44TH TURBOMACHINERY & 31ST PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 14 – 17 2015
GEORGE R. BROWN CONVENTION CENTER

Analysis and On-Stream Countermeasures of High Thrust Bearing Temperature of Centrifugal Compressor

SK energy
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Presentation Overview

1. Summary
2. Overview of the problems
3. Troubleshooting
4. Solutions Provided and Results
5. Lessons Learned

1. Summary

The problem of high bearing temperature is a frequent concern for most rotating machinery. In case of critical equipment such as critical compressors or turbines, its consequences could lead to total plant shut down and huge losses. Furthermore it is very hard to find its cause, and solutions. On-stream remedies are very limited because the machines aren't stopped.

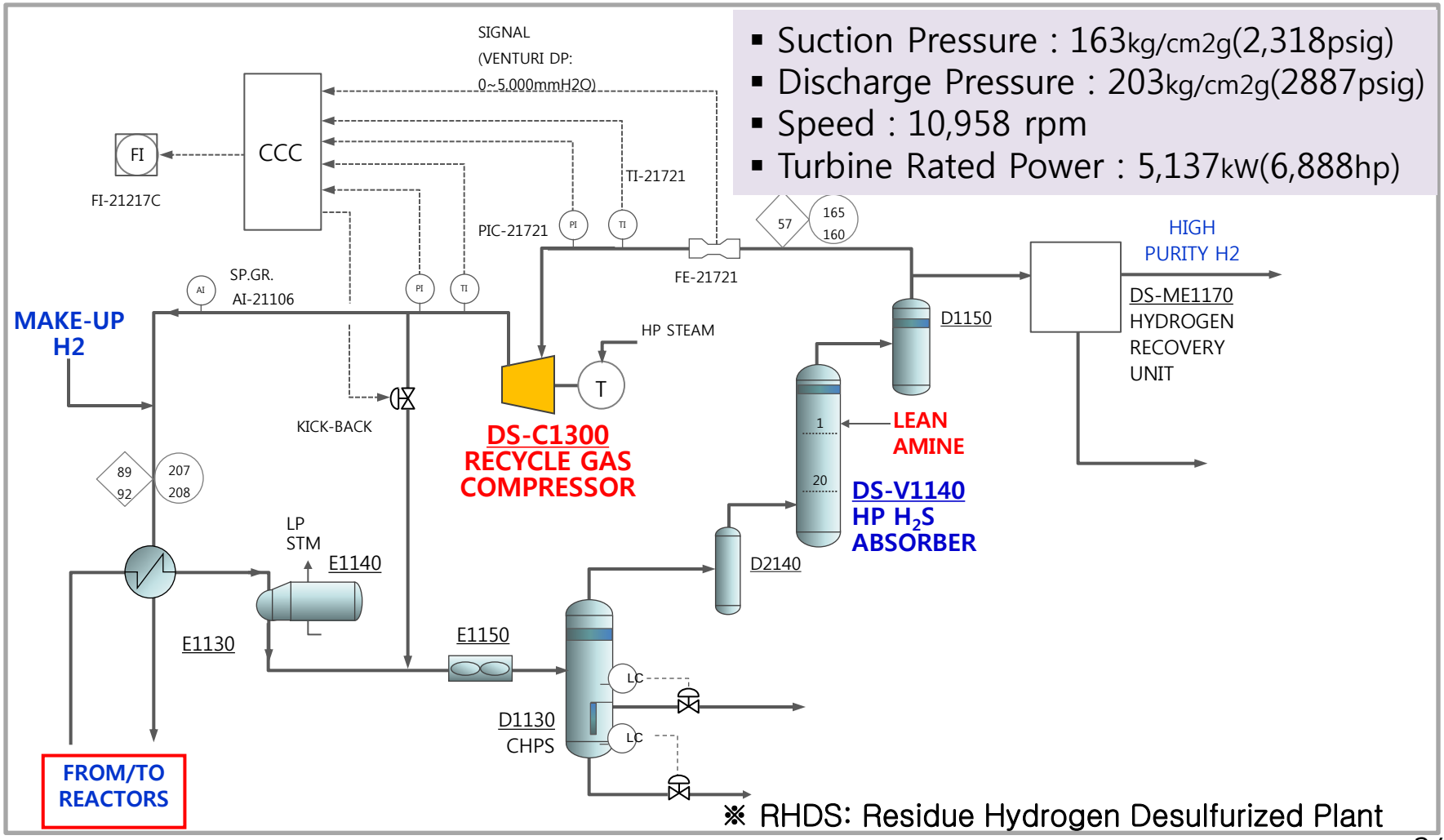
For the investigation and analysis of high thrust bearing problem of centrifugal compressor, it is required to understand the mechanism of bearing temperature increase as well as thrust load balance. In addition, it is also needed to review the quality and quantity of lube oil supply, and maintenance and operation history in various aspects.

Based on actual experience of high thrust bearing temperature rise in recycle gas compressor of Residue Hydrogen Desulfied(RHDS) plant, this case study will show how to analyze it and take on-stream countermeasures, as well as lessons-learned for maintenance and design.

2. Overview of the problem

System & Specification of Compressor

This compressor is located on recycle loop of reactor in RHDS Plant and deliver the H2 rich recycle gas to reactor in order to activate and cool down the catalyst.

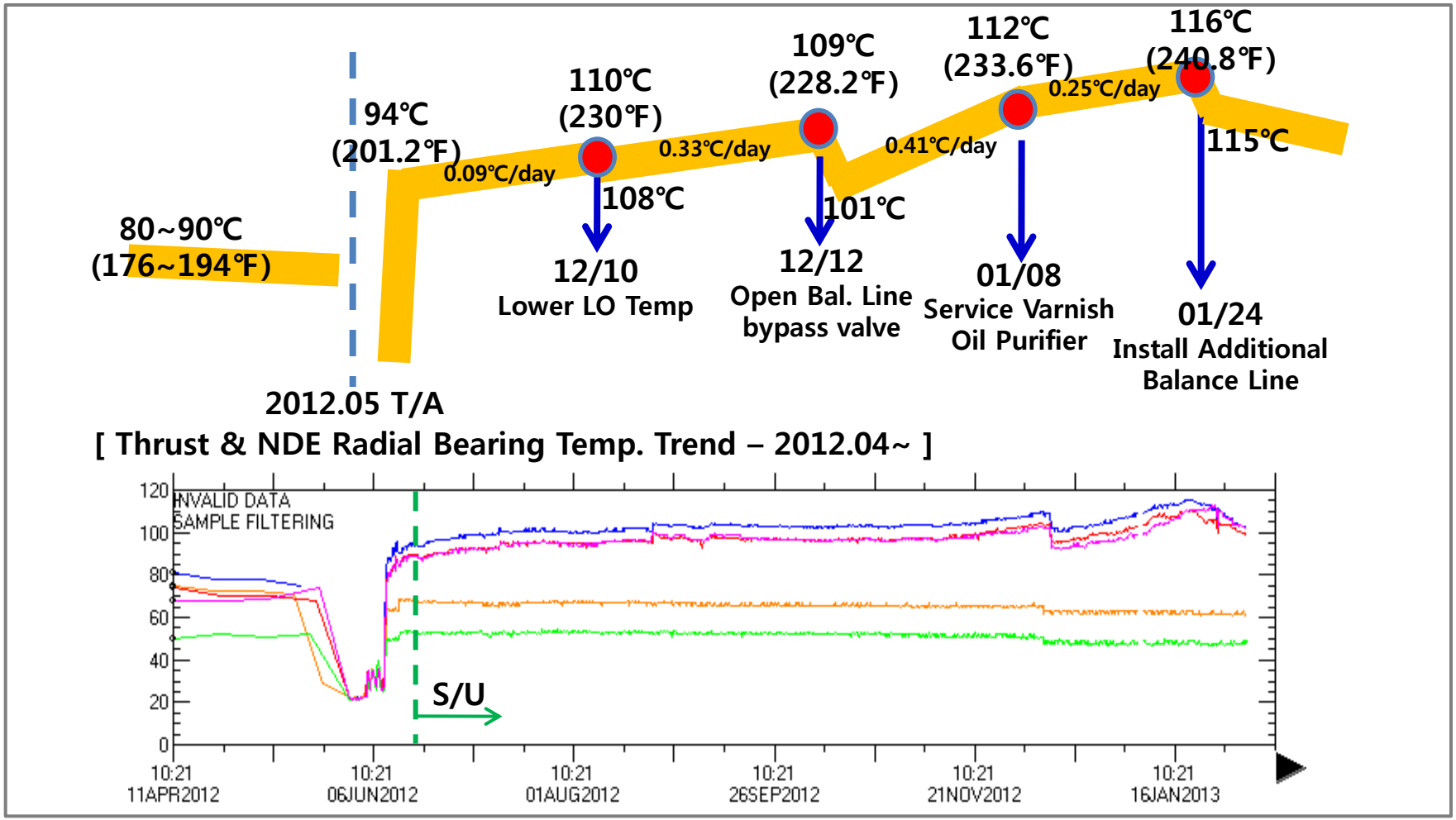


- Suction Pressure : 163kg/cm2g(2,318psig)
- Discharge Pressure : 203kg/cm2g(2887psig)
- Speed : 10,958 rpm
- Turbine Rated Power : 5,137kW(6,888hp)

2. Overview of the problem

Active side thrust bearing temperature was higher than previous run since Jun. 2012's T/A. It had reached 116℃(240.8℉) at the peak.

- Overall Trend and Counteractions (Alarm/Trip : 120/125℃ (248/257℉))



3. Troubleshooting

All possible causes for high thrust bearing temperature were deduced from thrust load, lubrication and bearing load capability. The detailed troubleshooting follows on the next pages.

Problem	Possible Causes	Possibility
Thrust Bearing Temperature Increase	**Excessive Thrust Force**	
	① Excessive Differential Pressure	Low
	② Insufficient Balance Force	High
	Insufficient cooling effect	
	③ Low Oil Flow	Low
	④ High Oil Supply Temperature	Low
	⑤ Varnish on bearing Pad	High
	Poor load distribution on bearing pads	
	⑥ Thrust bearing leveling plate malfunction	High

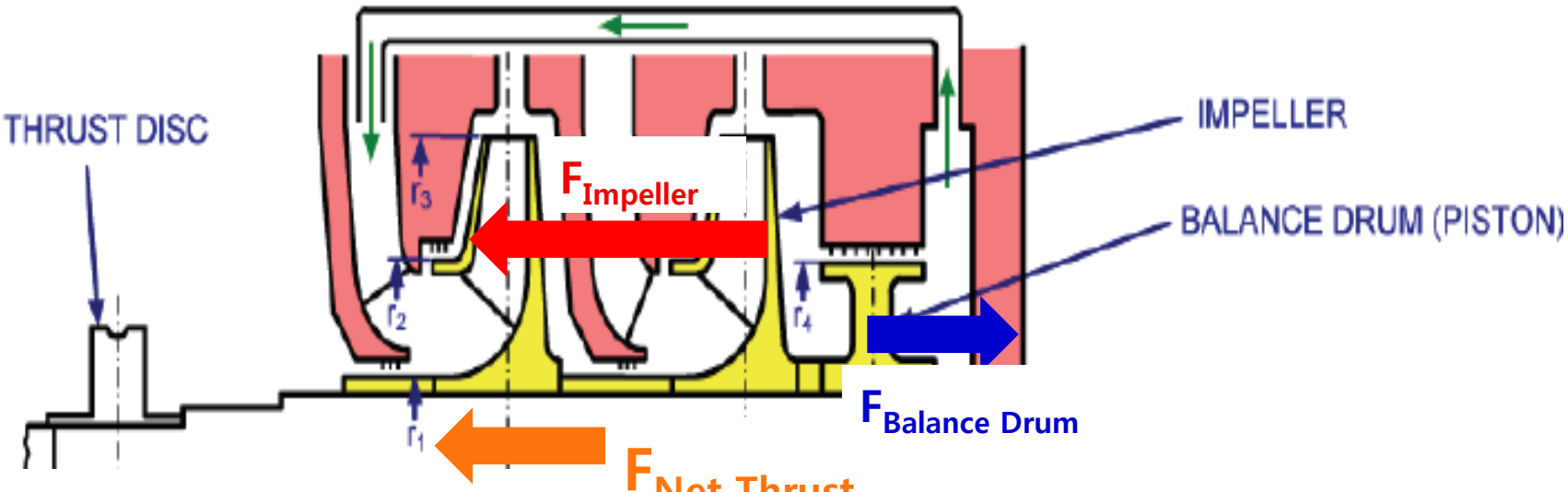
3. Troubleshooting

Excessive differential pressure and insufficient balance force could cause an increase of thrust force that could affect adversely bearing temperature.

① ($F_{Impeller}$) Excessive Differential Pressure

② ($F_{Balance\ Force}$)Insufficient Balance Force

→ Excessive Thrust Load → Thrust Bearing Temperature Increase



$$F_{Net\ Thrust} = F_{Impeller} - F_{Balance\ Drum}$$

$F_{Impeller}$ = Thrust Force across impellers

$F_{Balance\ Drum}$ = Thrust Force on Balance Drum

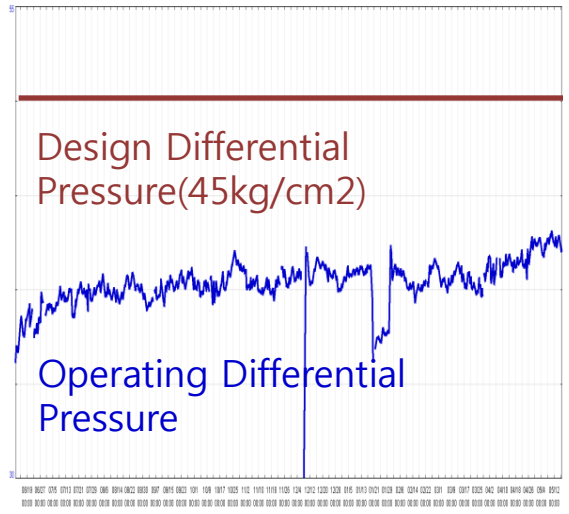
$F_{Net\ Thrust}$ = Net Thrust Force

3. Troubleshooting

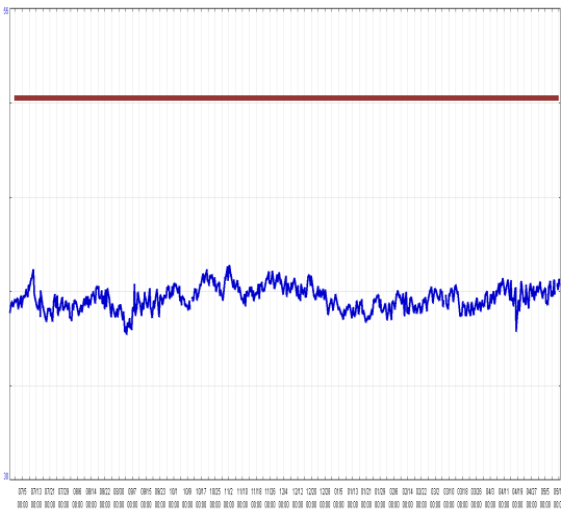
Possibility Low

① Excessive Differential Pressure

The actual operating differential pressure of compressor was maintained under design differential pressure and design thrust load at design differential pressure is much lower than allowable thrust load on bearing.



2012~2013



2012~2013

2013~2014

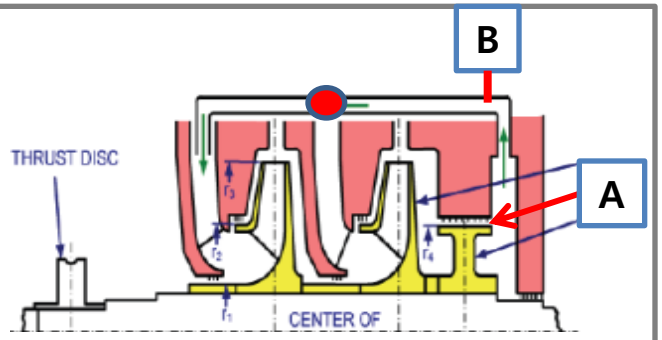
Design Compressor Differential Pressure	Allowable Thrust Bearing Unit Load	Design Thrust Unit Load
45 kg/cm²g (640 psig)	30 kg/cm²g (426.7 psig)	18.5 kg/cm²g (263.1 psig)

3. Troubleshooting

Possibility **High**

② Insufficient Balance Force

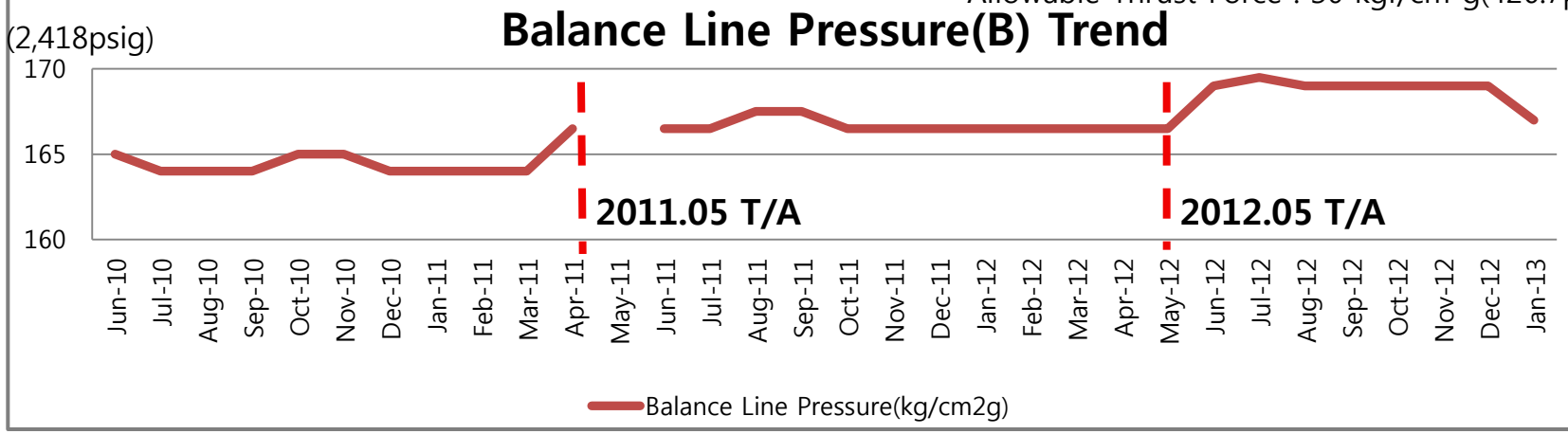
The balance drum labyrinth clearance had been increased above design clearance. Excessive clearance could cause higher balance chamber pressure which in turn negatively affected the balance force.



Decrease in Balance Drum DP due to excessive clearance at balance drum

	Balance Drum Labyrinth Clearance(mm(in)) "A"	*Thrust Force (kgf/cm²g(psig))
Design	0.5 (0.0197)	3 (42.67)
2004	0.43 (0.0178)	-4 (-56.9)
2007	0.53 (0.0209)	5 (71.1)
2011	**0.8** (0.0315)	**14** (199.1)

* Allowable Thrust Force : 30 kgf/cm²g(426.7psig)



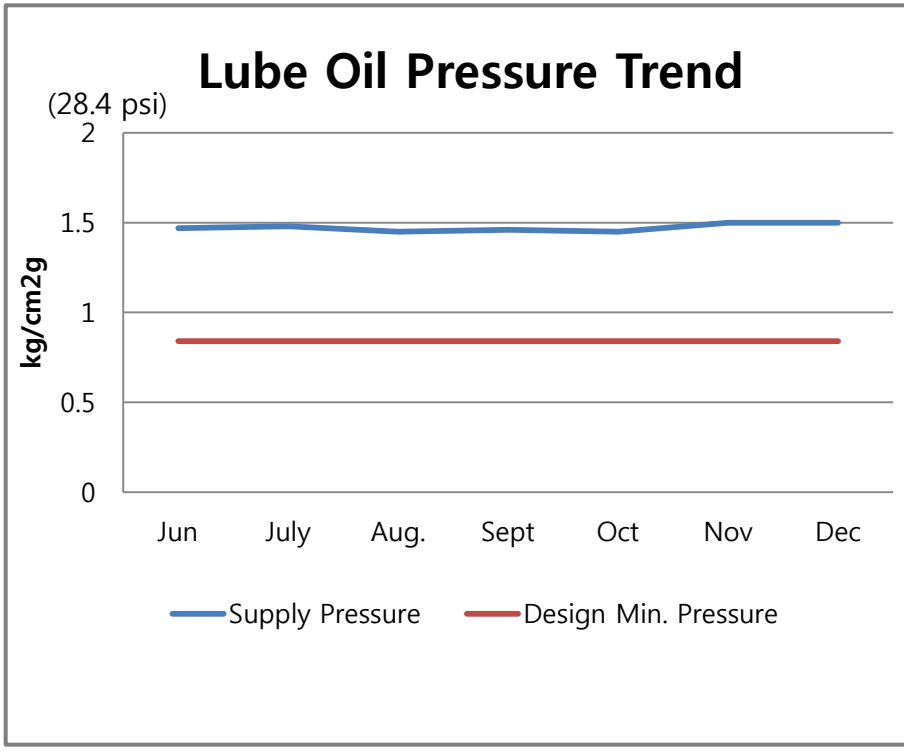
3. Troubleshooting

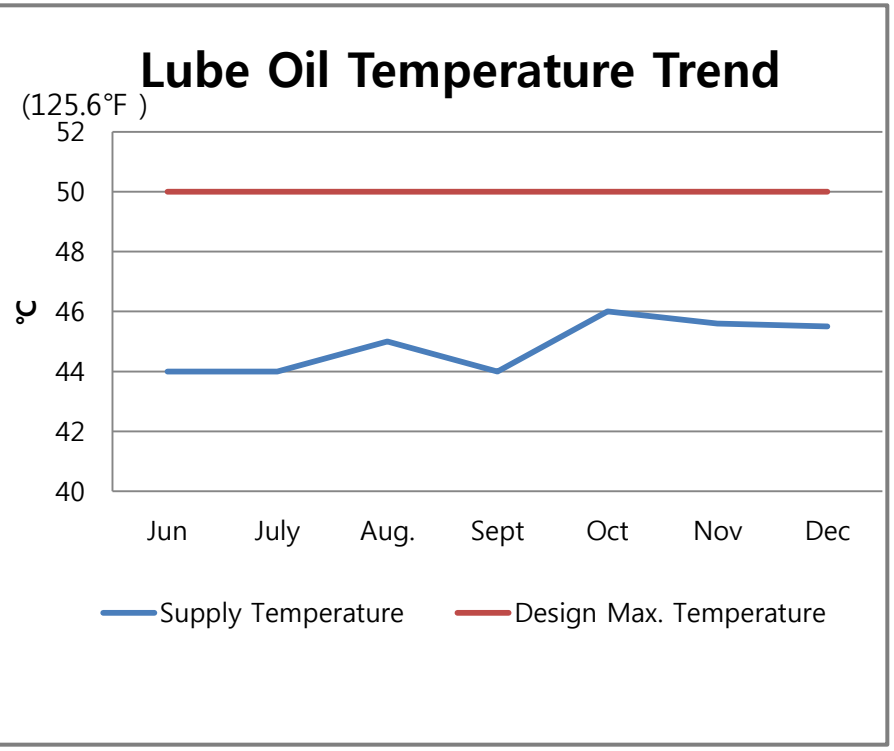
Possibility: Low

③ Low Oil Pressure(Flow)

④ High Oil Supply Temperature

The lube oil pressure was maintained higher than design min. pressure which result in enough flow being supplied. Lube oil supply temperature was maintained lower than design max. temperature which mean lube oil temperature **didn't affect high bearing temperature directly**.





Possibility **High**

⑤ Varnish on bearing Pad

MPC Test Result (21.37) was a little bit higher than normal value(15).
Varnish could be one of possible causes for bearing temperature increase due to lower cooling effect.

- Normal < 15, Observation < 30, Abnormal < 40, Danger >40
- MPC Test is to measure non-soluble varnish quantity in the lube oil
- MPC = Membrane Patch Colorimetry

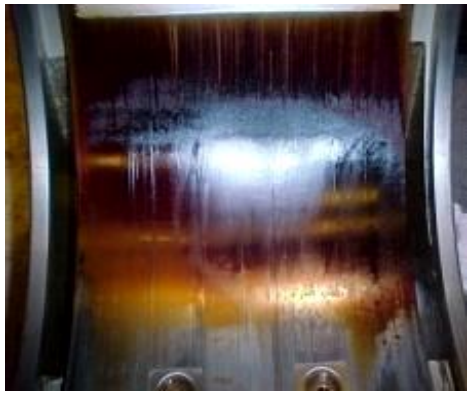
Varnish is a general term for **by-product of oil degradation**.

High temperature, contact with oxygen and entrained foreign material accelerate oil degradation

※ Influence of varnish

- Disturb formation of uninform oil film
- Low heat conductivity
- Increase Friction
- Form additional varnish

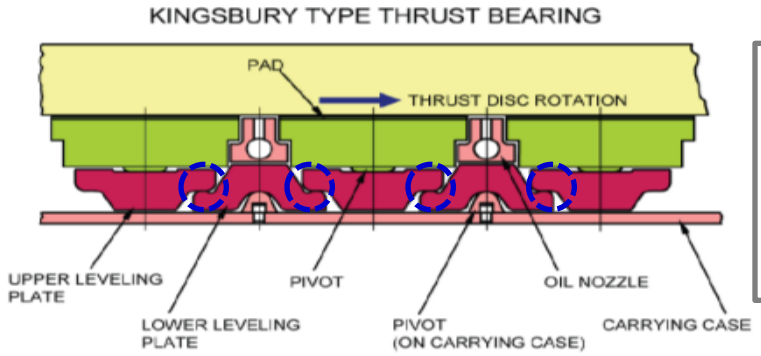
Bearing Temperature Rise !



Possibility **High**

⑥ Thrust bearing leveling plate malfunction

Sticking of leveling plate could cause uneven load distribution to all bearing pads. The temperature of bearing pads which the load is concentrated on could increase abnormally.

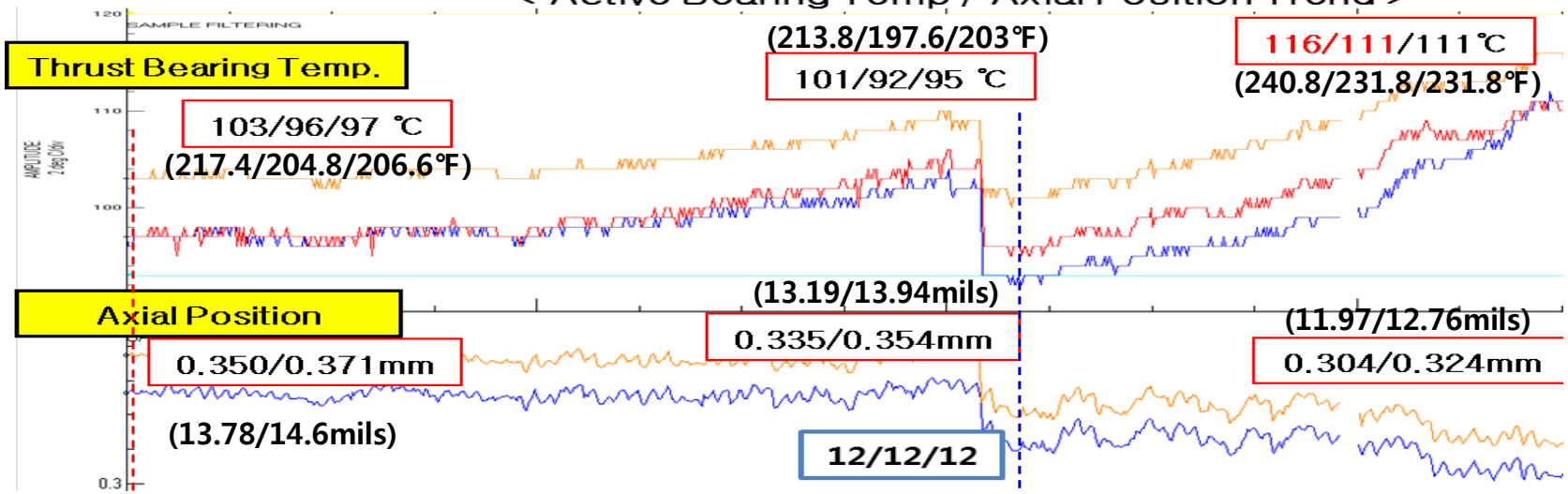


Deviation btw temp sensors was High

110/99℃(230/210.2℉) → 102/100℃ (215.6/212℉)

ΔT 11℃(19.8℉) → 2℃ (3.6℉)

< Active Bearing Temp / Axial Position Trend >

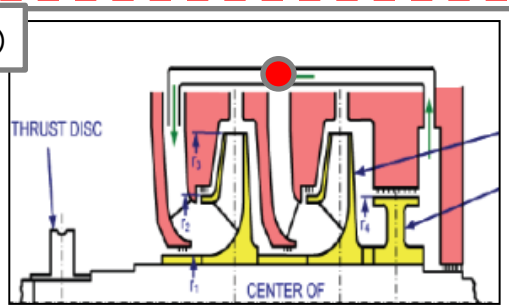


3. Troubleshooting

Summary

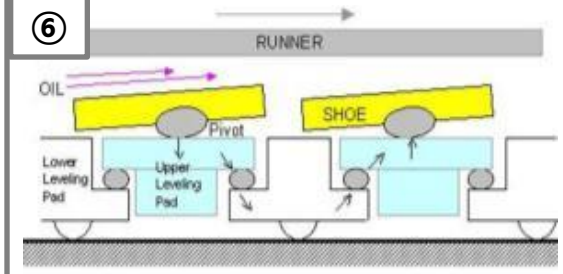
Primary Causes

②



Decrease of Balance Drum DP due to excessive clearance at balance drum

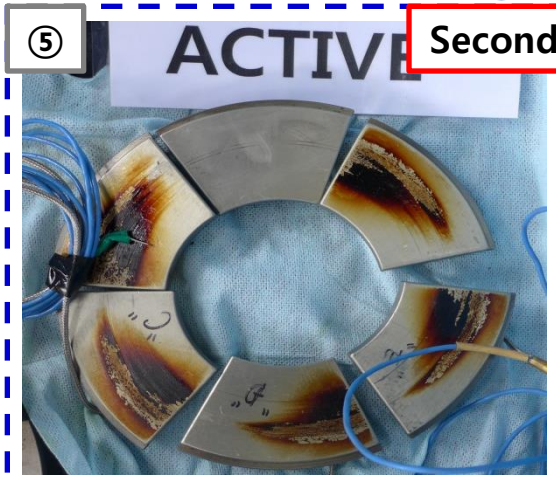
⑥



Sticking of Leveler
→ Uneven Load Distribution

Secondary Cause

⑤



High initial bearing temperature accelerate **Varnish Formation** and has a negative influence on bearing temperature increase

4. Solution Provided and its Result

On-Stream

(1) Adjust Oil Supply Temperature and Pressure

Lube oil temperature and Pressure were adjusted to lower bearing temperature even though those were not real causes of this problem.

	Lube Oil Pressure (kg/cm^2g (psig))	*Lube Oil Temperature(℃ (℉))*	*Active Thrust Bearing (℃(℉))*
Before	**1.47 (20.9)**	**44 (111.2)**	**110/108 (230/226.4)**
After	**1.7 (24.18)**	**41 (105.8)**	**108/106 (226.4/222.8)**

(2) Install varnish purifier to improve the oil quality and remove varnish

MPC had been gradually improved after varnish purifier was installed.
The increase rate of bearing temperature was mitigated and finally went down

Install Varnish Purifier

Sampling date	01/08	01/11	01/14	01/16	01/18	01/21	01/23
MPC	21.37	18.6	15.79	13.6	13.3	12.43	10.51

※ Varnish Purifier
- Remove tiny varnish particles(<4 micron),
- Remove varnish attached in piping, reservoir and bearings

4. Solution Provided and its Result

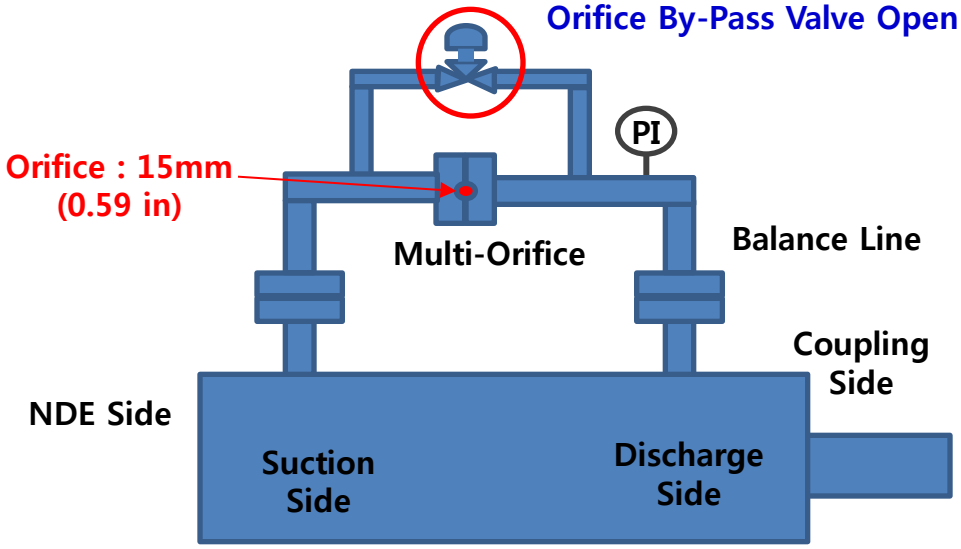
On-Stream

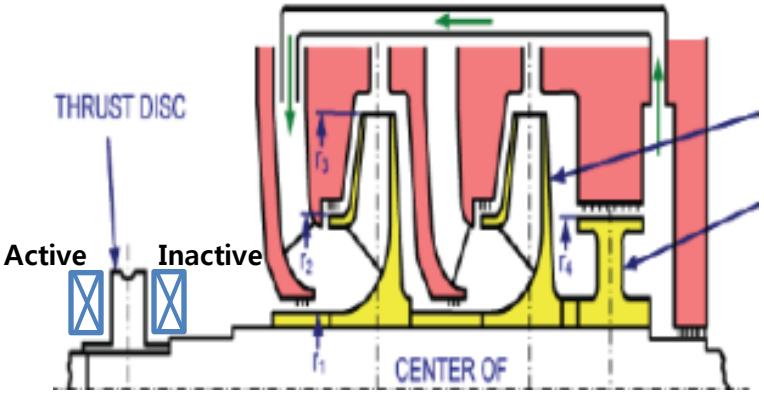
(3) Balance Drum Pressure Decrease

1st Adjustment

Balance Line Bypass Valve Opened to reduce balance chamber pressure

	Balance Line Pressure (kg/cm2g (psig))	*Thrust Position (mm (mils))*	*Active Thrust Bearing (℃ (℉))*
Before Valve Open	169 (2,403.8)	0.367/0.347 (14.45/13.66)	109/104 (228.2/219.2)
After Valve Open	**167 (2,375.3)**	**0.348/0.329 (13.70/12.95)**	**101/96 (213.8/204.8)**





4. Solution Provided and its Result

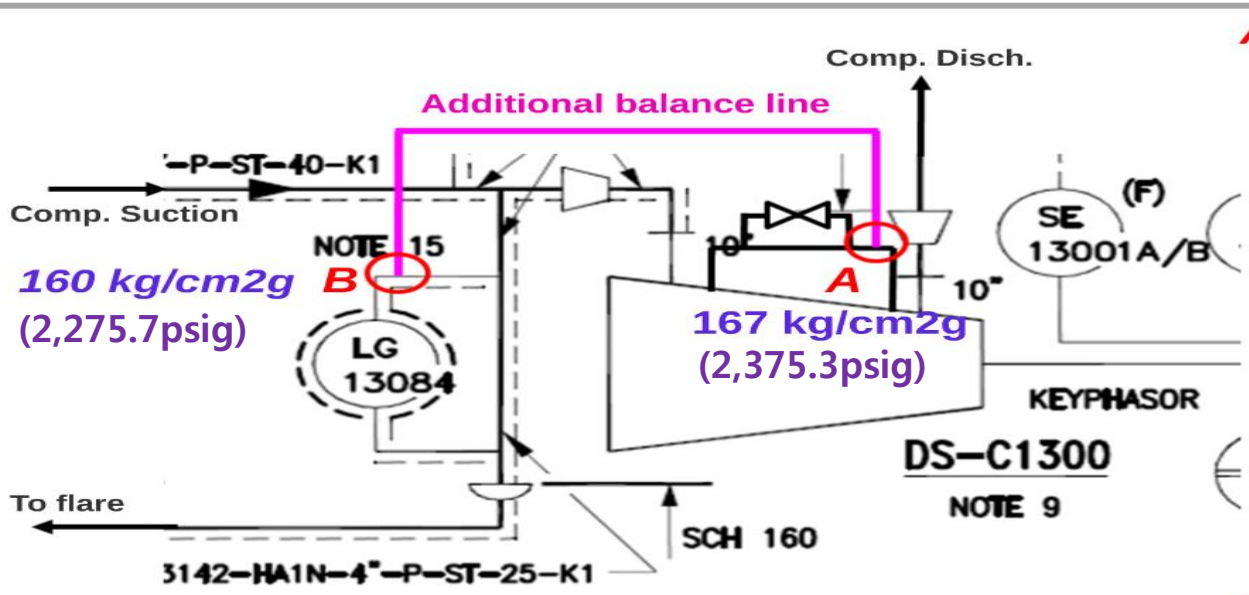
On-Stream

(3) Balance Drum Pressure Decrease

2nd Adjustment

Connect balance line to suction line to reduce the pressure of balance chamber

	Balance Line Pressure (kg/cm2g (psig))	*Thrust Position (mm (mils))*	*Active Thrust Bearing (℃ (℉))*
Before Service	167 (2,375.3)	0.295/0.314 (11.61/12.36)	116/106 (240.8/222.8)
After Service	**165.5 (2,354.0)**	**0.293/0.312 (11.54/12.28)**	**115/105 (239/221)**



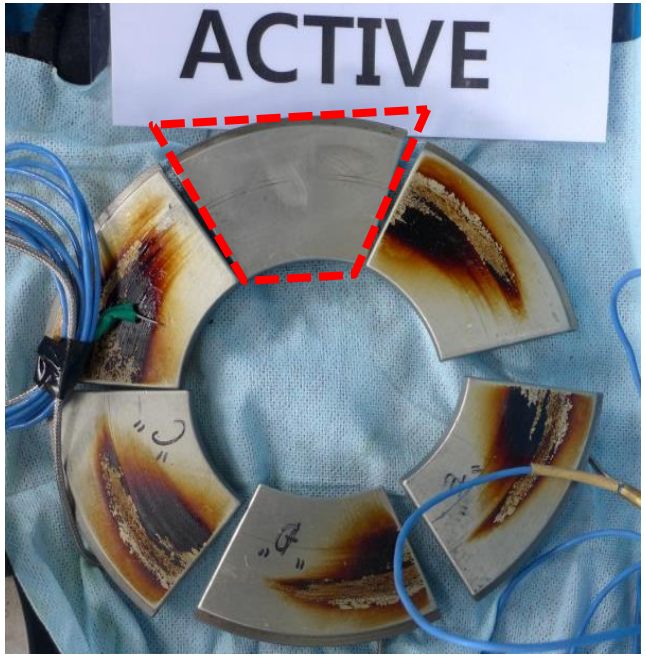
4. Solution Provided and its Result

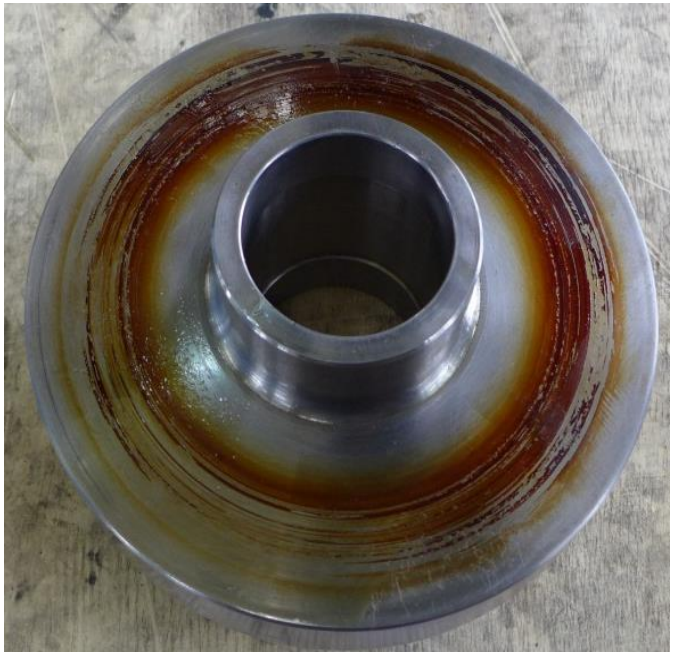
T/A

※ `2013 T/A Overhaul Results

ⓐ Varnish Formation on Bearing pads and thrust collar

ⓑ Uneven Load Distribution on each pad





ⓒ Balance drum labyrinth clearance was enlarged

	2012 T/A (mm(in))	2013 T/A(mm(in))
Left	0.37 (0.01457)	0.42 (0.01654)
Right	0.43 (0.01693)	0.48 (0.01890)
Total	**0.80 (0.03150)**	**0.90 (0.03544)**

4. Solution Provided and its Result

T/A

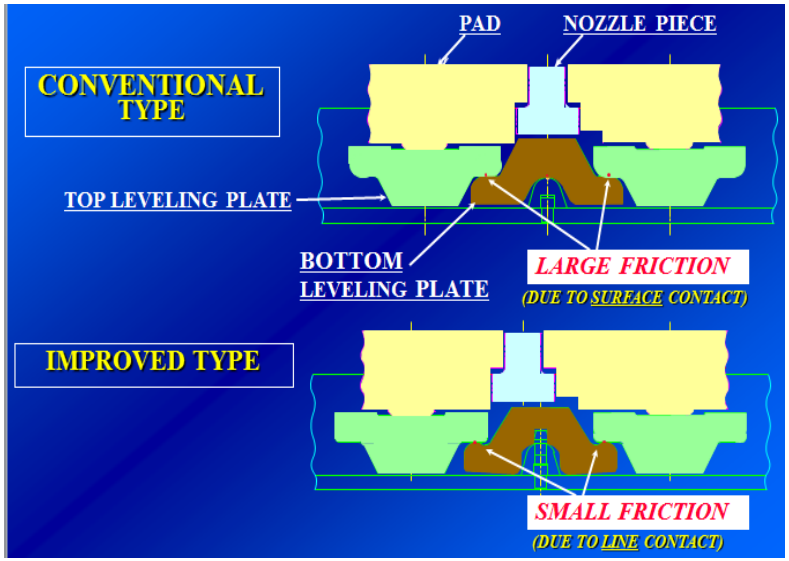
(4) Replace Balance Drum Labyrinth)

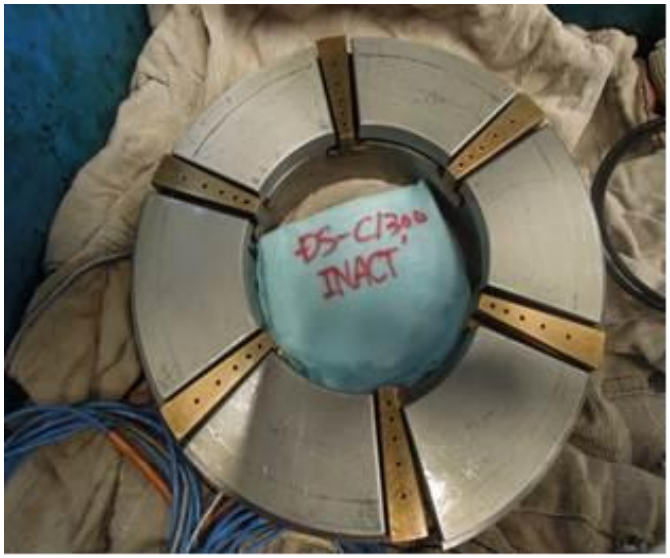
(Labyrinth Design Clearance = 0.5mm (0.0197in)

	Before (mm(in))	After(mm(in))
Left	0.42 (0.01654)	0.20 (0.00787)
Right	0.48 (0.01890)	0.27 (0.01063)
Total	**0.90 (0.03544)**	**0.47 (0.0185)**

(5) Thrust Bearing Up-grade

- Rounded Leveling Plate
- Cu-Cr Back Metal





4. Solution Provided and its Result

Possible Causes	Solution Provided	Aspect
④ High Temperature of Lube Oil Supply	▪ Adjust Oil Supply Temperature & Pressure	Operation
① Insufficient Balance Force	▪ Balance Drum Pressure Decrease ▪ Replace Balance Drum Labyrinth	Maintenance
⑤ Varnish on bearing Pad	▪ Install Varnish Purifier to improve the oil quality and remove varnish	Operation
⑥ Thrust bearing leveling plate malfunction	▪ Thrust Bearing Up-grade - Rounded Leveling Plate - Cu-Cr Back Metal	Design

As a result of above countermeasures, finally the thrust bearing temperature was stabilized and furthermore went down lower than 90℃ which was the temperature before start-up.

5. Lessons Learned

If faced with the thrust bearing temperature problem for compressor, the following steps should be taken into consideration.

- It is necessary to closely monitor the thrust bearing temperature, thrust position and balance drum pressure with balance drum labyrinth clearance for HP compressor.

- On-stream countermeasure for bearing temperature increase
  - Analyze "MPC" for lube oil,
    If MPC is high, varnish purifier will be effective
  - if feasible, thrust force adjustment can be performed as introduced.
  - Lube oil temperature is more effective than one's pressure

- Bearing Design Upgrade
  - Consider applying more heat dissipative material for bearing back metal (ex, Cu-Cr)
  - Offset Pivot, Direct Lubrication, Rounded Leveling Plate etc.

End Of Presentation

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Questions?