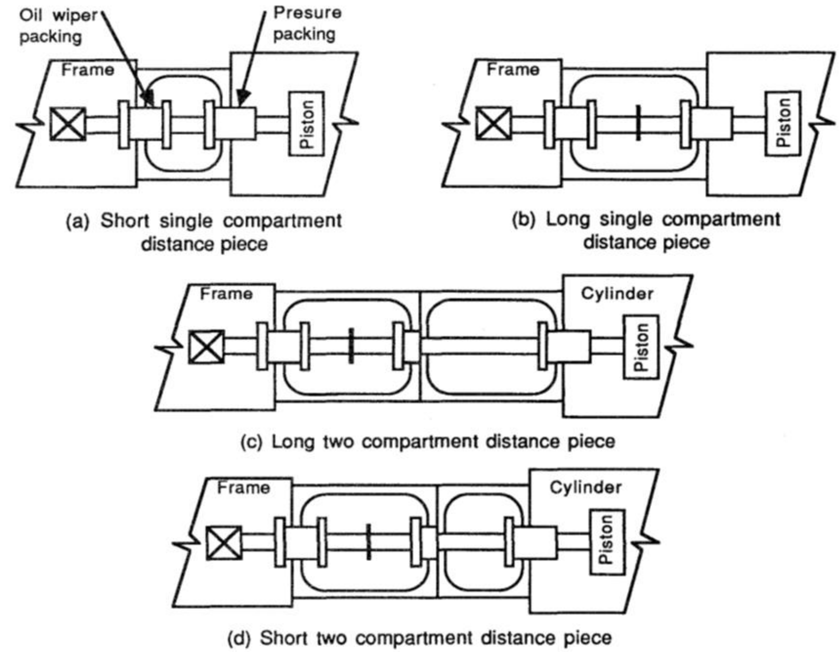
- Function
  - Guide reciprocating motion of crosshead
  - Enable lubrication of the sliding surfaces
- Design
  - Cast iron
  - Integral part of frame or integrated with distance piece



Distance Piece

- Function
  - Connect cylinder to crankcase
  - Provide barrier for process gas between cylinder and crankcase
- Design
  - Cast iron
  - Single or double compartment

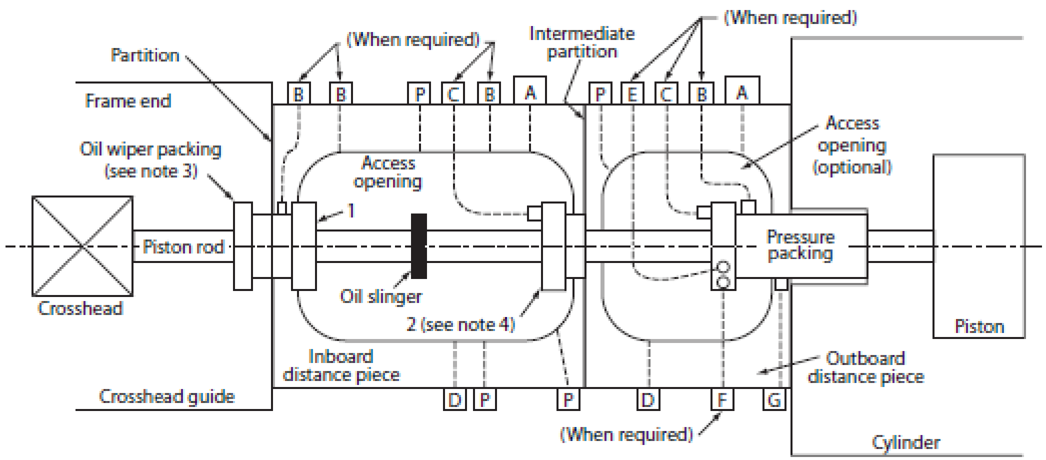
Distance piece arrangements



Source: API 618, 5th edition

- Type A
  - Single compartment, short
  - Non-flammable, non-hazardous gas
  - Oil carry-over acceptable
- Type B
  - Single compartment, long
  - Non-lube or oil carry-over not acceptable
- Type C
  - Double compartment, long/long
  - Only for special service, e.g. oxygen
  - Normally not used on process gas compressors
- Type D
  - Double compartment, long/short
  - For flammable, hazardous or toxic gases

Distance piece arrangements



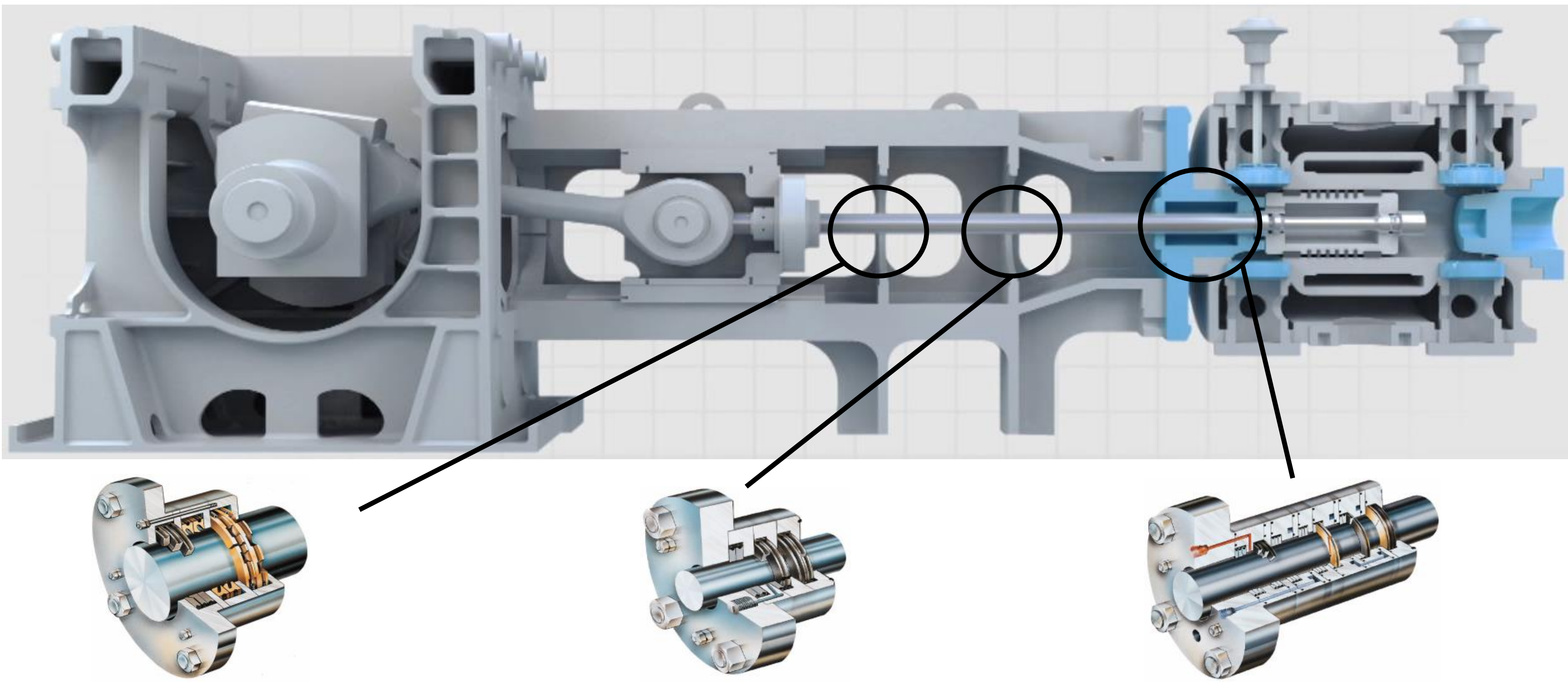
TYPE D
SHORT TWO-COMPARTMENT OR DOUBLE DISTANCE PIECE ARRANGEMENT
(INBOARD DISTANCE PIECE OF SUFFICIENT LENGTH FOR OIL SLINGER TRAVEL)

Legend:
1. Seal or buffer packing, distance piece
2. Intermediate seal or buffer packing, distance piece (solid access covers required)

Connections (see 6.12.2 for sizes):
A Vent, distance piece
B Purge, buffer, or pressure, packing or distance piece
C Lube, pressure packing
D Drain, distance piece
E Coolant out, pressure packing
F Coolant in, pressure packing
G Common vent and drain, pressure packing
P Plugged connection

Source: API 618, 5th edition

Piston rod sealing



Oil wiper packing

Wipes of the motion work lubrication oil from the piston rod. Seals crankcase from inboard compartment.

Intermediate packing

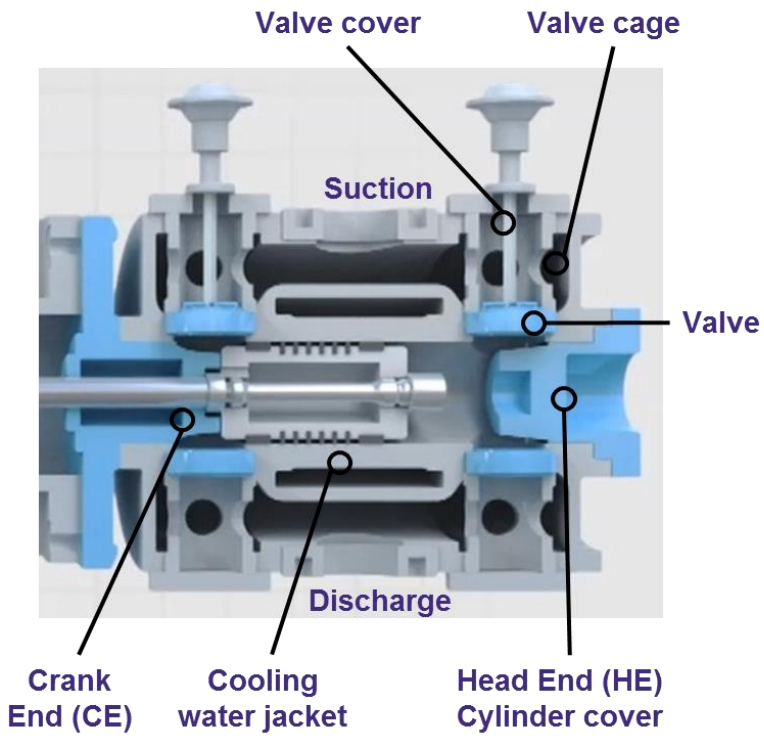
Seals the inboard compartment from the outboard compartment

Stuffing box

Main pressure seal.
Seal between compression chamber and compartment.

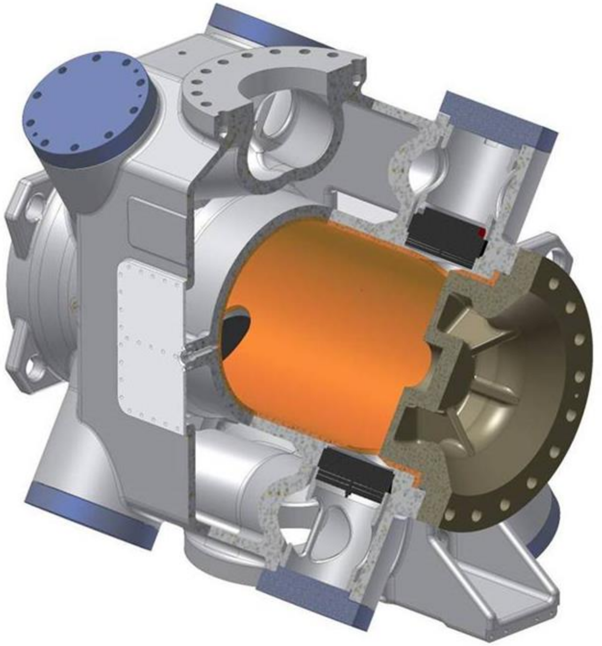
Cylinder

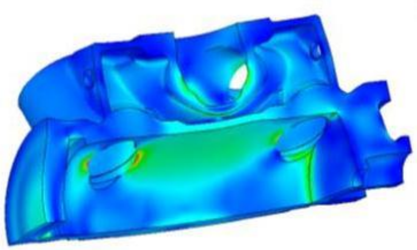
- Function
  - Transfer process gas to/from compression chamber
  - Contain process gas during compression
- Design
  - Double acting (DA) most common
  - Cast iron, cast steel or forged steel

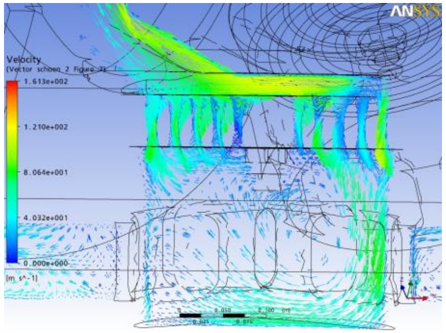


Cylinder

- Design & analysis
  - Casting
    - <100 bar(g): Cast iron
    - <180 bar(g): Cast steel
  - Forged steel block for higher pressures
  - Cooling water channels
  - Replaceable liner

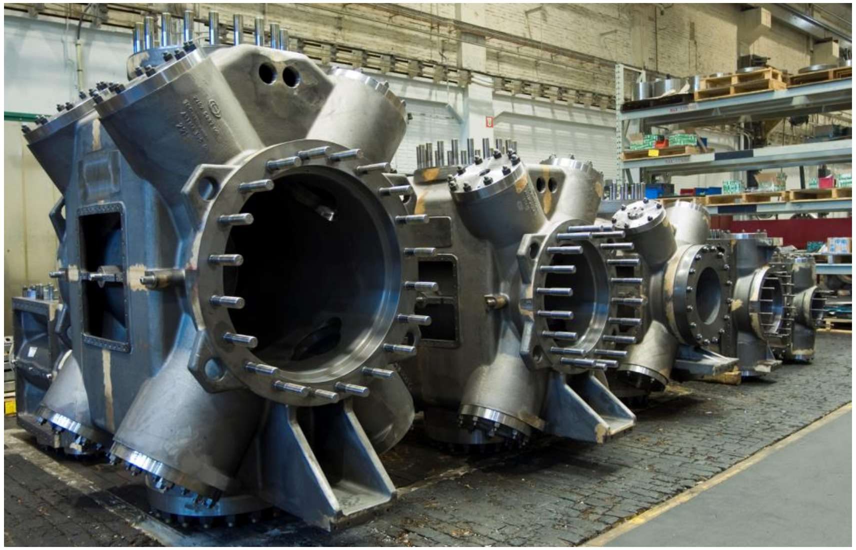






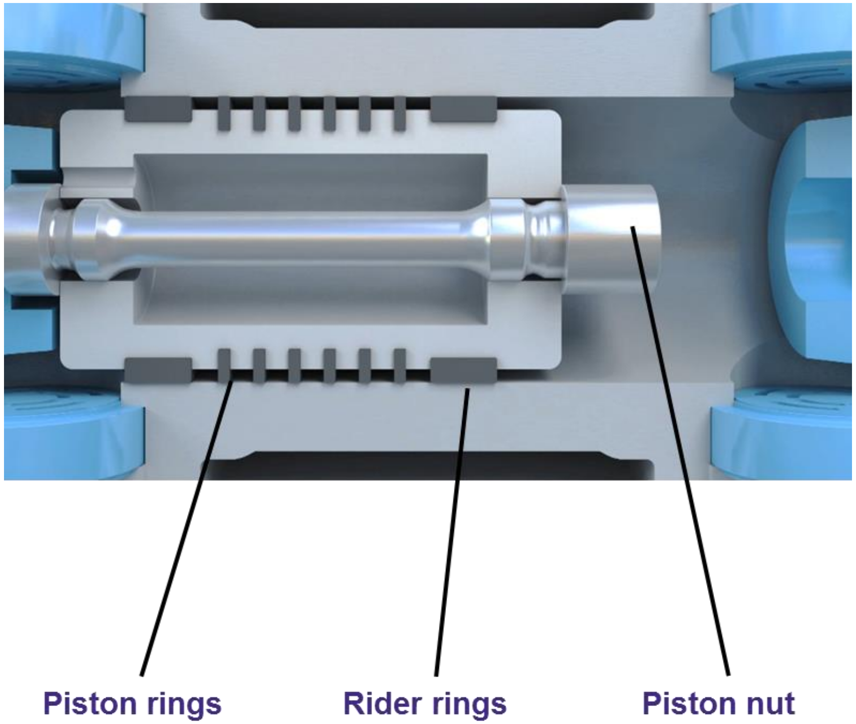
Cylinder

- Testing
  - Hydrostatic
    - Mechanical integrity
    - Using water
    - 1.5 x P_{design}
  - Pneumatic
    - Leakage test
    - Using inert gas
    - 1 x P_{design}



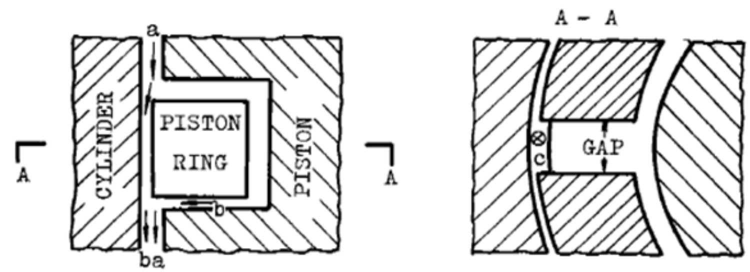
Piston

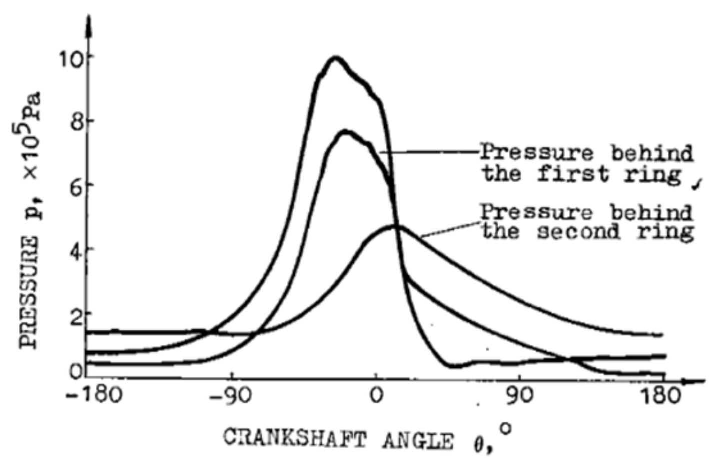
- Function
  - Reduce process gas volume
- Design
  - Cast iron, stainless steel or aluminium alloy
  - Solid or hollow
  - Vent hole
  - Grooves for piston rings and rider rings



Piston rings

- Provides dynamic sealing between HE and CE piston side in order to minimize leakage due to differential pressure
- Leakage mainly due to gap (80% to 90%)
- Gap is necessary for mounting of the piston ring and to allow thermal expansion
- Required number of piston rings depends on differential pressure suction/discharge





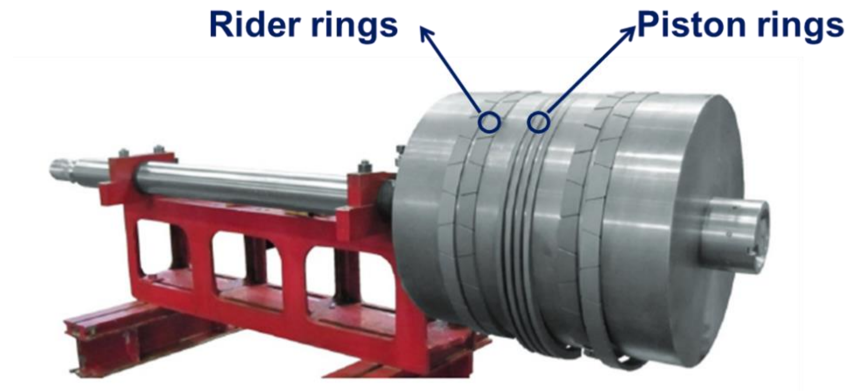
Source: Prediction for the Sealing Characteristics of Piston Rings of a Reciprocating Compressor, Liu & Yongzhang, 1986

Rider rings

API 618, 5th edition, 6.10.3.2

‘For non-lubricated, horizontal cylinders, the bearing load on nonmetallic wear bands shall not exceed 0.035 N/mm2 based on the mass of the entire piston assembly plus half the mass of the rod divided by the projected area of a 120º arc of all wear bands.

For lubricated horizontal cylinders, the bearing load on wear bands shall not exceed 0.07 N/mm2.’

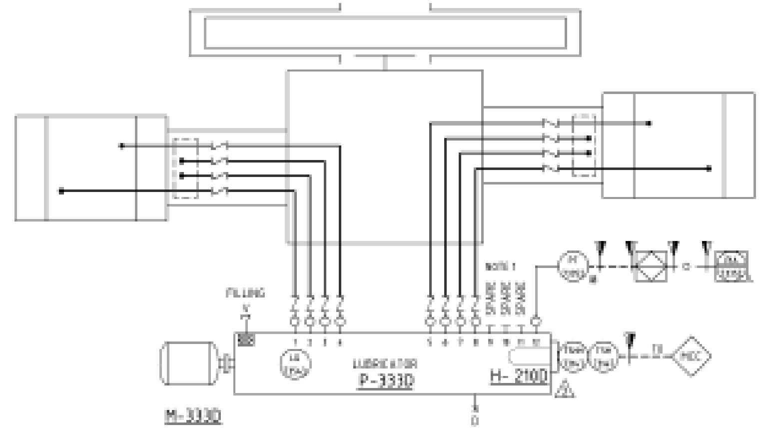


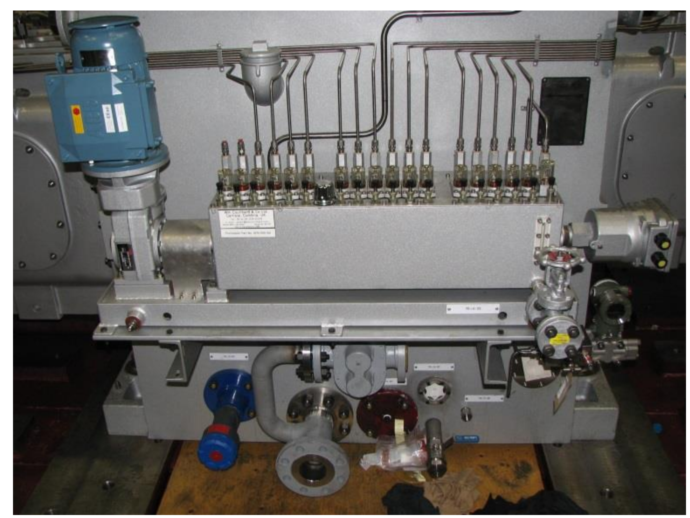
$$L_B = \frac{M_{PA} + (M_R/2)}{(0.866 \times D \times W)}$$

L_B	is the bearing load on wear band in N/mm^2 (lbf/in.^{2});
M_{PA}	is the weight of piston assembly in N (lbf);
M_R	is the weight of piston rod in N (lbf);
D	is the cylinder bore diameter in mm (in.);
W	is the total width of all wear bands in mm (in.).

Cylinder lubrication

- Yes or no?
  - Lubricant allowed in process?
  - Reliability?
  - Operating pressure?
- Lubricated
  - Pump-to-point
  - Divider block





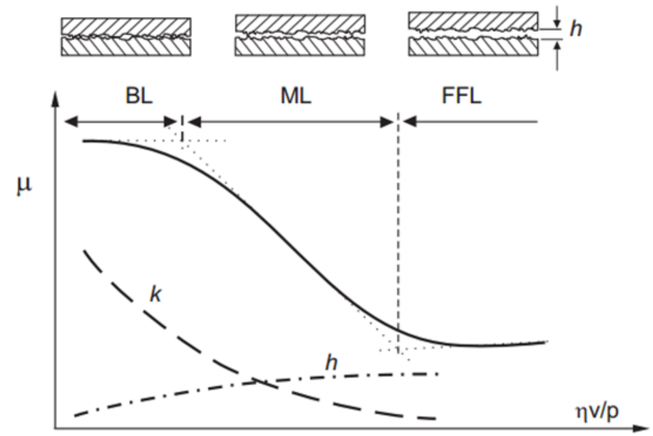
Cylinder lubrication

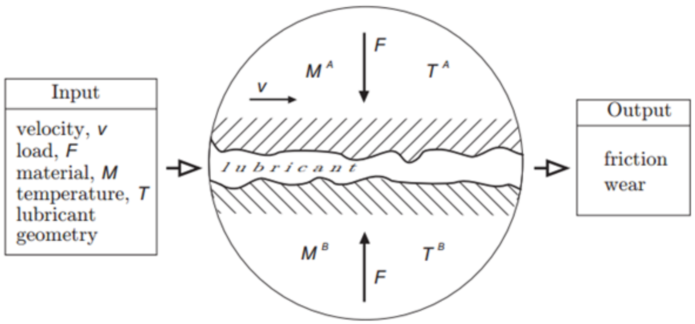
- Mineral oils
- Synthetic oils
- White oils

- Viscosity
  - Gas components may reduce viscosity, effect of pressure

Lubrication - Theory

- Boundary Lubrication
  - Contact dominated by interaction between sliding and stationary surface
  - High wear rate
- Mixed Lubrication
  - Asperity contact may occur
  - Partial fluid-film lubrication
  - Viscosity of lubricant is important
- Full Film Lubrication
  - Sliding surfaces are separated
  - Virtual absence of wear





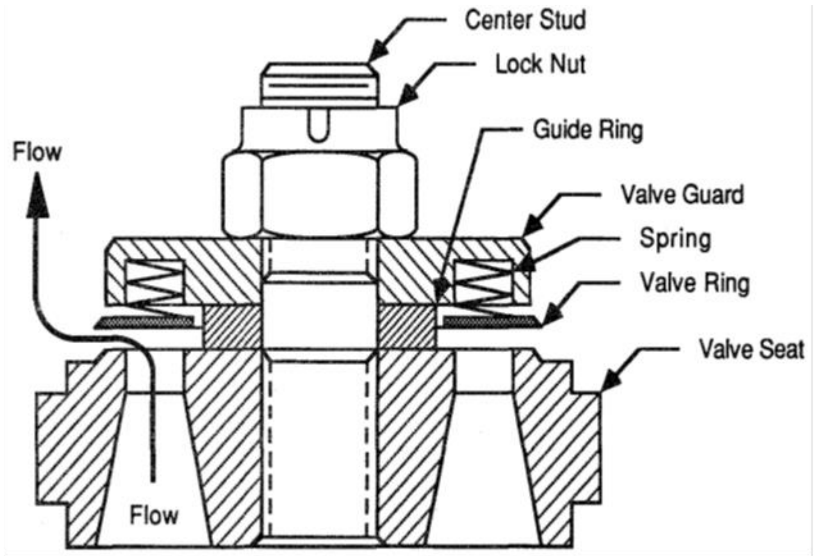
Source: On the design of lubricant free piston compressors, PhD thesis, P. Owczarek, 2010

Lubrication - Quantity

- Getting it just right is crucial
- Over-lubrication leads to accumulation of lubricant in compression space, on valves, in channels and vessels
- Under-lubrication leads to boundary lubrication situation; excessive wear rate

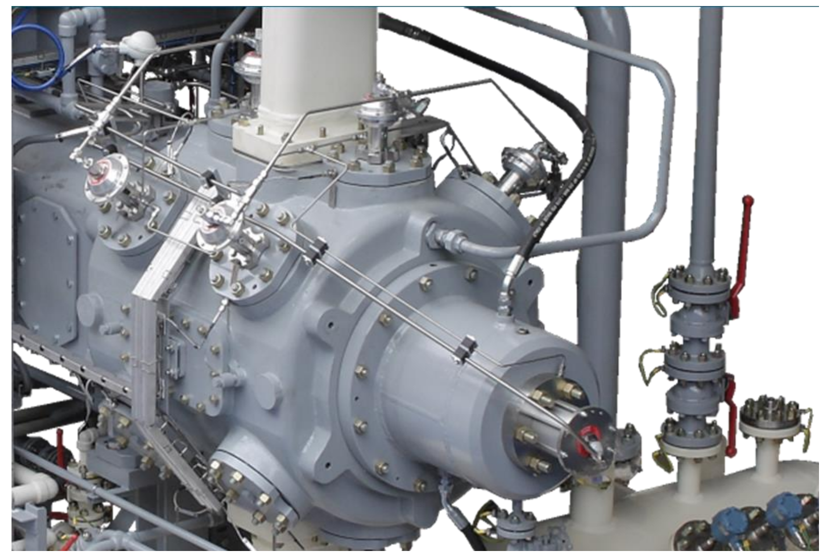
Valves

- Function
  - Retain gas during compression and expansion
  - Allow flow during suction/delivery stroke
- Design
  - Check valves
  - Valve elements either metallic or plastic plates or rings

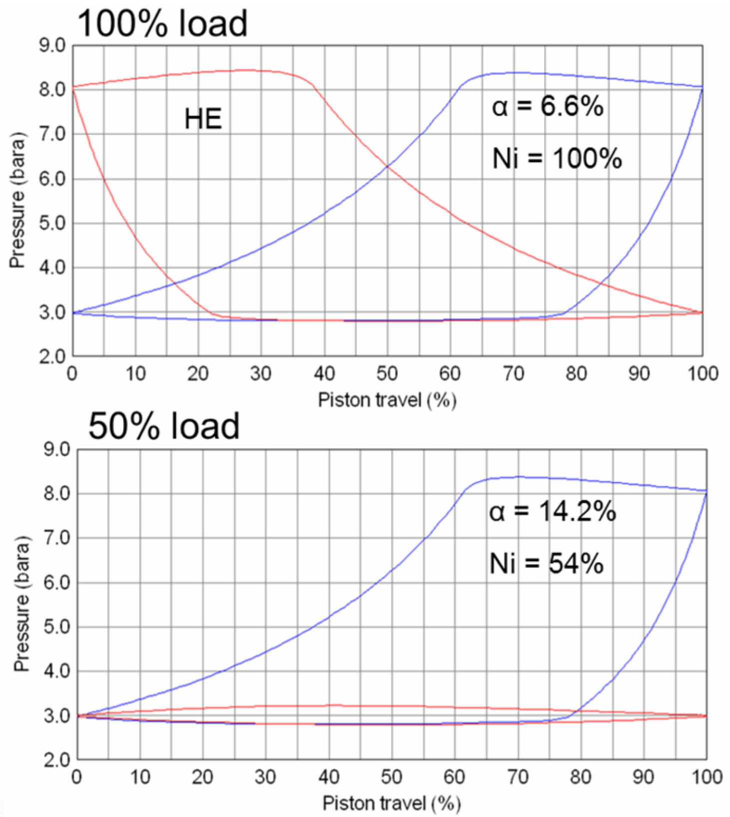


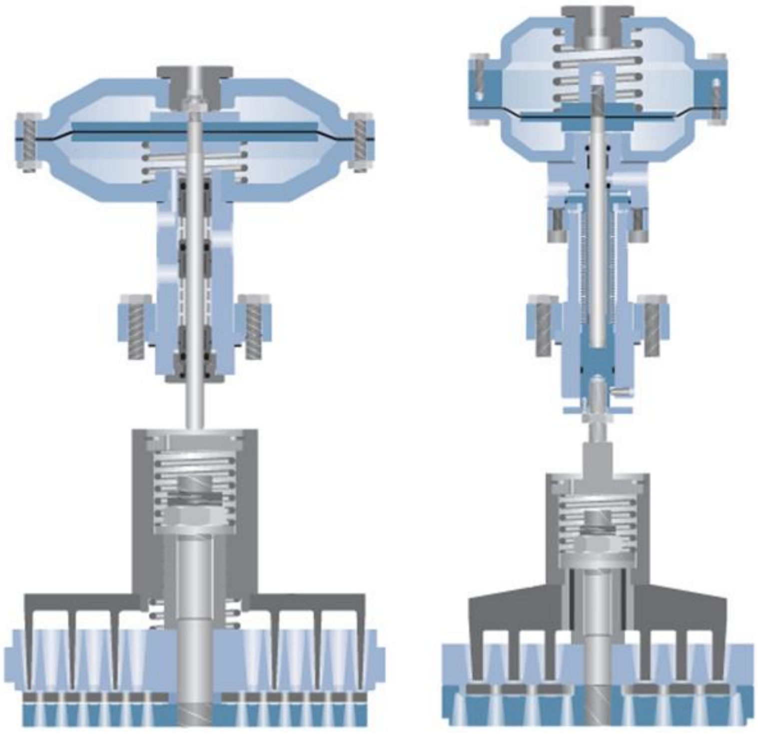
Capacity control

- Stepped
  - Suction valve unloading
  - Fixed clearance pocket
- Stepless
  - Reverse flow control
  - Recycle/spillback
  - Variable speed drive

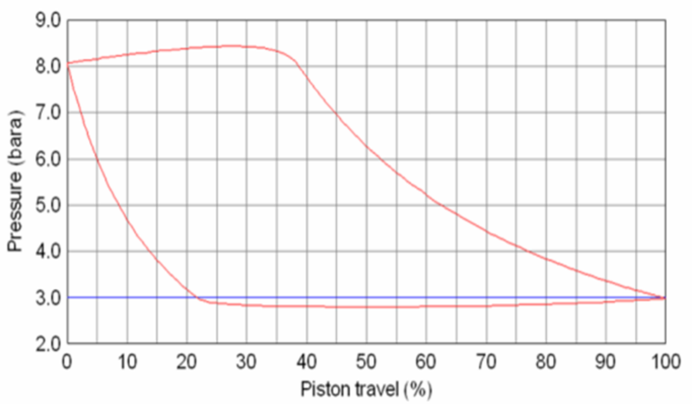


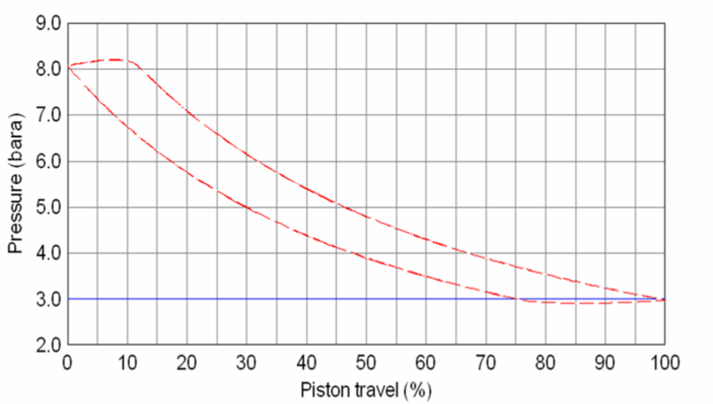
Valve unloading

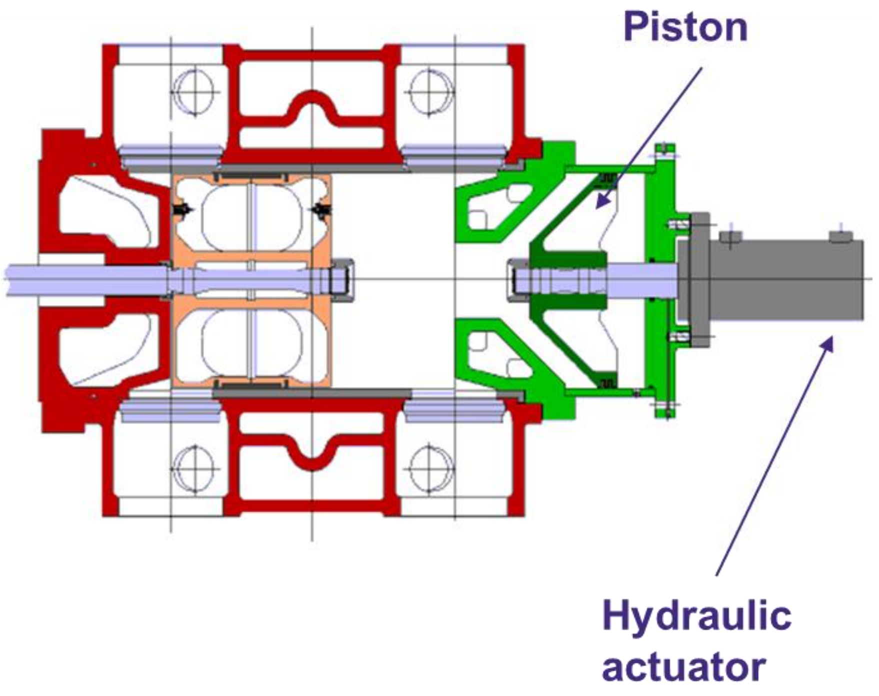




Clearance pocket







Drivers

- Electric motor
  - Induction
  - Synchronous
- Steam turbine
- Gas/diesel engine

Electric motors

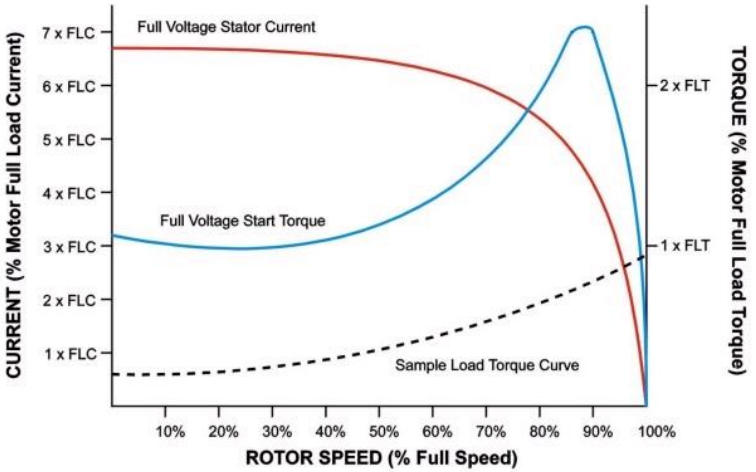
- Basics
  - $n = \frac{f \times 120}{p}$
  - where:
    - n = motor speed [rpm]
    - f = frequency [Hz]
    - p = number of poles

p	50 Hz	60 Hz
8	750	900
10	600	720
12	500	600
14	429	514
16	375	450
18	333	400
20	300	360

- Induction
  - Motor speed lagging from rotating magnetic field – “slip” required to induce torque
- Synchronous
  - Motor speed synchronized with supply current frequency
  - Not self-starting

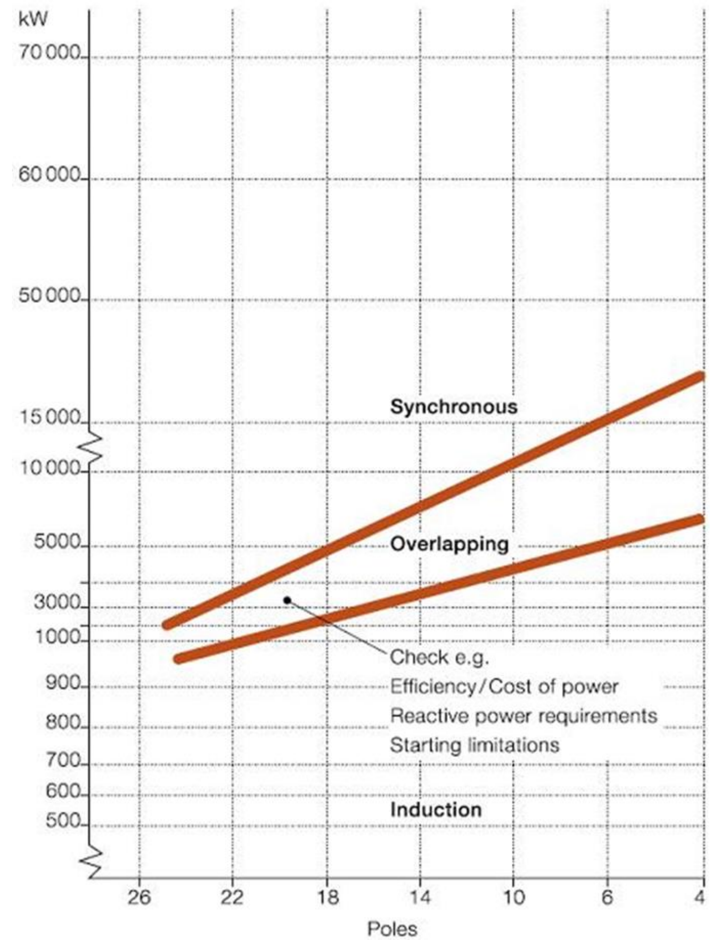
Induction motors

- Characteristics
  - High efficiency
  - High starting current
- Application area
  - Small to medium size motors



Synchronous motors

- Characteristics
  - Very high efficiency
  - Low starting current
- Application area
  - Power factor correction
  - Large size, slow speed motors



Coupling

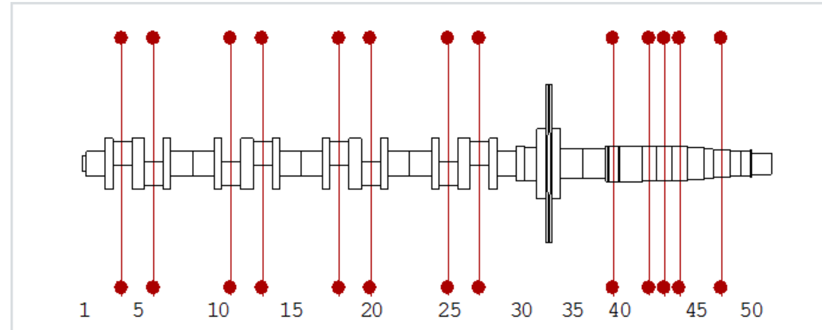
- Single bearing motor
  - Rigidly coupled
- Double bearing motor
  - Rigidly coupled
  - Highly elastic coupling

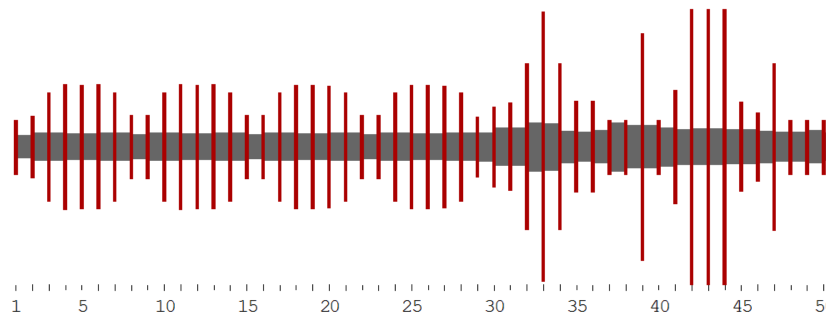
Image source: VULKAN Kupplungs- und Getriebebau Bernhard Hackforth GmbH & Co. KG

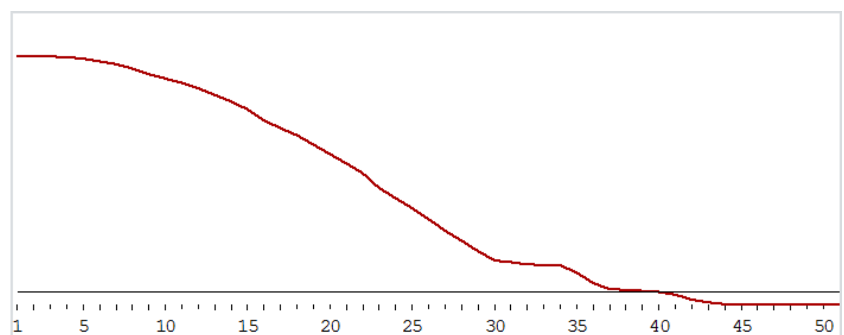
Torsional analysis

- Determine torsional natural frequencies

- Separation margins
  - Operating speed
    - 1 x : ±10%
    - Up to 10 x : ±5%
  - Power frequency
    - 1 x : ±10%
    - 2 x : ±5%

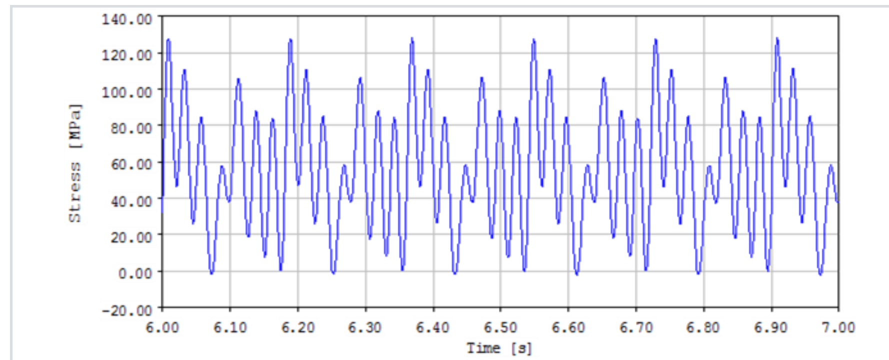


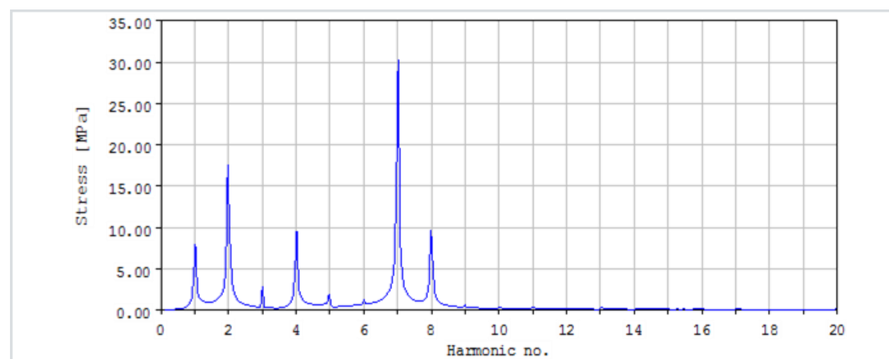




Torsional stress analysis

- Required when torsional natural frequencies are within the separation margins
- Simulation
  - Normal operating
  - Start
  - Stop
  - Short circuit





Conclusion

- API 618 heavy duty reciprocating compressors are rugged, flexible and highly efficient
- State of the art design & analysis tools are applied to optimize equipment safety and reliability