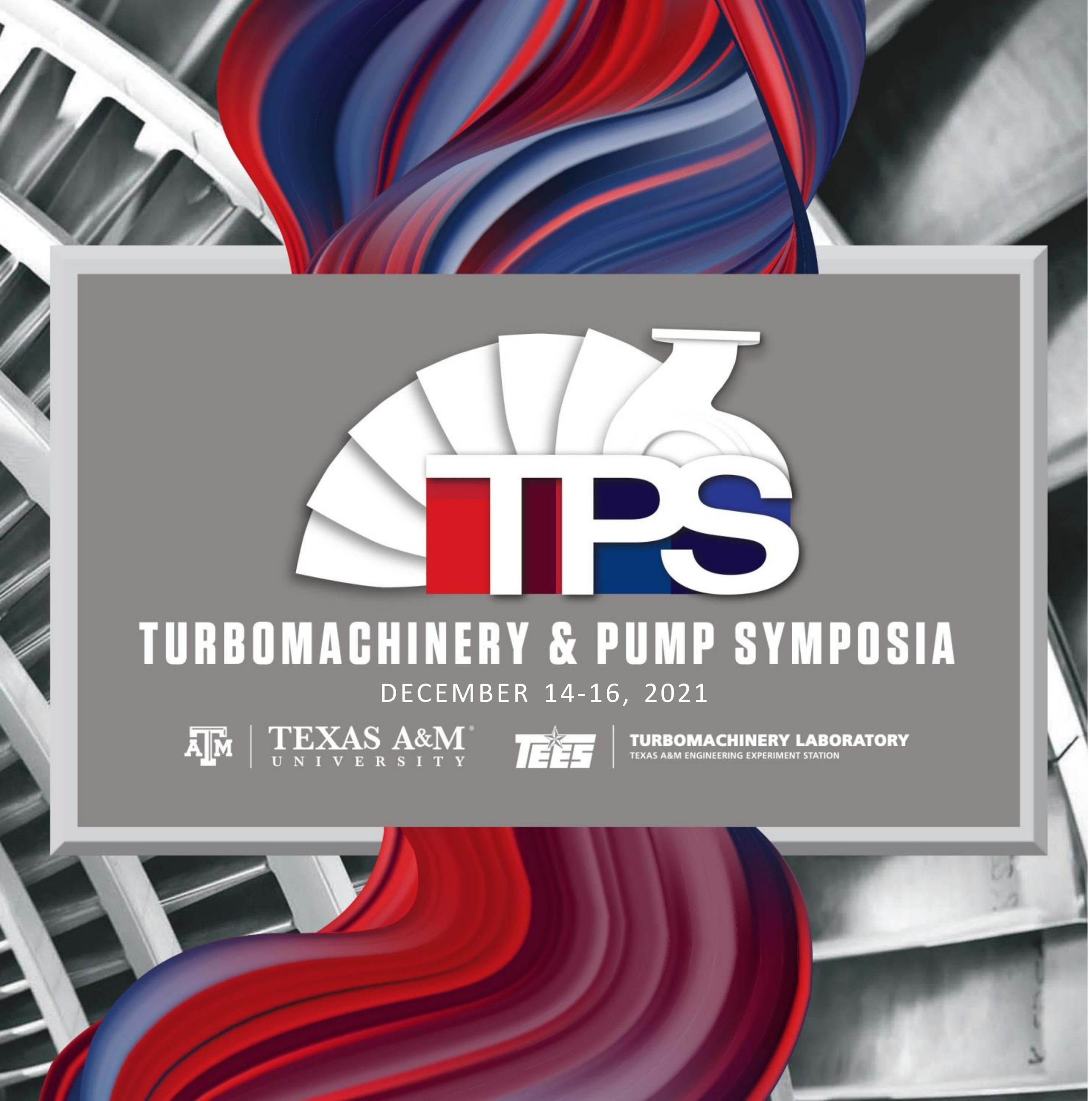


# Vibration Spike During Start-up of an Integrally Geared Compressor

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AIR PRODUCTS

# Presenters

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# Abstract

During workshop testing of a new 3-stage main air compressor, higher than expected vibration levels were detected at stage 1 and 2 at start up. They are high enough that the machine could not be brought to the full speed. This case study will cover the basic design of the compressor, the history of the problem, the root cause analysis, conclusions and corrective action.

# Outline

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

# Background – The Compressor

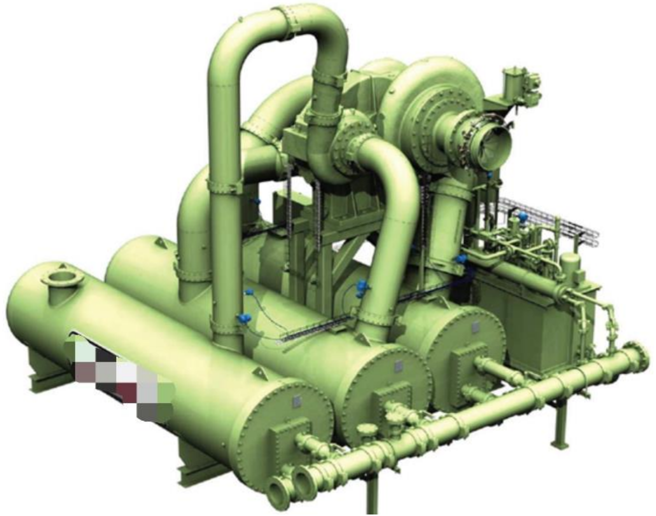
New Main Air Compressor for a middle size Air Separation Unit (ASU).

Main Air Compressor brings air flow into the system for feeding the downstream process.

* 3-stage, 2-pinion, integrally geared centrifugal compressor
* Atmospheric air suction pressure and 6 bara (87 psia) at final discharge
* Driven by 5500 HP, 1800 rpm induction motor, no VFD

Pinion Speeds:

| | |
|---|---|
| * Stage 1&2 | 14,135 rpm |
| * Stage 3 | 20,062 rpm |



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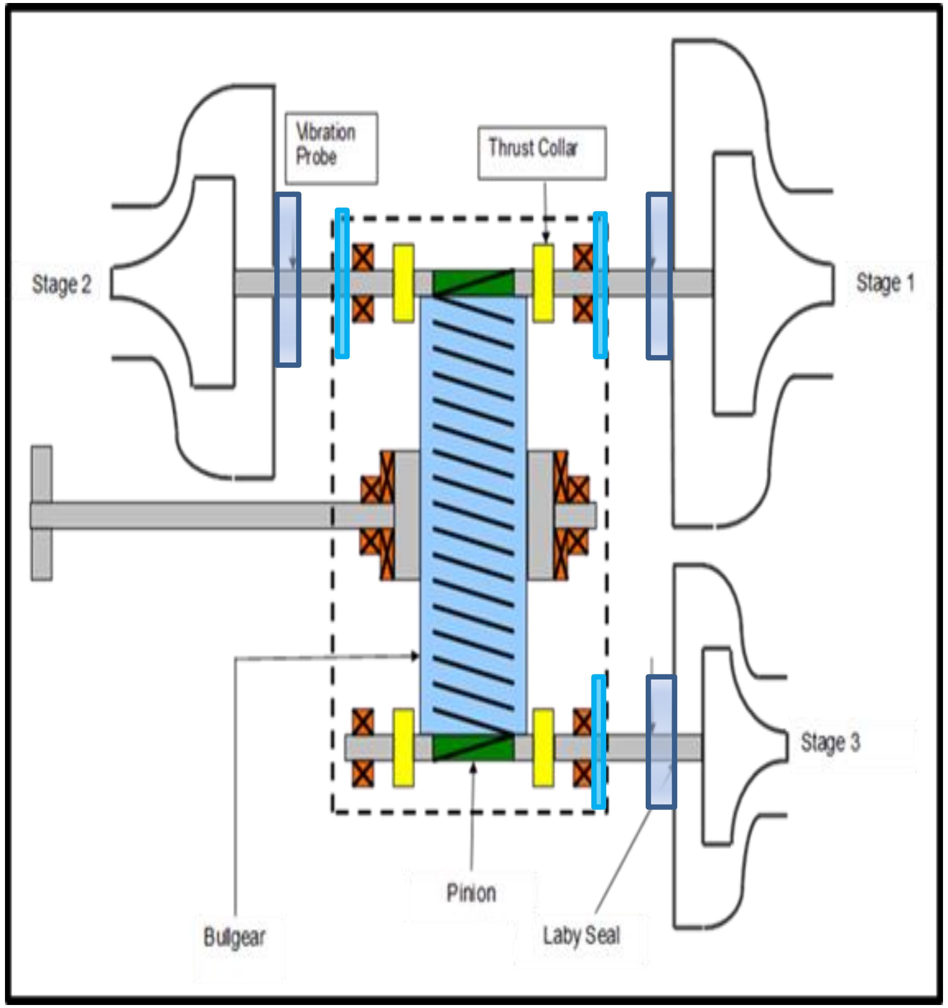
# Background – The Compressor

Single vibration probe adjacent to each impeller

Thrust collars on the LS and HS pinions and thrust bearings on the BG.

Stationary labyrinth air-seal and oil-seal on each stage



# The Problem

The machine was initially set in the new testing bed at the supplier's newly established workshop. It was a packaged type compressor testing with the workshop coupling and motor. The motor was driven by a VFD.

When the machine was in cold condition, the $1^{st}$ and $2^{nd}$ vibration exceeded the vibration transmitter range (0~5 mils) during the startup, and it tripped the machine.

The API vibration level for a new machine at the operating speed

| | |
|---|---|
| * Stage 1&2 | 0.9 mil |
| * Stage 3 | 0.8 mil |

In U.S. Customary units, mils: A= $\sqrt{\frac{12000}{N}}$

A = amplitude of unfiltered vibration, (mil) true peak-to-peak
N = maximum continuous speed, rpm

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# The Problem

The VFD ramping speed was changed from 50 rpm per second to 5 rpm per second which helped in starting the machine successfully during the $3^{rd}$ attempt.

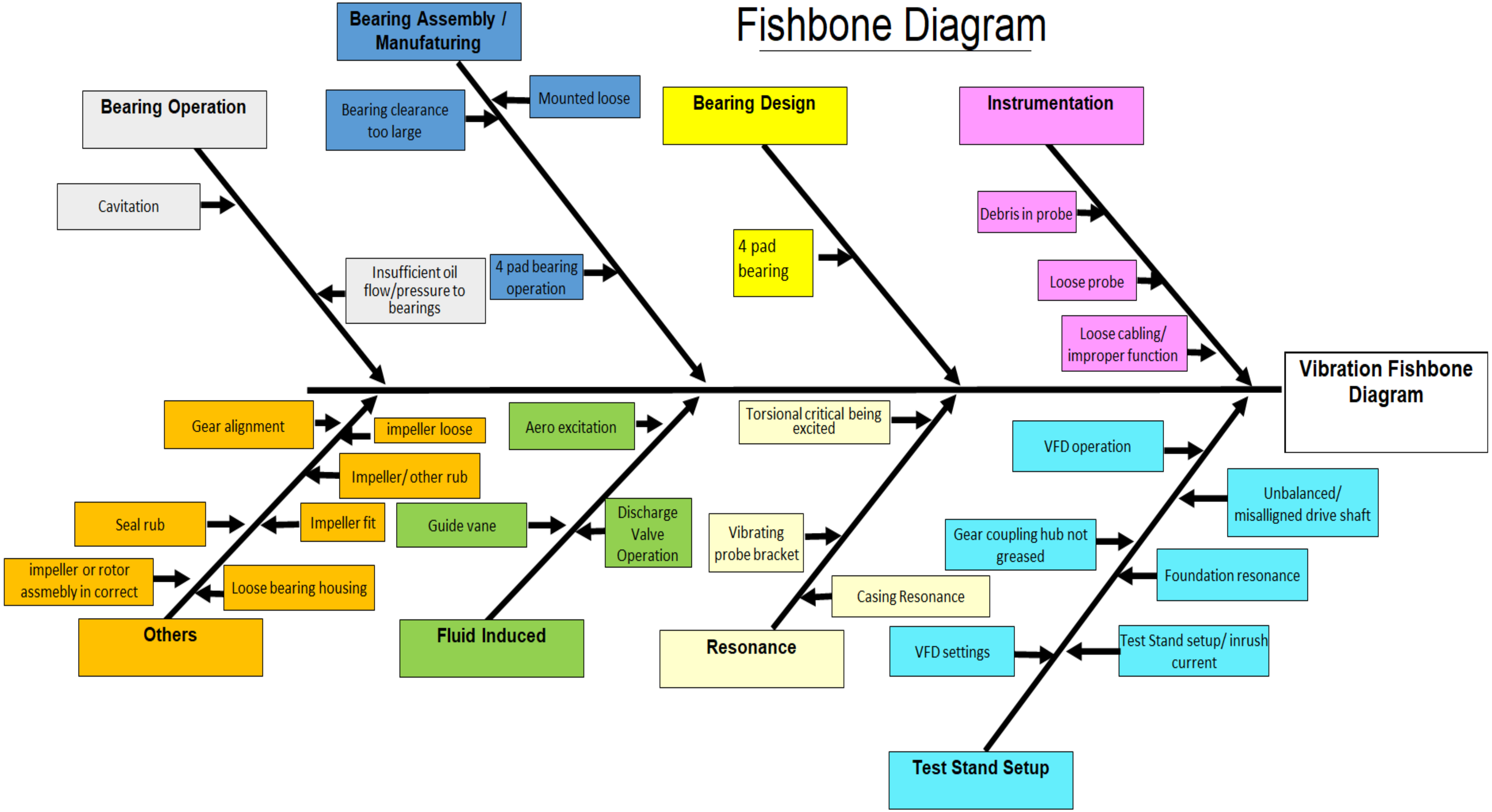
The performance test was done and during that period the vibration for all 3 stages was below the API limits. Oil supply temperature was stable at 46 deg C (115 deg F).

The machine was tripped after the 110% overspeed test and it couldn’t be re-started when the machine was in warm condition due to high $1^{st}$ and $2^{nd}$ stage vibrations.

# The Problem

The large compressor vibration spike during the compressor start-up was not expected and the compressor OEM could not explain it nor the difference in behavior with cold versus warm oil.  The compressor supplier was concerned there was possible mechanical issue.

# Investigation – Fishbone Diagram



# Investigation

Potential Root Causes Considered:

Bearing was mounted loose or bearing clearance was not set properly

✓ Bearing clearance was checked and all was within the design tolerance

Instrumentation noise

✓ Instrument probe and cabling installation was inspected. Everything was fine.

Test Stand and its VFD were not set properly

✓ Test Stand and VFD settings were verified. Nothing was found.

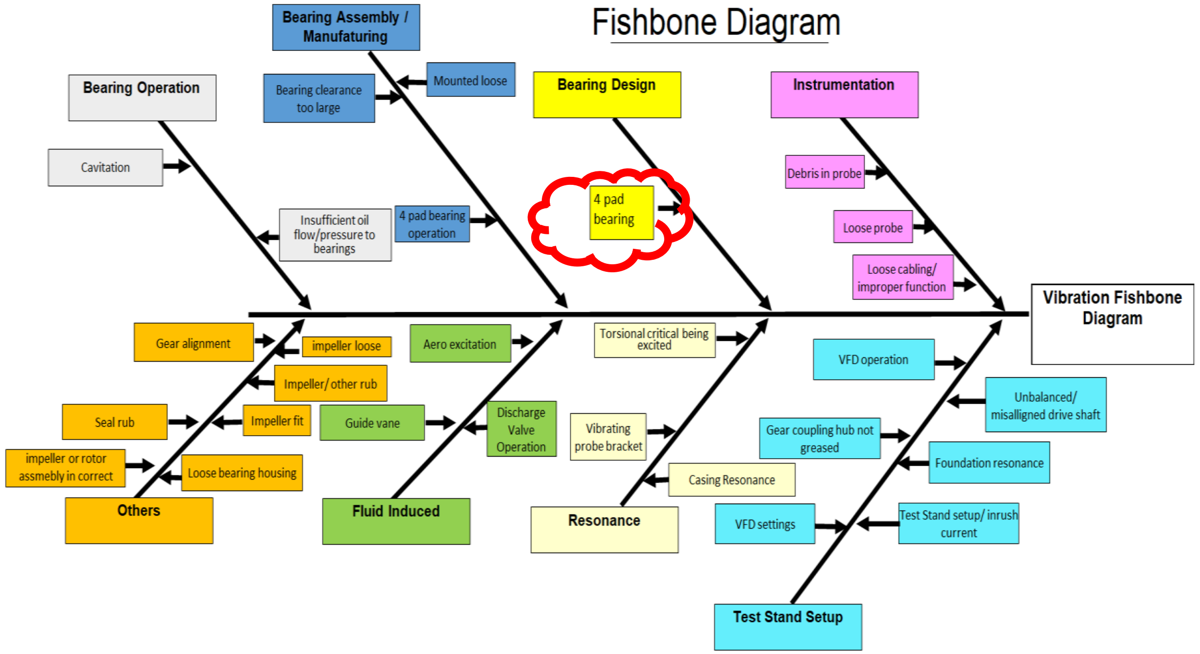
Longer than usual flexible coupling was used on the new test bed

✓ Used a shorter coupling with a rigid steel spool piece for replacing the original long coupling. Machine could be started smoothly at cold condition while it still couldn't be started at warm condition.

# Investigation

Potential Root Causes Considered:
It was decided to send the machine to a different facility for more in depth testing. The initial test showed the same behavior as the previous shop tests.

The collected data and Fishbone Diagram were reviewed.

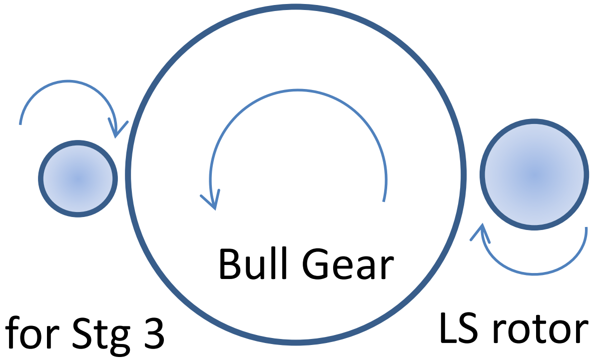


# The Solution

**Root Cause:**

The LS rotor for the $1^{st}$ and $2^{nd}$ stages in the compressor is up driven. For up driven pinions during start-up, the initial torque can push the rotor upward. With the low aero load at start-up, the rotor can instantaneously move upward in the pinion bearings.

Besides, the LS rotor on this machine is installed with smaller impellers and it's the lightest weight LS pinion assembly being installed in this compressor frame size.

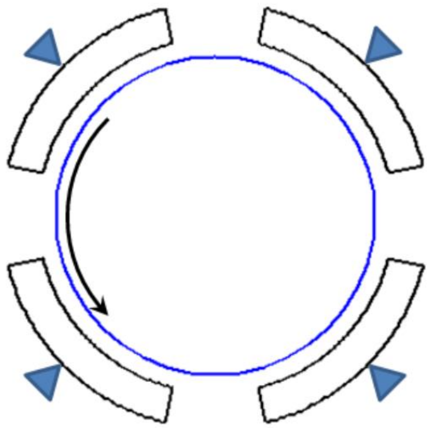


# The Solution

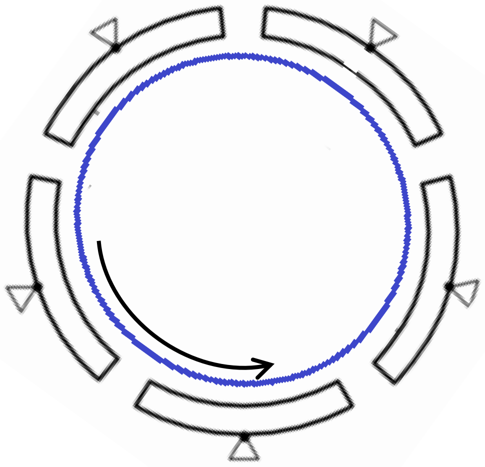
**<u>Root Cause:</u>**

The 4-pad, load between pad tilting pad pinion bearings were replaced with a 5-pad, load on pad tilting pad bearings.

With the same clearance (7 mils), the 4-pad design will lead to more displacement than the 5-pad one due to the geometric arrangement.



**Before**



**After**

# The Solution

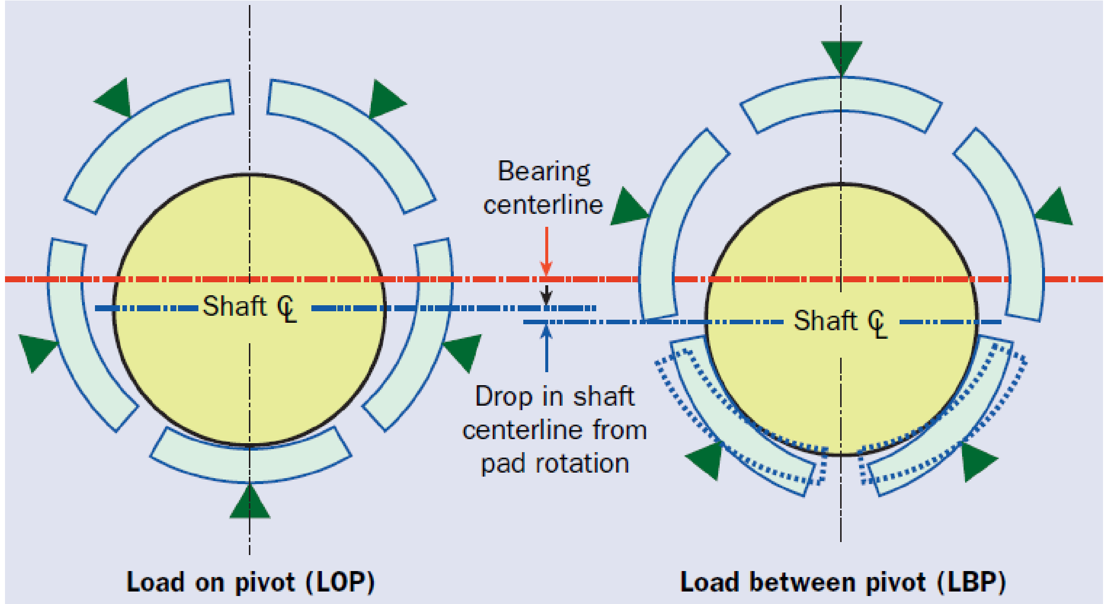
## Root Cause:

Brg Clearance = Factor x Lift → Lift = Brg Clearance ÷ Factor

Vibration Probe is detecting the Lift Displacement

**Bearing Clearance, Lift and Factor Table***

| | LOP | LBP |
|---|---|---|
| 3 pads | 0.667 × lift | 0.667 × lift |
| 4 pads | lift | 0.707 × lift |
| 5 pads | 0.894 × lift | 0.894 × lift |
| 6 pads | lift | 0.866 × lift |




* By Robert C. Eisenmann Sr.
Tilt-Pad Bearing Preload, Sulzer Technical Review 2/2004

# The Solution

The 5-pad design results in less shaft displacement in the bearing.  On start-up with the new bearings, the vibration spike was much lower and the test results were accepted.

The machine was able to be started smoothly in both cold and warm conditions.

# Lessons Learned

Upward driven pinions can be driven to full bearing displacement during start-up when the gear reaction forces exceed the static load due to the pinion weight. This cause momentary high vibrations. And, if the displacement exceeds the range of the vibration transmitter this can lead to a bad quality signal from the vibration probe until the pinion vibration settles down. This will trip the machine if the vibration protection system is configured to trip on bad quality with no time delay.

Different bearing designs can help reduce the effect, but if it is desired to not incorporate a time delay, the maximum shaft displacement for light weight upward driven pinions should be considered when selecting the vibration transmitter range.

Questions?

Thanks!