EFRC Training Workshop

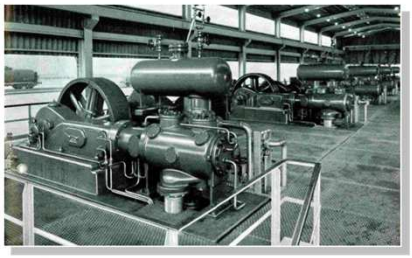
Design and operation of reciprocating compressors

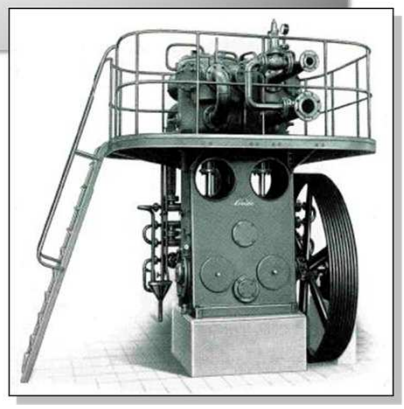
Installation, Operation and Maintenance Aspects

Harry Lankenau – NEAC

„A machine shall become older than the engineer who designed it“

Source unknown

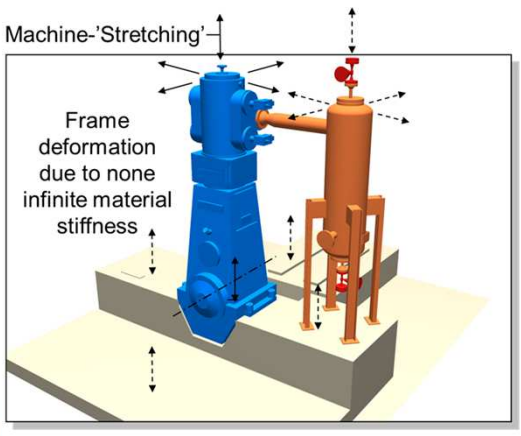




Compressor Unit Forces & Foundation Basics

Mechanical Compressor Unit Forces

Forces and moments generated directly from the machine causing the compressor unit to vibrate

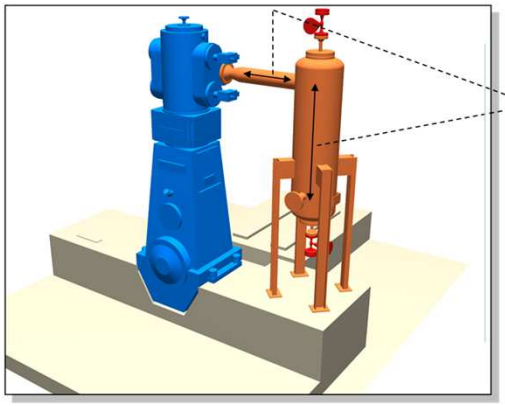


- The alternating gas pressure generates loads - such as elongation of the machine, the vessel and pipeline.
- Mass forces act directly on the foundation and consequently also on the accessories as well as on its environment.

Training Workshop October 24/25 2013

Gasdynamic Compressor Unit Forces

Impact of shaking forces due to pressure pulsations



- Shaking forces are generated through gas pulsations inside the pipeline and vessels.
- They become visible from the outside in terms of mechanical vibrations.

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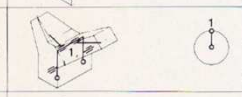
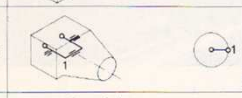
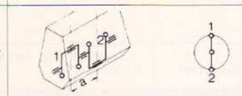
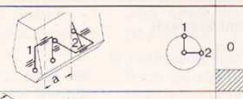
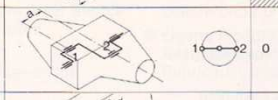
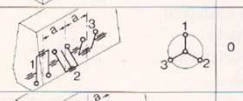
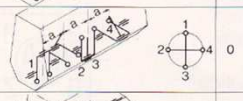
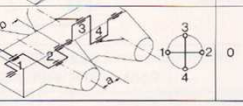
Variety of Piston Compressor Mass (Inertia) Forces and Moments

Kurbelzahl	Anordnung der Kurbelkröpfung	Result. Kräfte F_R	Result. Kräfte F_I	Result. Kräfte F_{II}	Result. Momente M_R	Result. Momente M_I	Result. Momente M_{II}
1			$m \cdot r \cdot \omega^2$	$m \cdot r \cdot \omega^2 \cdot \lambda$	0	0	0
1	Ausgleichgetriebe 				0	0	0
1				$m \cdot r \cdot \omega^2 \cdot \lambda \cdot \sqrt{2}$	0	0	0
1			$m \cdot r \cdot \omega^2$	$m \cdot r \cdot \omega^2 \cdot \lambda$	0	0	0
2		0	0	$m \cdot r \cdot \omega^2 \cdot \lambda \cdot 2$		$m \cdot r \cdot \omega^2 \cdot a$	0

Kurbelzahl	Anordnung der Kurbelkröpfung	Result. Kräfte F_R	Result. Kräfte F_I	Result. Kräfte F_{II}	Result. Momente M_R	Result. Momente M_I	Result. Momente M_{II}
2		0	$m \cdot r \cdot \omega^2 \cdot \sqrt{2}$	0		$m \cdot r \cdot 2 a \cdot \frac{\sqrt{2}}{2}$	$m \cdot r \cdot \omega^2 \cdot \lambda \cdot a$
2		0	0	0	0	$m \cdot r \cdot \omega^2 \cdot a$	$m \cdot r \cdot \omega^2 \cdot \lambda \cdot a$
3		0	0	0		$m \cdot r \cdot \omega^2 \cdot a \cdot \sqrt{3}$	$m \cdot r \cdot \omega^2 \cdot \lambda \cdot a \cdot \sqrt{3}$
4		0	0	0		$m \cdot r \cdot \omega^2 \cdot a \cdot 2 \cdot \sqrt{2}$	$m \cdot r \cdot \omega^2 \cdot \lambda \cdot a \cdot 2$
4		0	0	0	0	$m \cdot r \cdot \omega^2 \cdot \sqrt{2} \cdot (b-a)$	$m \cdot r \cdot \omega^2 \cdot \lambda \cdot \sqrt{2} \cdot (b+a)$

balanced through counter weights

m = Mass // r = Radius (0.5 x Stroke) // $\omega = 2\pi f$ // f = n/60 // n = Speed (1/min) // λ = r/L // L = Connecting Rod Length

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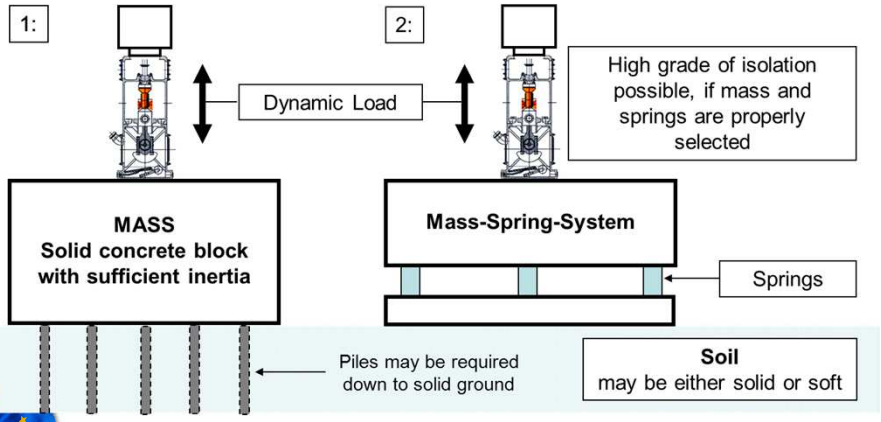
Note: Only **rotating mass forces** can be balanced through **counterweights** !

Foundation Type

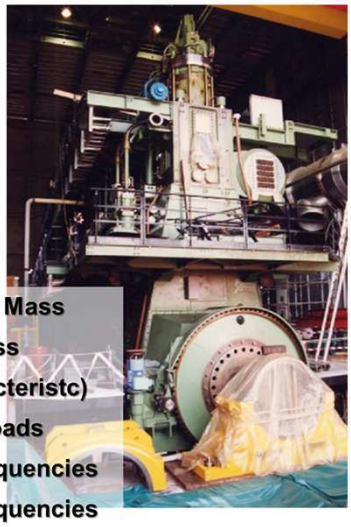
Depending on the compressor load and the soil characteristic:

1: Solid Block Foundation(1) – or 2.: Spring Actuated Foundation



Foundation Criteria

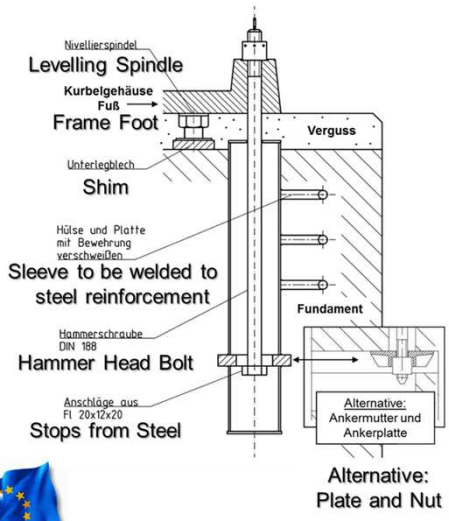
Due to the potentially massive loads from the compressor and pulsation induced unbalanced shaking forces a properly design foundation is required.



- **Foundation Mass**
- **Soil Stiffness (Soil Characteristc)**
- **Dynamic Loads**
- **Driving Frequencies**
- **Natural Frequencies**
- **Damping Capability**

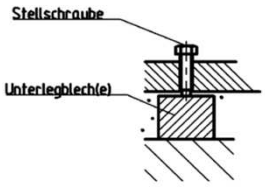
Foundation and Compressor Installation

Compressor Anchoring Options



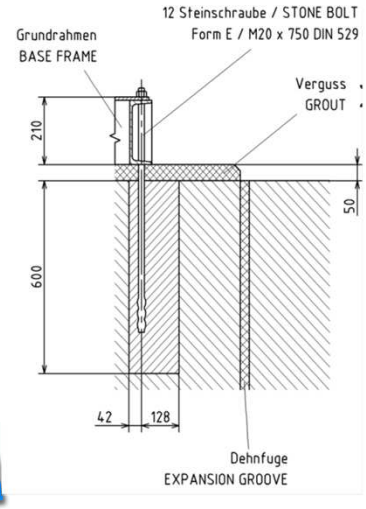
Alignment of crankcase through levelling spindles (jack screws - picture left)

Positioning and levelling before grouting also through jackscrews and shims or blocks (picture below)

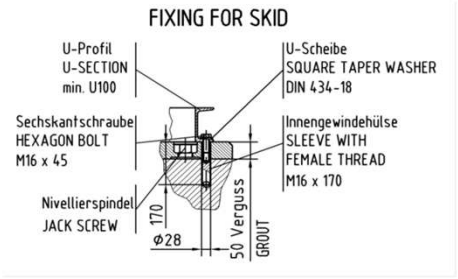


Above: Levelling only with Jackscrews (without Spindles)

Compressor Skid Mounting through Foundation Bolts



To avoid deflection of the skid from high mechanical loads it may be necessary to guide the foundation bolts through to the top of the skid beams and add reinforcement sleeves (picture left).



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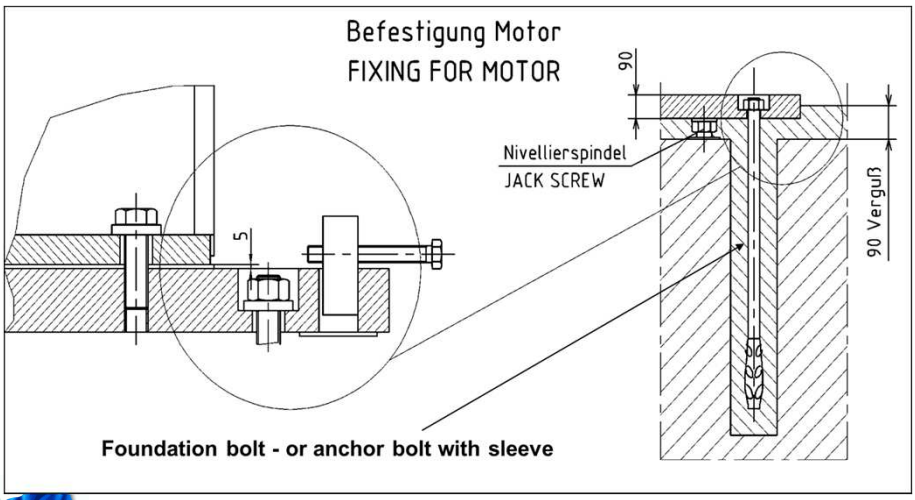
Fixation of Accessories (e. g. Motor)



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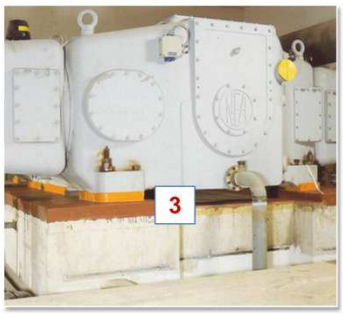
Compressor “Footwear”

When the compressor is dispatched from the workshop it is practically “barefooted“.

At site the “shoes“ are fitted to “run” well.



The “footwear“ of the compressor is that what links it to the foundation:

1. Skid or
2. Anchorage and
3. Grouting

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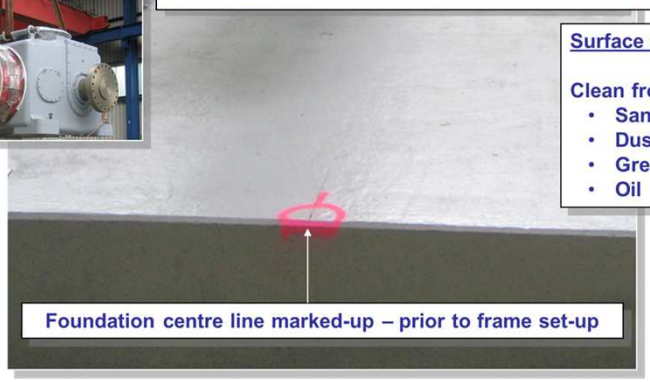
Foundation Check and Centre Lines

Perform a dimension check to verify correct foundation lay-out (!) - And its condition:

Surface Condition

Clean from:
- Sand
- Dust
- Grease
- Oil



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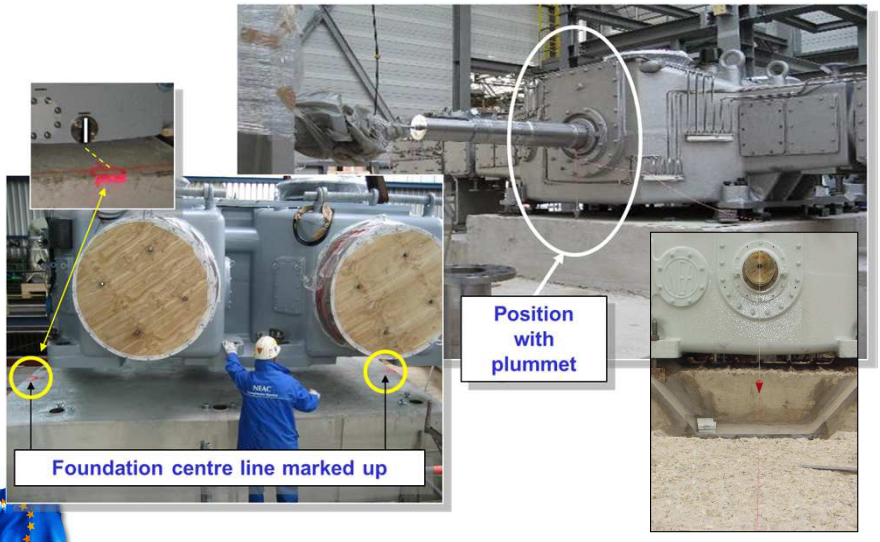
Foundation Check and Spindle Position

Make sure - prior to the compressor set-up - that anchor holes for anchor bolts are in correct position. The same applies for foundation bolts or similar to take up a skid with pre-fabricated holes and re-inforcements.

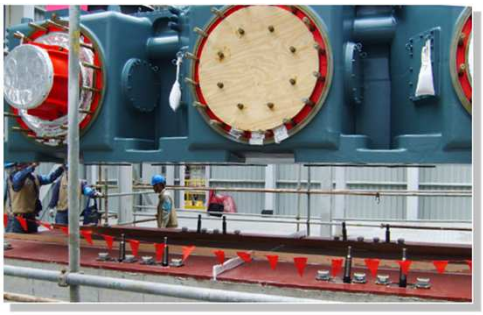
Put jacking spindles in place and check proper level.

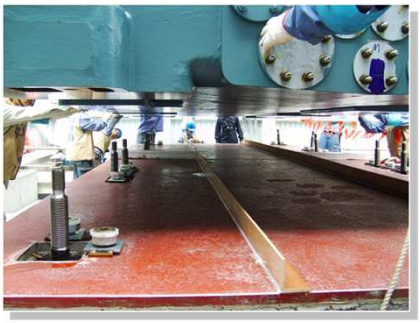
Foundation with pre-arrangement of levelling spindles prepared

Frame Positioning



Spindle Leveling





Prior to frame set-up the planarity of the various spindles shall be checked through optical or laser levelling equipment ! – Point to point water level gauge check may not be accurate enough.

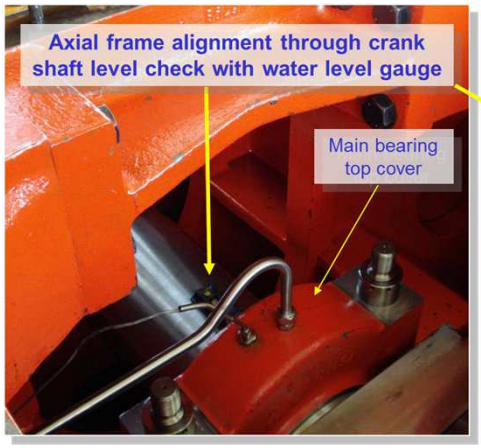
Position and Leveling through Water Level Gauge

Axial alignment on frame top surface

Level check in horizontal orientation - perpendicular to crank shaft axis

Note: Frame top is not a true face referring to crank shaft and main bearing bore (but often good enough to utilize …)

Check of crank shaft and main bearing journal level with water level gauge



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Check of crank pin level with water level gauge

Crank pin put in various positions for level check

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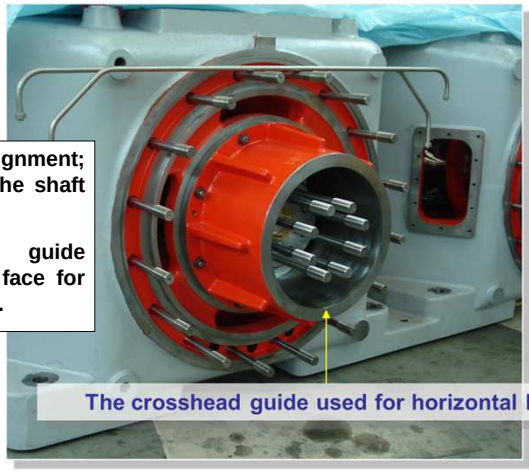
Frame alignment with water level gauge:

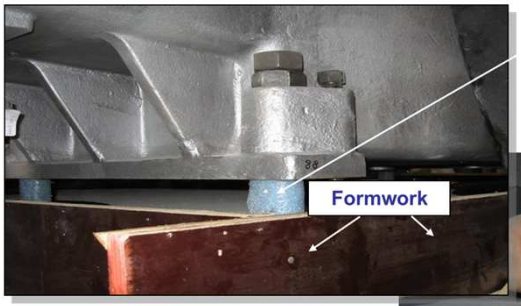
Horizontal alignment; perpendicular to the shaft axis:

The crosshead guide surface is a true face for levelling purposes.



The crosshead guide used for horizontal levelling

Grouting Preparations



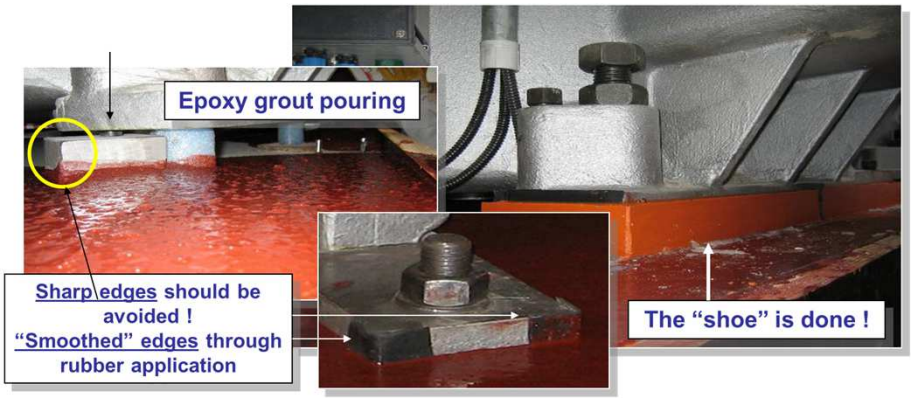
Wrapping of the anchor bolt with plastic foam, rubber or tape (*)

Anchor sleeve to be filled with :

- Glass Sand
- Polyurethane Foam

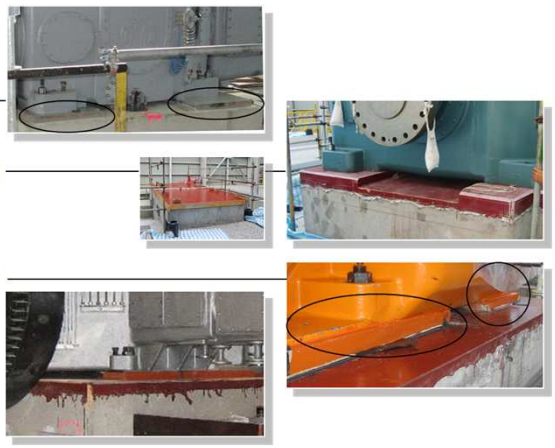
(*) In comparison with plastic foam or rubber the tape has the advantage of being much thinner, which enables easy fitting through the frame foot.

Grouting Preparations



Footing / Grouting Type

- Rail type
- Full size epoxy layer with additional rail type
- Full size epoxy layer with individual frame feet layer
- Two different epoxy grades



Frame Support

Remove jack screws and/or spindles or not:

- **“Pro and Con” - Discussion**

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Epoxy Grout Issues

In case of incorrect application:

Possible causes:

- **Too high temperature**
- **Wrong mixing**
- **Poor link to basement**

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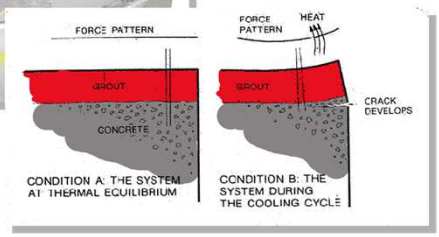
Epoxy Grout Issues

Cracks in epoxy grout and concrete below motor due to high temperature differential



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Liquid Removal - Separators

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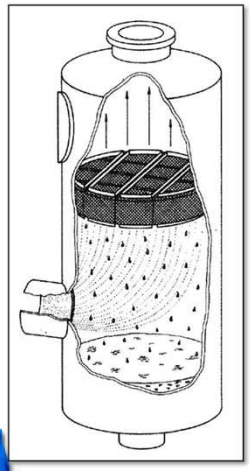
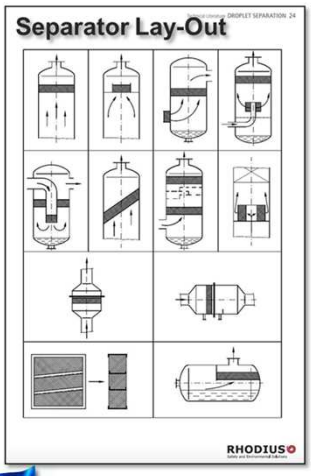
Separator Tasks



- Water Condensate Knock-Out
- Gas Condensate Separation
- Oil Mist Removal
- Special Applications
  - Gas Dryer (Humidity Removal)
  - Gas Washer + Separator

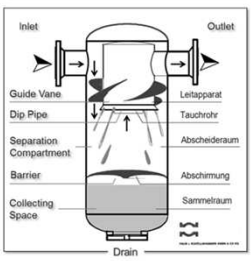
Separator Types



Typical Demister Type

Technical Terms:

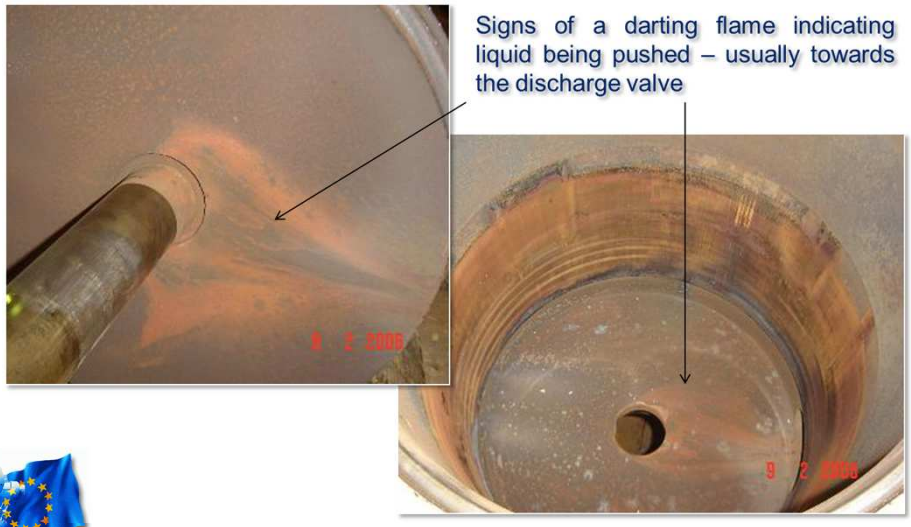
- Separator
- Knock-out Drum
- Scrubber
- Mist Eliminator



Cyclone Separator

Examples of Water Slugging, Liquid carry-over and consequential Damage

Indications of Water Slugging



Severe Damage from Liquid carry-over

Piston rod to crosshead connection pulled apart from water that had been trapped inside the cylinder – with consequential damage from continued rod back and forth movement.

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Severe Damage from Liquid carry-over

Piston dis-integrated from water which had been forwarded into the cylinder – due to poor condensate removal

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Compressor Units with Separators

➢ Drain Valves – important !

Drain valves and condensate traps at the far end of small tubing may be subject to elevated vibration - and damage - unless properly supported !

Potential “Secondary” Condensation

- Between separator outlet and next stage cylinder inlet – e. g. through cold wind or low ambient temperature
- Inside cylinder, through cooling water temperature being lower than the gas inlet temperature

CO_2 Compressor Unit

Is Separator Sizing correct ?
(Done by Accessories Supplier)

Frequent 2nd Stage Suction Valve Corrosion and Failure

CO_2 Compressor Unit

Suction Valve 1st Stage: Dry – no water or corrosion visible

CO_2 Compressor Unit

Suction Valve 2nd Stage: Water trapped in valve pocket. Valve cage is wet

Indication of poor water separation and/or insufficient condensate drain

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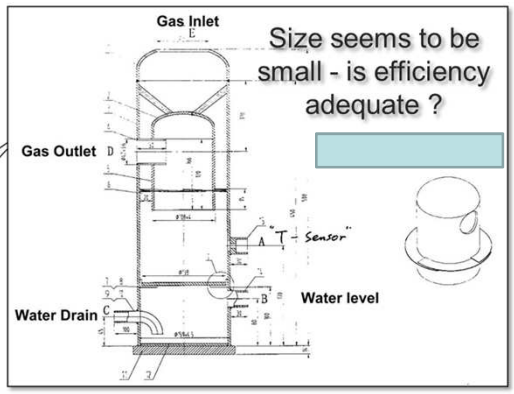
CO_2 Compressor Unit – Cyclone Separator



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CO_2 Compressor Unit – Process Conditions

	1. Stufe	2. Stufe	Zylinder
/Gaseingang bar	/	4	/
/Gasausgang bar	4	18	/
Gaseingang T, °C	???	40	/
Gasausgang T, °C	145	139	/
Kuhlwassr eingang °C	20	20	20
Kuehlwasser Ausgang °C	/	27	24
Ole, bar	3.2		/
Oel, °C	40		/
Kondensat, kg/h	4 kg/h		

Condensate Calculation:	
Suction Temperature	Water Condensate
20°C	2.4 kg/h
24°C	**4.0 kg/h**
30°C	7.2 kg/h
Which temperature is correct ?	

The table on the right depicts the importance of the true suction temperature - which is not shown in the process data list on the left – for the amount of water being created between the stages

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Typical Separator Failures

- Drain valve not working
  - E. g. damaged internals through elevated vibration
  - Outlet blocked from debris
- Secondary condensation
  - Cylinder cooling water temperature < gas inlet temperature
- Oil recycling through spill back
  - None sufficient or no oil separation after last stage
- Separator internals not properly working, because
  - cracked (e. g. baffles or cyclone internals) and/or
  - corroded (e. g. demister pads)
- Consequential compressor damage
  - Frequent valve failure
  - Water slugging and mechanical damage along the throw

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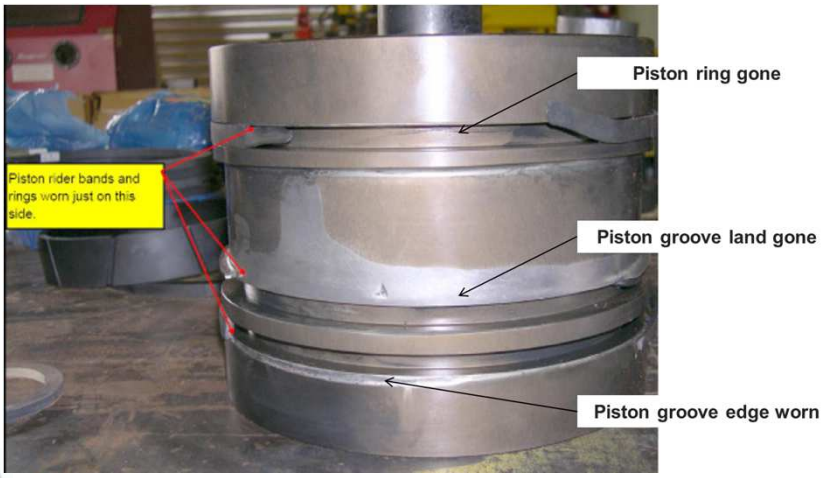
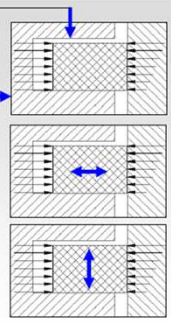
“Wear and Tear” in Operations

Rapid Rider/Piston Ring Wear and Piston Groove Wear



Rapid Rider/Piston Ring Wear and Piston Groove Wear

- Cylinder liner roughness too high; thus causing abnormally high ring rubbing
- Piston surface hardness ⇔ coating quality
- Piston body quality (e. g. sand cast or forged aluminium)
- Fluctuating radial pressure across piston ring ⇔ radial impact load
- Fluctuating axial pressure across piston ring ⇔ add. axial dynamic load

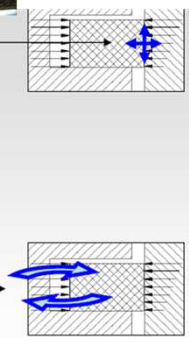


- Poor lubrication (since lube oil supply interruption or complete stop)
- Wrong ring dimensions

Rapid Rider/Piston Ring Wear and Piston Groove Wear

- Debris brought into the cylinder from the process

- 'Slip-Stick-Effect' (sticktion) based on:
  - Liner surface roughness
  - Friction characteristics between liner and ring surface
  - Piston ring mass
  - Piston ring material quality
  - Cylinder lube oil condition / contamination through product formation and/or liquids from the process gas
- Ring rotation in groove through dynamic effects



- Not suitable material selection (e. g. confusion lube/none lube cylinder)
- Local overheating of the ring(s)

Rapid Rider/Piston Ring Wear and Piston Groove Wear

Investigation of worn rings concerning signs of …

- Local overheating
- Abrasive material imbedded in ring surface →
- Squeezing from lack of space in piston groove
- Chemical impact ("Corrosion")
- Piston groove quality (Coating; hardness) →
- Too dry surface (in case of lubricated service)

Rapid Rider/Piston Ring Wear and Piston Groove Wear

Investigation of cylinder lubrication system (in case of lubricated service) …

Cylinder lube oil system

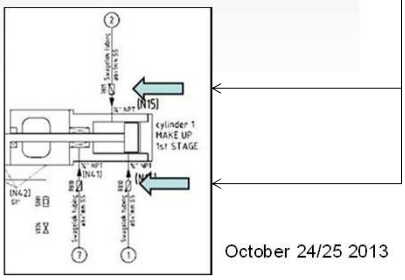
- None evenly oil distribution - e. g. depending on temperature or debris in the tubing
- Check valves not working ⇔ gas working its way back into system causing distortion
- None sufficient individual oil supply at certain lube points
- Low pump flow capacity – e. g. due to leaking plunger

Poor lubrication - potentially intermittent lubrication with not identified interruption phases

Oil quality or viscosity not fit for particular purpose

True flow vs. specification may differ

Make sure the oil none return valves at the cylinder injection inlet points are (a) installed and (b) properly working !

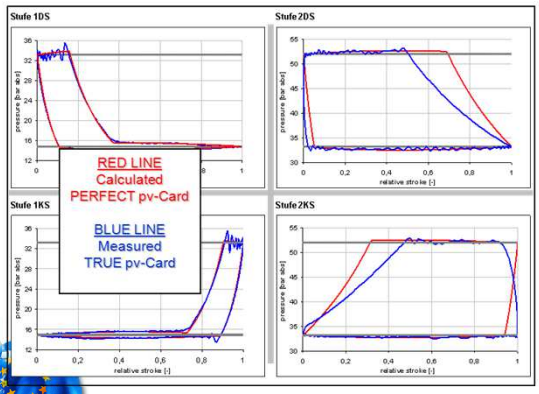


Field Experience

Compressor:

Two throw vertical 2-stage H_2-compressor; lubricated double acting cylinders. Capacity control through continuous reverse flow suction valve lifting in both stages.

Mobile diagnosis equipment and thermodynamic simulation was applied here.



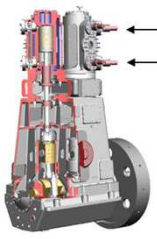
The measured 1st stage pv-card was well matching the perfect diagram.

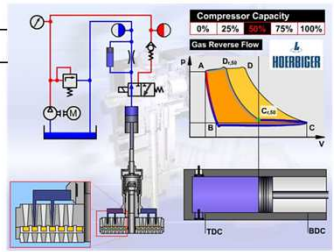
The 2nd stage, however, was showing a tremendous off-set.

The Benefit:

Condition Monitoring made it obvious that the 2nd stage was in a critical condition.

Field Experience





The History:

Most time the machine had been operated at reduced load by utilizing the continuous reverse flow suction valve lifting devices.

Handicap No. 1:

The automatic capacity control compensated the losses of the 2nd stage. Therefore the bad condition had not been recognized.

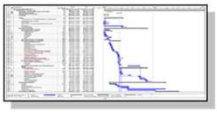
Handicap No. 2:

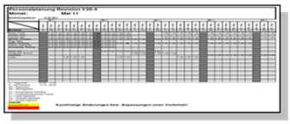
Measurement was performed too late. During the measurement the piston touched the cylinder liner. Piston and rider rings had almost completely disappeared.

Maintenance

Maintenance Activity Organisation

- Job Schedule
- Human Resources Plan
- Cost Assessment and Controlling
- Documentation
- Site Coordination
- Internal and External Project Follow-up
- Reporting
  - Work progress - with applied torque values for fasteners
  - Measurements (dimensions; clearances; surface roughness etc.)
  - Findings – and remedies (if any)
  - Parts replaced through spares – to fill up stock
  - Management of Change (MoC) in case of alterations





Complete revision?
- Or only the gas side?
- Or only the driving gear?

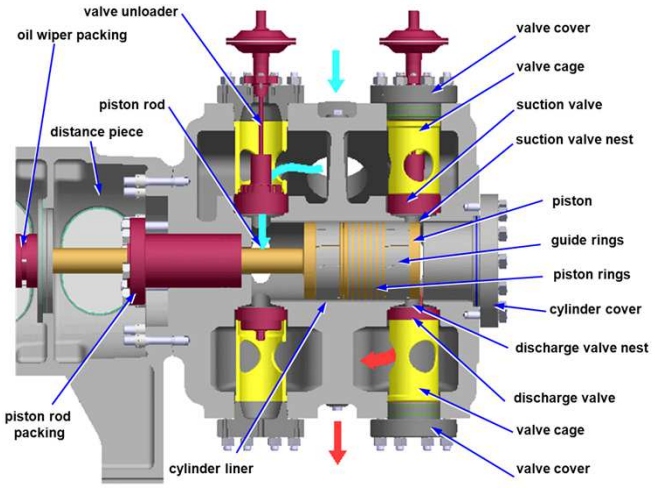
Must crankshaft be removed for check and refurbishment?

Be aware that scope may have to be extended based on findings ⇔ Items update !

Gas Side (Cylinder; Valves Gas Packings)

Make sure all required spare parts are in stock.

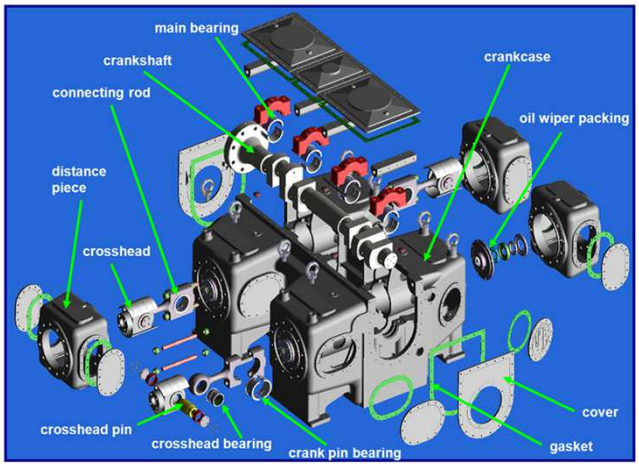
And be prepared that more parts may be needed than expected and scheduled !



Driving Gear

Make sure that techn. documentation is available; particularly:

1. Clearances, gaps and tolerances (e. g. for bearings)
2. Torque values for all major fasteners



Typical Work Scope

Total scope and time depends on number of throws/stages and mass (weight) of equipment – if e. g. a crane is needed for the lifting and movement of the parts.

Visual unit inspection of the compressor and accessories
Dis- and reassembling suction-, discharge- and non return valves
Inspection and Replacement of valves; depending on requirements
Dis- and reassembling cylinder head, crankcase covers
Dis- and reassembling piston/piston rod
Inspection cylinder and cylinder liner; surface roughness measurement
Visual Inspection and measuring piston and piston rod; rod roughness measurement
Visual Inspection and measuring piston- and guide rings – Replacement if required
Dis- and reassembling piston rod packing, intermediate packing and oil wiper packing
Inspection/Replacement of packing internals where necessary
Visual crankcase inspection
Clean oil filter and oil suction filter in crankcase
Change oil (if necessary; new oil supplied by the customer)
Mechanical test run (without suction or discharge valves)
Check gas and oil system tightness
Test run under normal running conditions of the compressor
Handover compressor to the client

Additional activities as per findings and actual requirements after approval from customer

Valve Service

Two Options:

1.: Remove valves; disassemble; check and replace internals.

- Risk of wrong reassembly
- Time consuming
- Maybe no spare available if valve housing is bad (sealing faces damaged)

2.: Remove valves; replace by complete set of spares (or new) and have used ones refurbished by OEM

- Quick
- Safe & presumably cheaper

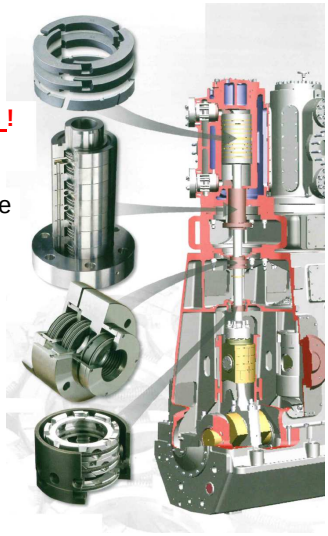
Note: In case of frequent and/or abnormal wear/damage:
Contact OEM for remedy options !

Piston & Guide Rings; Packings and Oil Wipers

Before the compressor is opened:

Make sure you have all spares available –

including relevant O-rings; gaskets and washers !



- Piston & Guide Rings – also check the ring groove condition.
- All packings: Replace by complete sets. Not only the internals are the sealing components but also the cup contact surfaces (which may be worn).
- If only internals are replaced:

  Be sure to have the relevant drawings available to ensure proper reassembly !

EFRC

Careful treatment, thorough observation
and regular or in-time maintenance
of the machine and its accessories
are the best preconditions
for cost efficient
and trouble free
operation

Why does everyday practice often try to tell us differently … ?

EFRC

Thank you for your attention