Carbon Ring Seal Failure in a High Pressure CO_2 Compressor

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AIR PRODUCTS

Presenters

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Abstract

During commissioning of a new 8-stage CO_2 pipeline compressor, higher than expected seal vent flows were detected from the carbon ring seals in the high pressure (HP) stages. The problem was severe enough that the machine could not meet design performance. This case study will cover the basic design of carbon ring seals, the history of the problem, the root cause analysis, conclusions and corrective action.

Outline

1. Background – Machine & Seals
2. The Problem
3. Investigation
4. Root Cause & Solutions

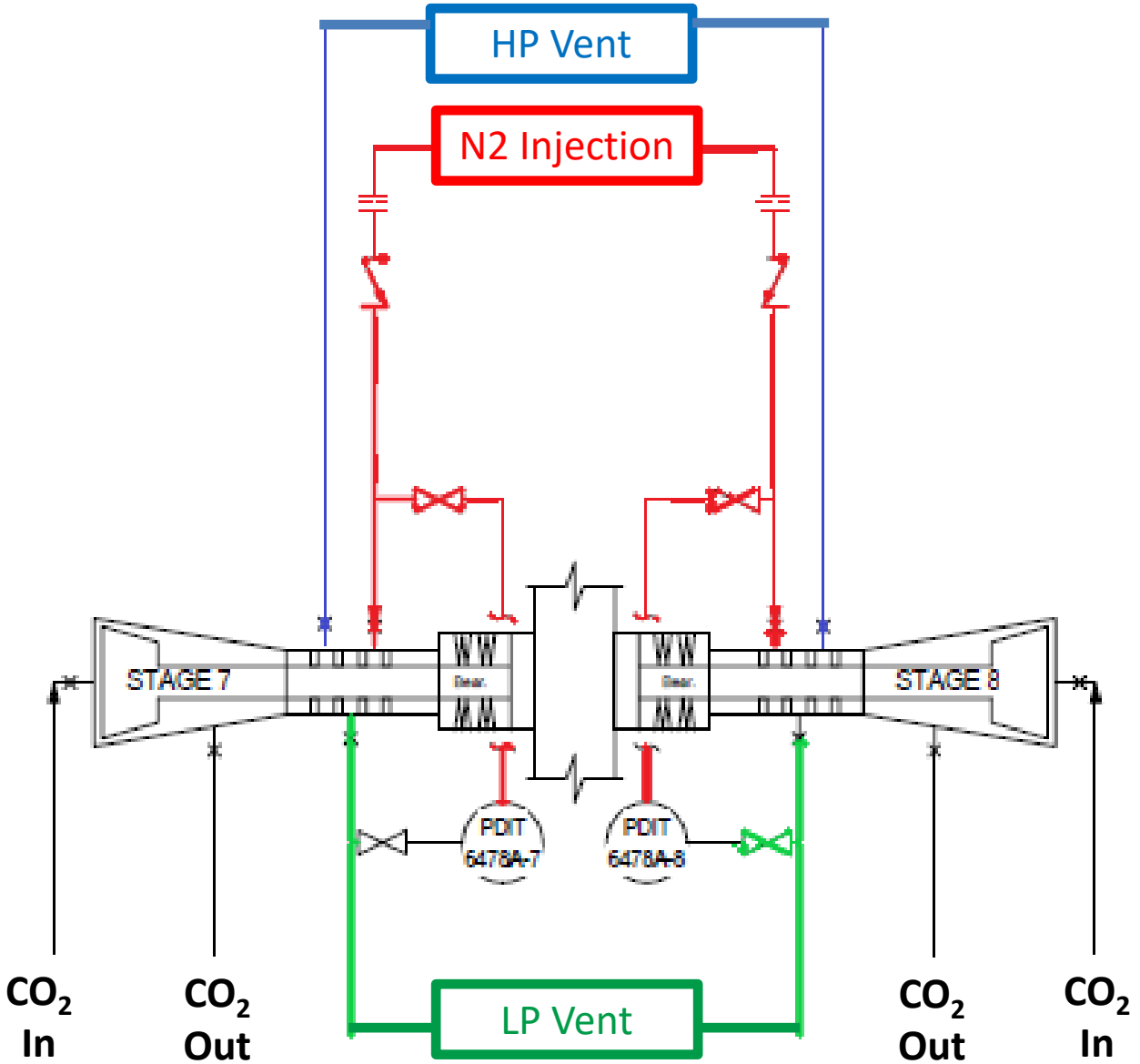
Background – The Compressor

- New CO_2 Capture Plants commissioned in December 2012

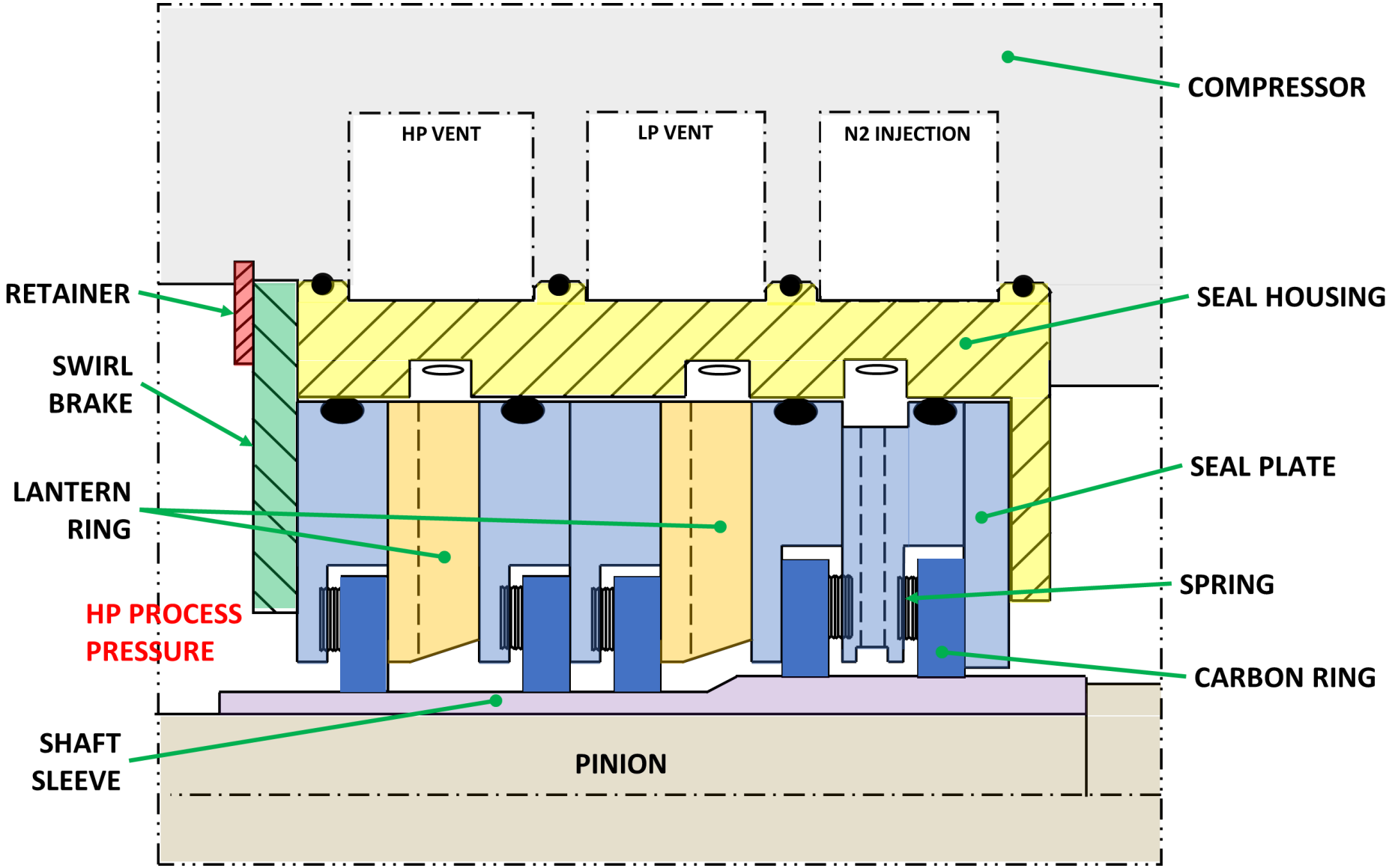
- Plants utilize a single CO_2 Pipeline Compressor to export product
  - 8-stage, 4-pinion, integrally geared centrifugal compressor
  - 1.0 psig suction pressure and 2260 psig final discharge pressure
  - 95% - 97% Carbon Dioxide. Wet in stages 1-5; Dry in stages 6-8.
  - Driven by 13 MW (17,500 HP) / 1800 rpm electric motor
  - Pinion Speeds:
    - Stages 1&2 8,842 rpm
    - Stages 3&4 15,480 rpm
    - Stages 5&6 23,815 rpm
    - Stages 7&8 18,764 rpm

Background – The Seals

LP: Low pressure
HP: High pressure

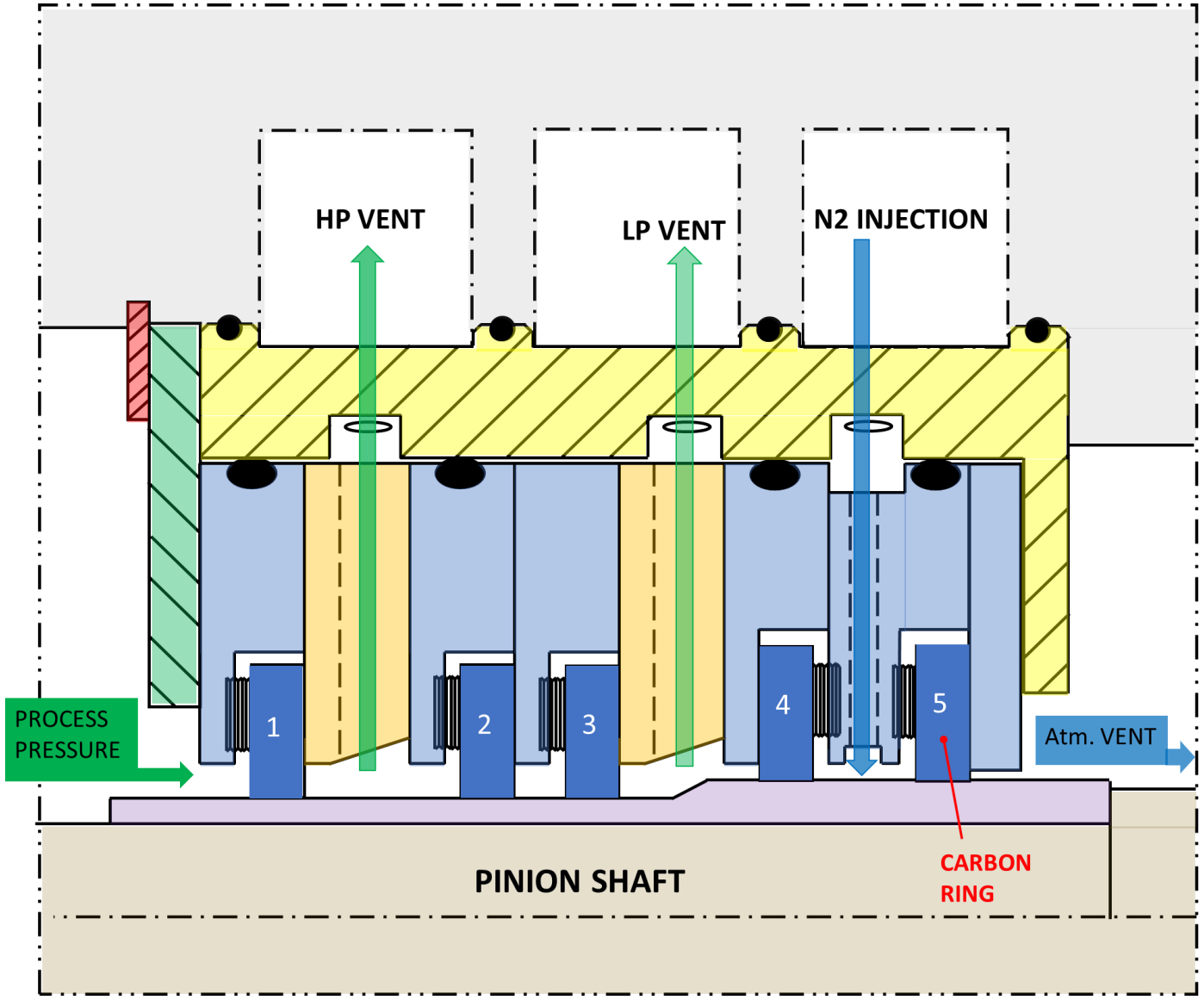


Background - Seal Configuration



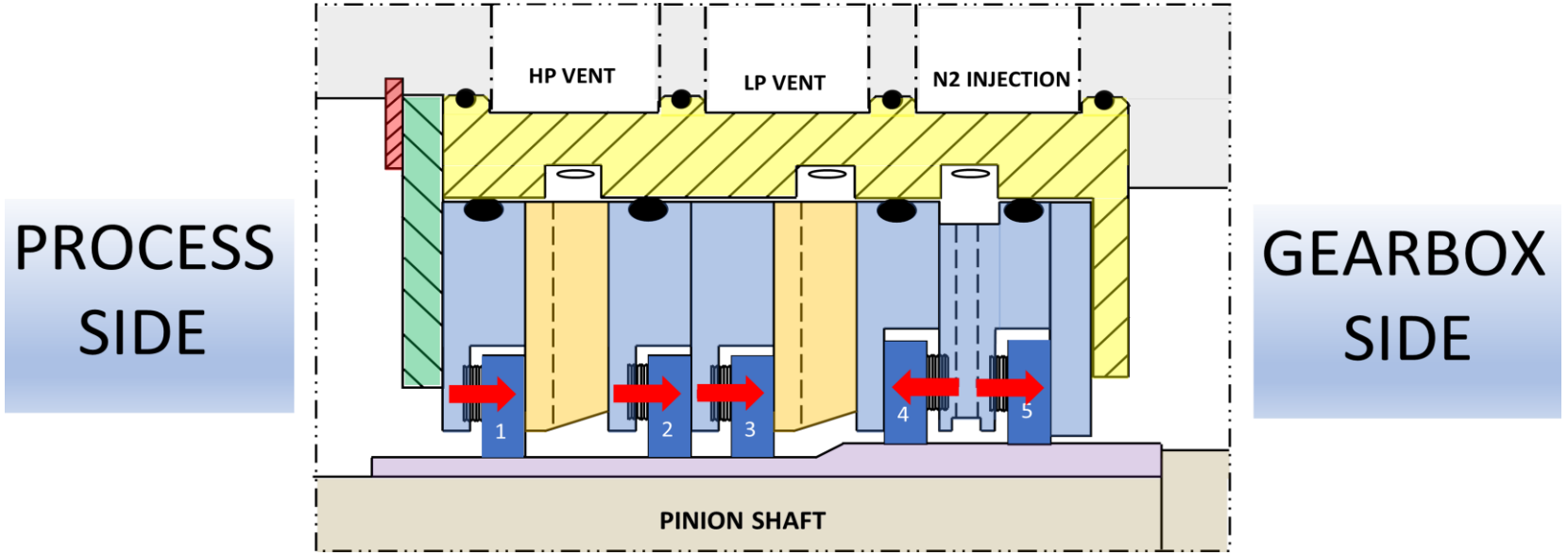
Background – Design Operation

LP: Low pressure
HP: High pressure



Background – Carbon Ring Seals

- Carbon ring seals, a dynamic mechanical seal type, restricts leakage from the rotating shaft (pinion) as it passes through the stationary housing (scroll) and prevent process gas from escaping to atmosphere and/or into the bearing / gearbox.



- Carbon rings are a one-piece design and axially loaded by pressure. Additionally there are axial springs which apply force in the same direction as the normal operating pressure force. This is to ensure that the rings stay in place during low pressure operation, stand still, and start-up.

Background – The Seals

LP: Low pressure
HP: High pressure

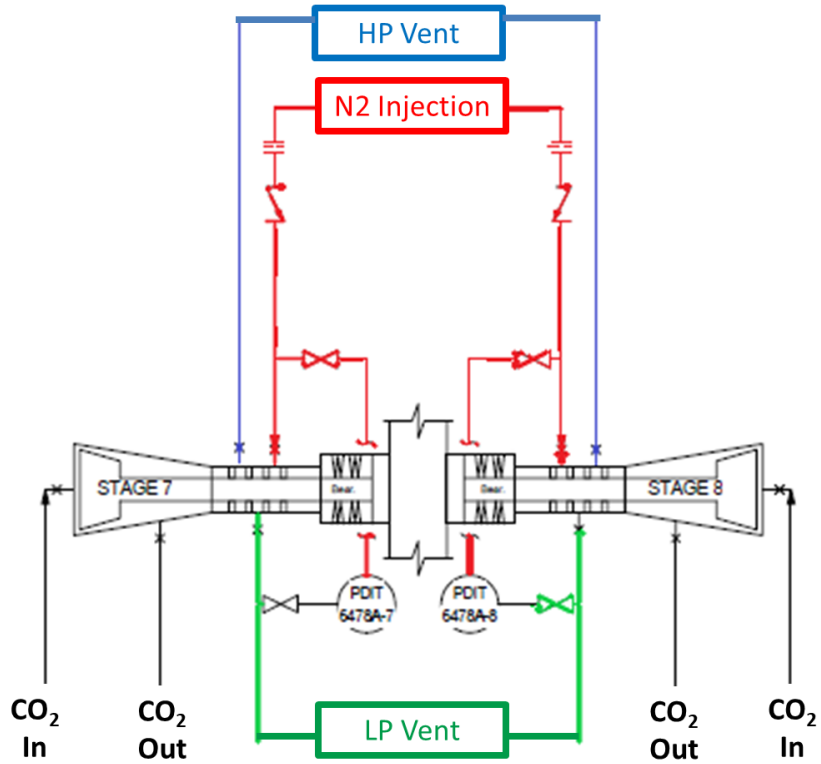
- Nitrogen buffered, carbon ring seals on all pinions. Same design on each stage but with different number of rings based on the operating differential pressure.
  - Stage 1 has 3 rings, Stage 2 has 4 rings, and Stages 3 to 8 have 5 rings.
- All seals have an atmospheric vent on the gearbox side of the seal gland, then a N_2 injection port, then a (LP) vent to the 1st stage suction. Seals on stages 6, 7, and 8 have a HP vent to the 6^{th} stage suction after LP vent (closest to stage).
- One piece rings are side-loaded with coil springs to maintain zero leakage across the face of the seal and to keep the ring loaded in the active direction.
- Design diametral clearance is 0.030 mm (0.0012 in.) cold and ~0.040 mm (0.0016 in.) at operating conditions. Axial clearance is 1.35 mm (0.053 in).

The Problem

- During commissioning (first test runs), HP vent flow meters went off scale on the stages 6, 7 and 8 shaft seals. A design error was identified with the flow meter specification which resulted in an inadequate range. However, after retrofitting with higher range flow meters, the flow meters still read off scale.

- A manual valve added to the HP vent header to allow for throttling and increasing back pressure on the vent ports.

- Four new plants feed into this compressor and each was new so that there was a long list of open issues. A decision was made to continue operating while open issues were worked through.



Problem

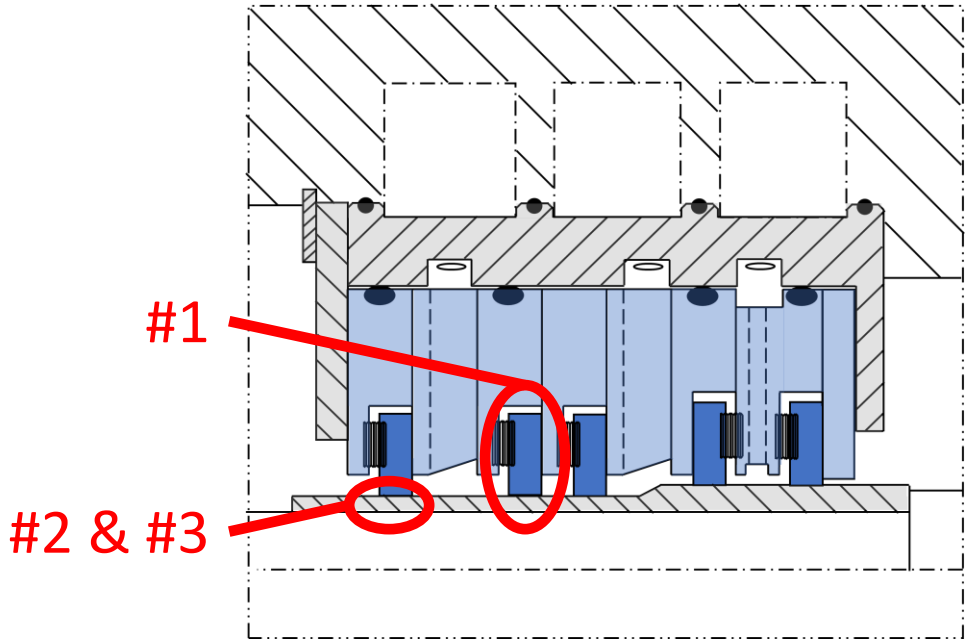
- **Commissioning Test #1**:

Stage	6	7	8
Suction pressure, psig	**618**	**1108**	**1504**
Discharge pressure, psig	**1108**	**1505**	**2017**
N2 injection flow, lb/hr	35	42	9.9
LP vent port pressure, psig	8.2	16.0	8.4
HP vent port pressure, psig	755	816	821
HP vent flow, lb/hr	1234+	1234+	1940+

- NOTE: HP vent flows above are all off-scale on the flowmeters. Design estimate was for 372 lb/hr total for all three stages combined.

Investigation

- **Potential Root Causes Considered:**
  1. Excessive carbon ring clearances (parts out of tolerance)
  2. Carbon ring damage from assembly / commissioning (broken rings)
  3. Excessive carbon ring clearances from wear to ring and/or sleeve

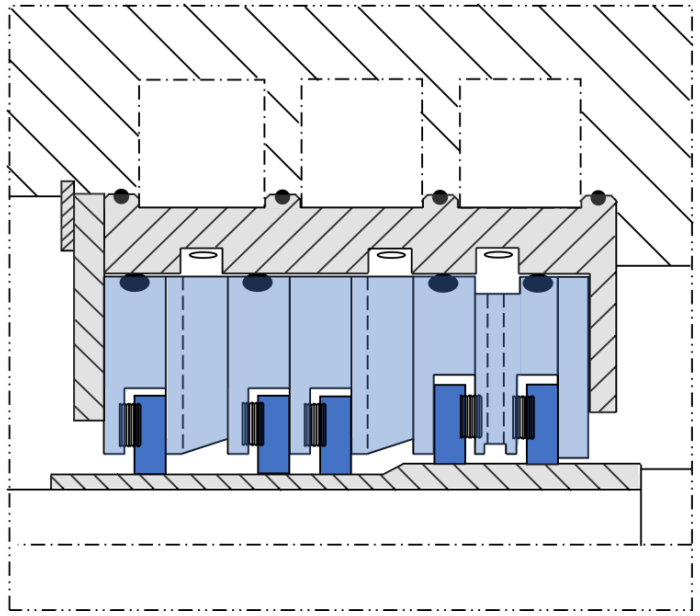


Investigation

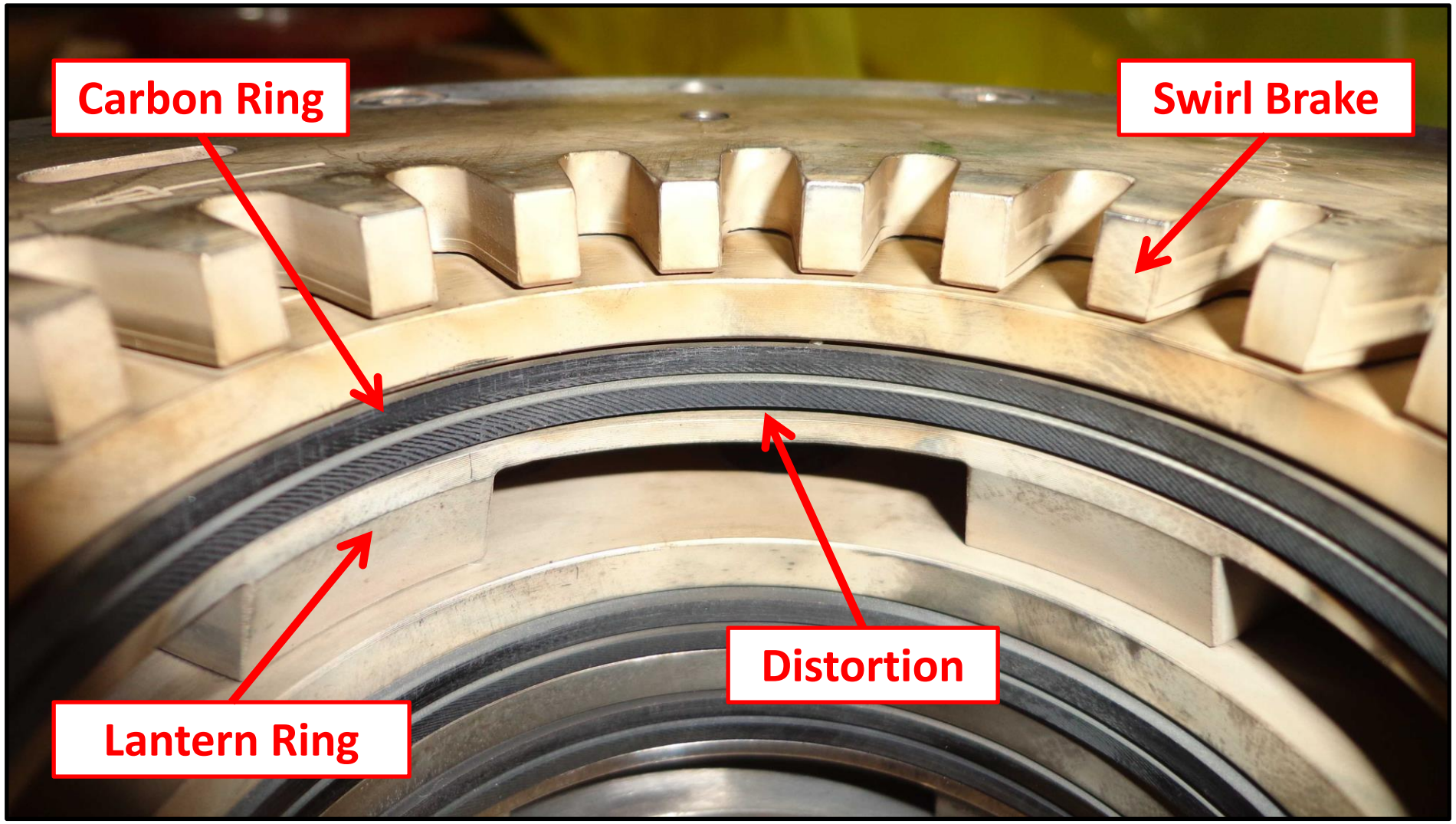
- The compressor continued to operate with the high vent flows while the cause was investigated. Plants were online at this time so the machine could not be shutdown for internal inspections without causing curtailments.

- After a few months in service, the machine tripped on high vibration. While repairing the cause of the vibration, the stage 7 and 8 seal cartridges were changed out with spares.

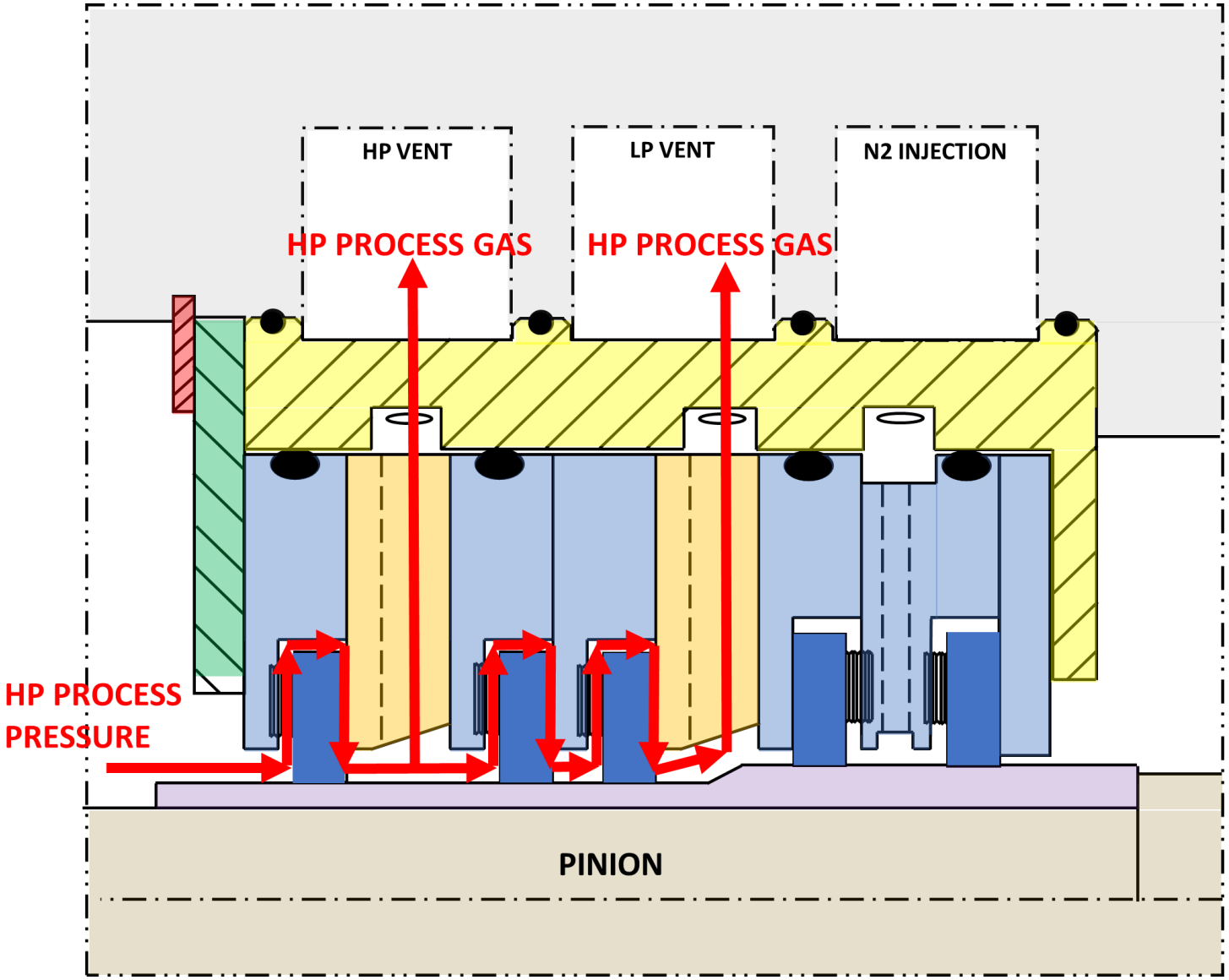
- After the outage, the stage 7 and 8 seals were inspected with the OEM and substantial deformation of the seal support plates (lantern rings) was discovered.



Investigation



Investigation



The Solution

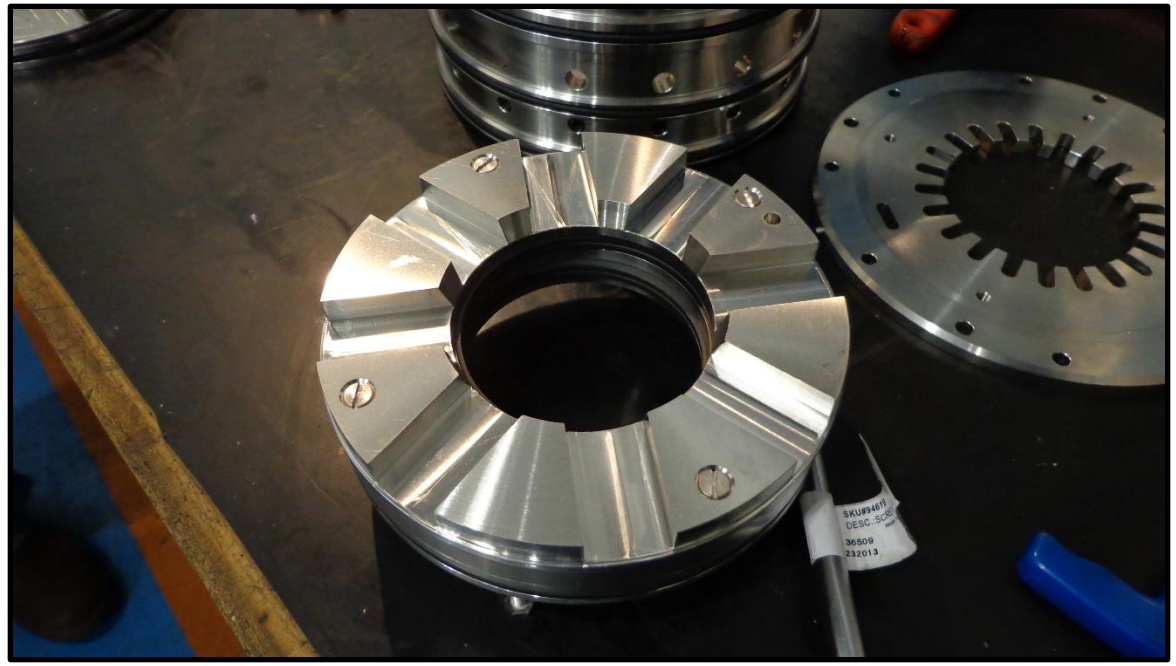
- **<u>Root Cause</u>:** The axial force from differential pressure across the seal rings transmitted to the lantern rings and their thin sections were permanently deformed. This allowed substantial high pressure gas to leak past the carbon ring seal faces.
  - ~8,000 lbf axial force from pressure differential on 7th stage.
  - Lantern rings deformed ~0.040 inch (1 mm) at midspan between supports. Plate thickness in this area is ~0.110 inch (2.8 mm).

- **<u>Solution</u>:** Strengthen the thin areas of the lantern rings by increasing the number of support ribs.

The Solution

- **Lantern Rings:**

Original Design



Modified Design

Conclusion

- Modified lantern rings in the spare seal cartridges and took an outage in the 2nd year of plant operation to install upgraded seals.
  - Prior to the outage, HP section capacity was 11% short of design.
  - After the outage, HP section capacity was 3% short of design capacity.
  - Upgraded seals resulted in a 77% reduction in capacity shortfall.
  - Total HP vent flow is 1784 lb/hr (4.8x design flow of 372 lb/hr)

- **Currently have ~48,000 operating hours on the upgraded seals** (Spring 2020). No additional problems or degradation. HP vent flow is above original design but has been steady since seal upgrade.

Lessons Learned

- Request Experience References during Design Review
  - Exact components and operating conditions – not just “close to”.
  - Is this a step-out for the OEM or operating company?

- Consider all Components in RCA
  - All possibilities, not just previous failure experience

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Questions?

Thanks!