45TH TURBOMACHINERY & 32ND PUMP SYMPOSIA
HOUSTON, TEXAS | SEPTEMBER 12 – 15, 2016
GEORGE R. BROWN CONVENTION CENTER

Analysis and on-stream countermeasures of sub-synchronous vibration of a centrifugal compressor

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0. Bio of Author

I, Sangjoo Lee, have been a rotating machinery engineer in reliability for SK energy in Ulsan, Korea since 2007.

I received a M.S. degree(Mechanical Engineering from Ulsan University) and am a key member of KRMEA(Korea Rotating Machinery Engineers Association)

My experience include compressor and vibration in refinery, petrochemical plants

Mr. Bumsu Kim and Mr. Sangsuk Lee are co-authors of this case study

Presentation Overview

1. Abstract

2. Overview of the problems

3. Troubleshooting

4. Solutions and Results

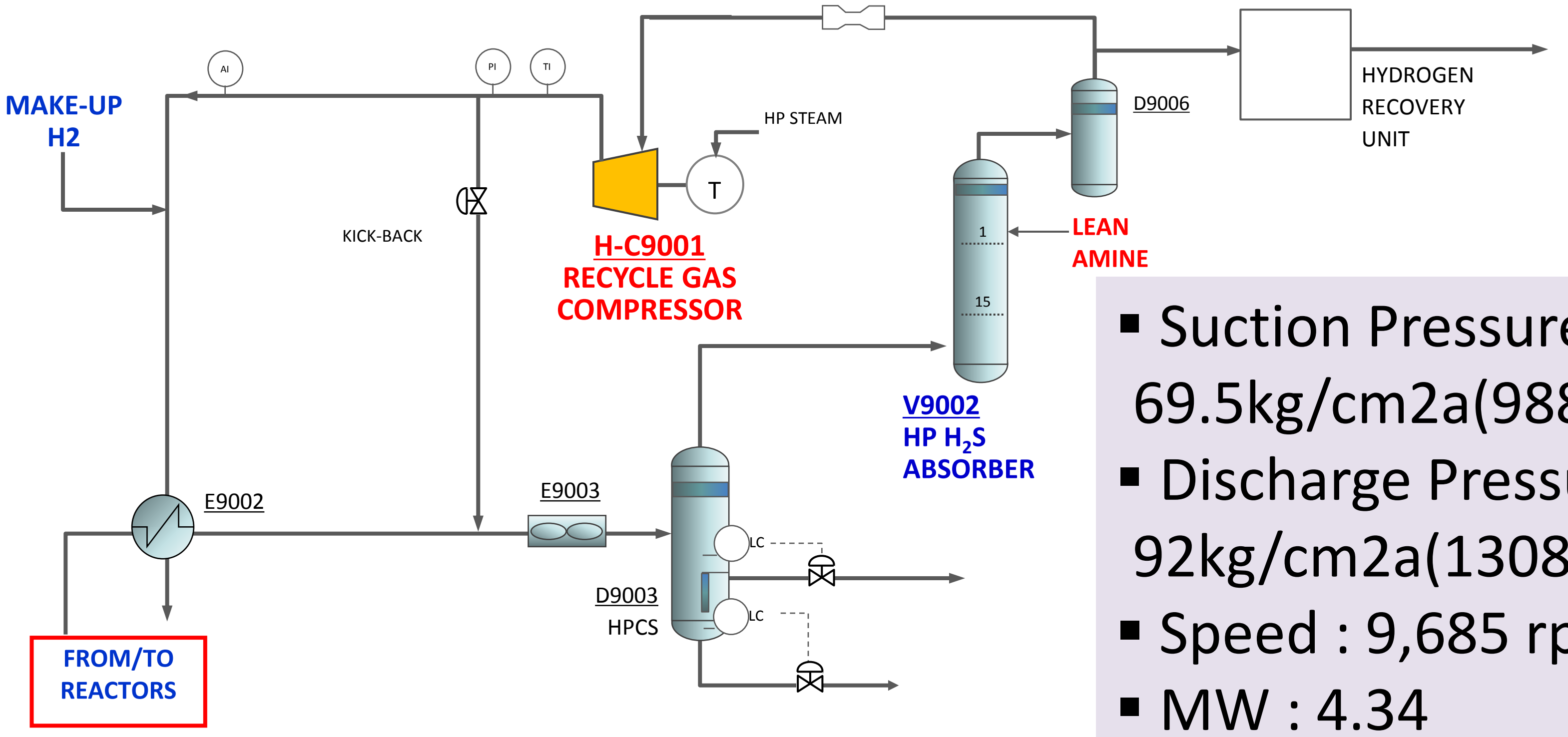
5. Lessons Learned

1. Abstract

The **sub-synchronous vibration** could be attributed to many causes such as gas-whirl, oil whirl, looseness and so on. To prevent sub-synchronous vibration, manufacturer analyzes stability during design stage. But field condition can be changed because of process issues. Based on actual experience of sub-synchronous vibration in recycle gas compressor of MDU(Middle Distillation Unit) plant, this case study will show **how to analyze and reduce vibration without compressor shut down by applying on-stream countermeasure.**

2. Overview of the problem System & Specification of Compressor

This compressor is located on recycle loop of reactor in MDU Plant and delivers the H2 rich recycle gas to reactor

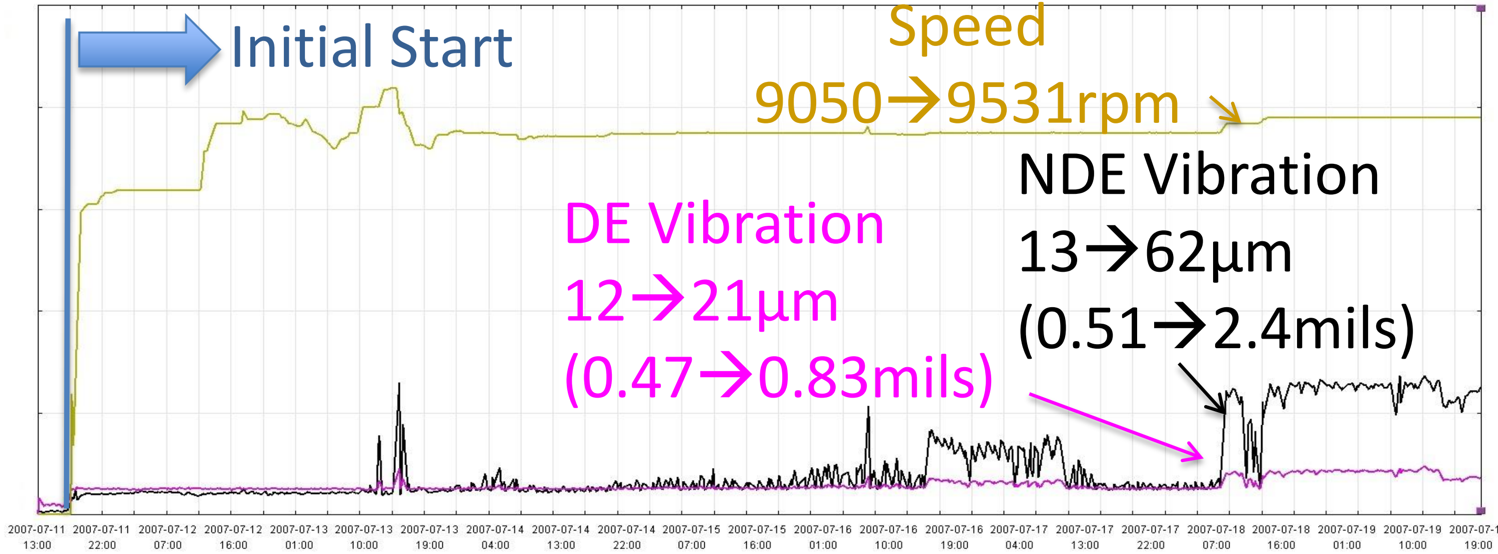


- Suction Pressure : 69.5kg/cm2a(988psi)
- Discharge Pressure : 92kg/cm2a(1308psi)
- Speed : 9,685 rpm
- MW : 4.34

2. Overview of the problem

The Recycle compressor started initially in 2007. After initial start-up, radial vibration of compressor was relatively stable. But the radial vibration of compressor increased during increasing compressor speed to supply more H_2 to reactor.(Higher H_2/feed ratio is better for catalyst lifespan)

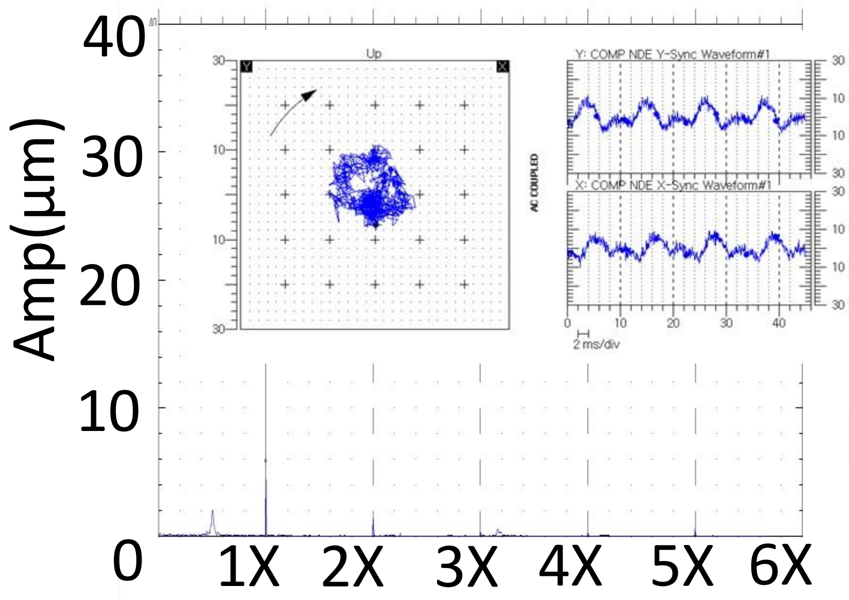
[Speed & Radial Vibration. Trend]



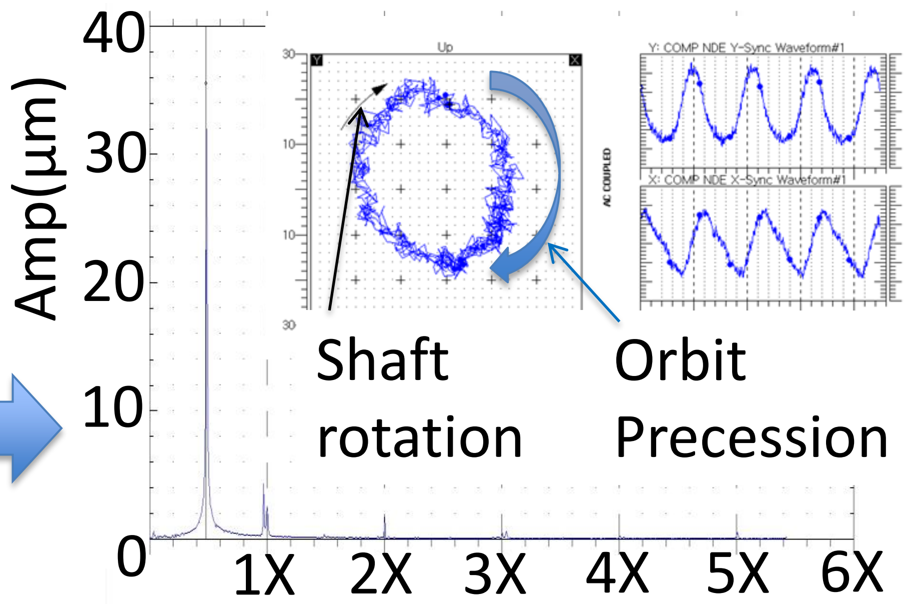
Vibration Alarm
72µm(2.8mils)
Trip
102µm(4mils)

3. Troubleshooting

Before high vibration occurred, dominant frequency was 1X with small sub-synchronous . When high vibration occurred, dominant frequency of high vibration was sub-synchronous which is 0.48X.



[Stable vibration – 5.79@1x Order]



[High vibration – 35.5@0.48x Order]

3. Troubleshooting

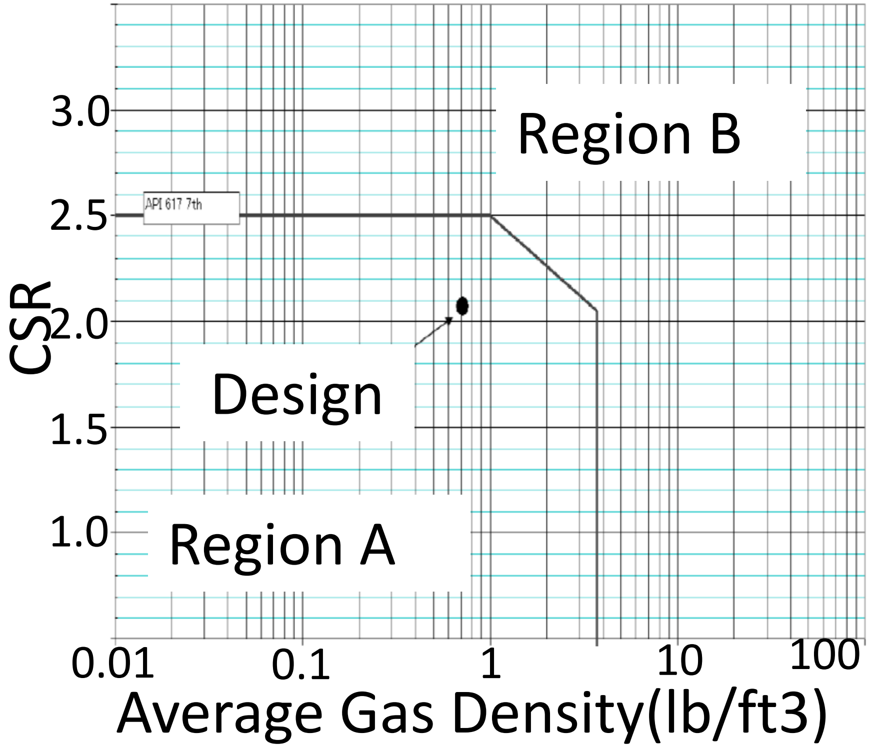
All possible causes for high sub-synchronous vibration were considered as shown below.

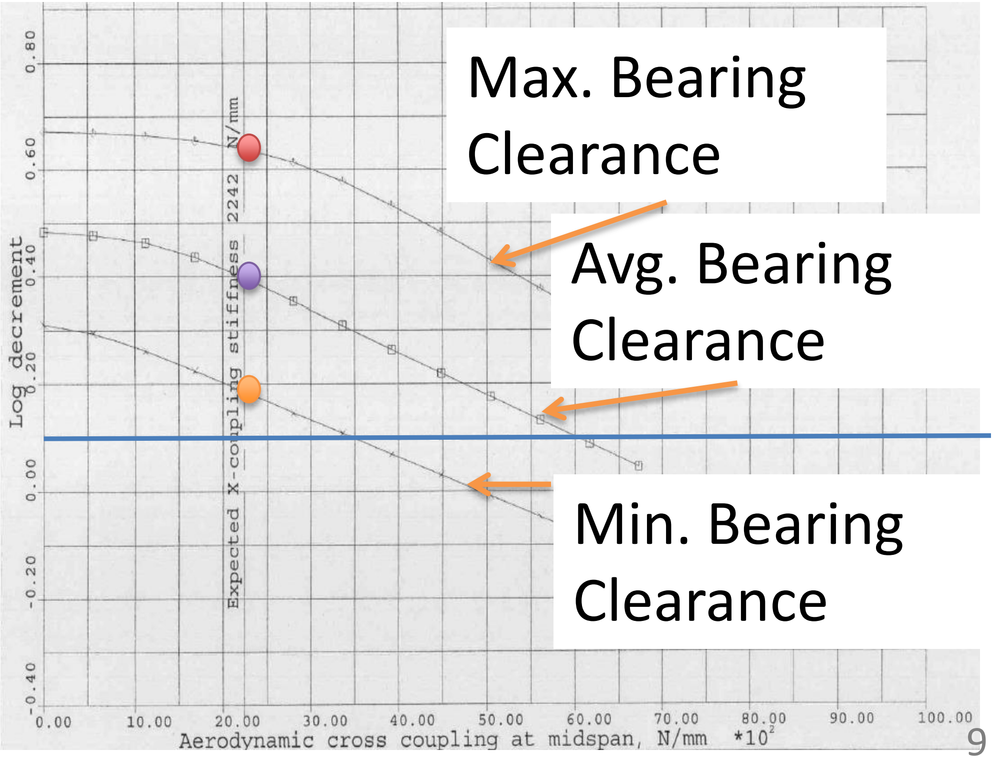
Problem	Possible Causes	Probability
Sub-synchronous Vibration For Compressor	**Gas Whirl**	
	① Insufficient Stability Design	Low
	② Improper Operating Condition for Stability	Low
	③ Unexpected High Destabilizing Force	High
	Oil Whirl	
	④ Bearing Design	Low
	Looseness	
	⑤ Any Looseness	Low

3. Troubleshooting - ① Insufficient Stability Design

Low

Base on the stability analysis result, the API Level I criteria was satisfied. (i. Qo/QA=2.16 > 2.0, ii. δA=0.194 > 0.1, iii CSR Region A)

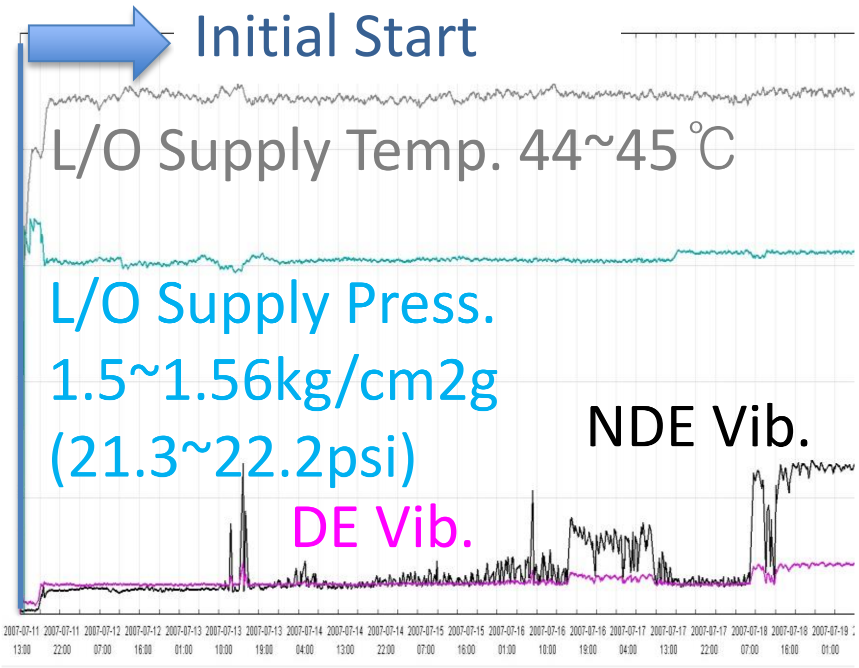


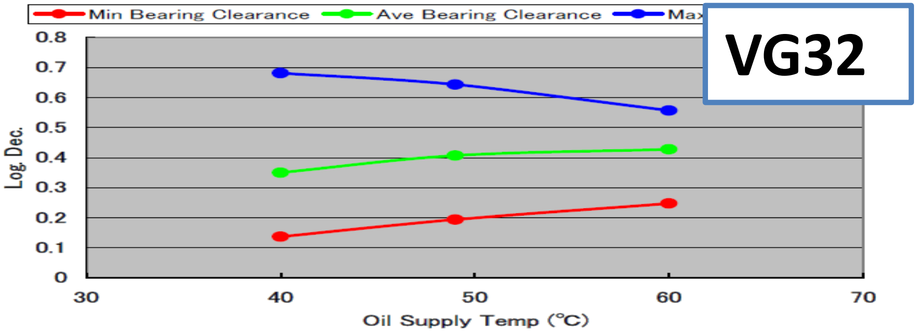


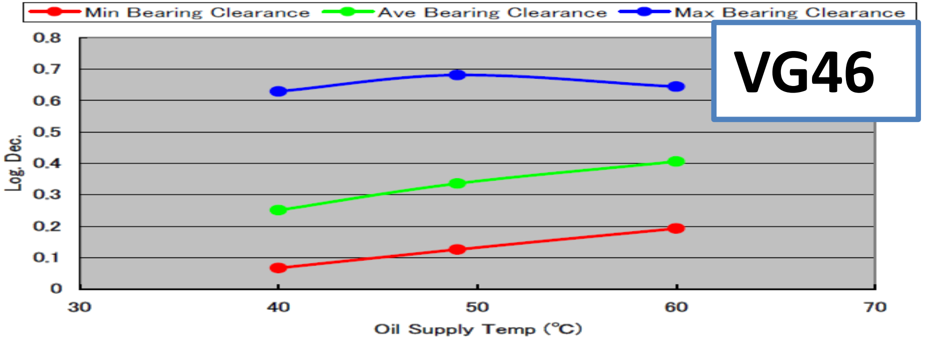
3. Troubleshooting - ② Improper Operating Condition

Low

Base on the stability analysis, the Log Dec. was predicted to decrease with decreasing supply temperature and higher viscosity oil. Actual operation maintained design temperature (44℃)and manufacturer viscosity recommendation(VG32)



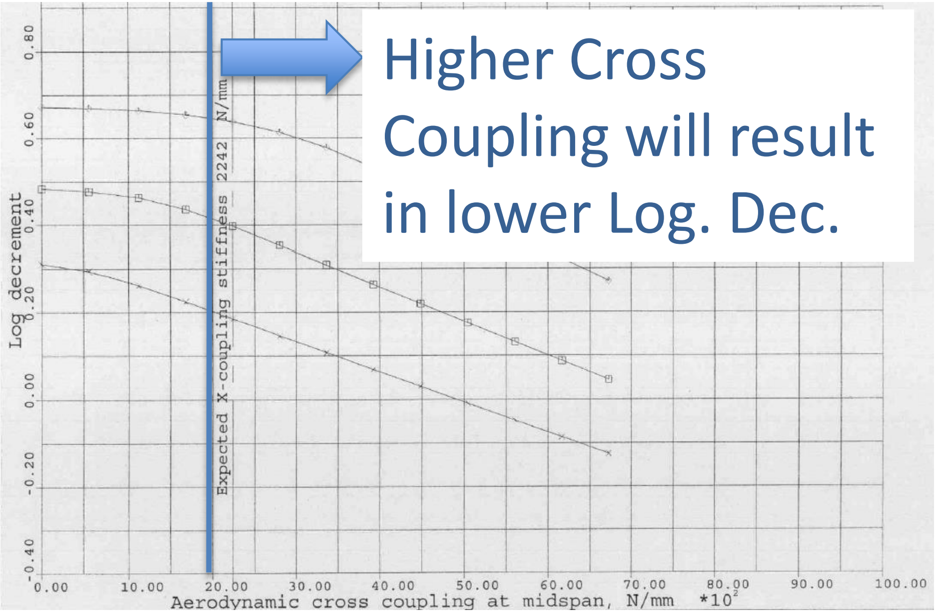




3. Troubleshooting - ③ Unexpected High Destabilizing Force **High**

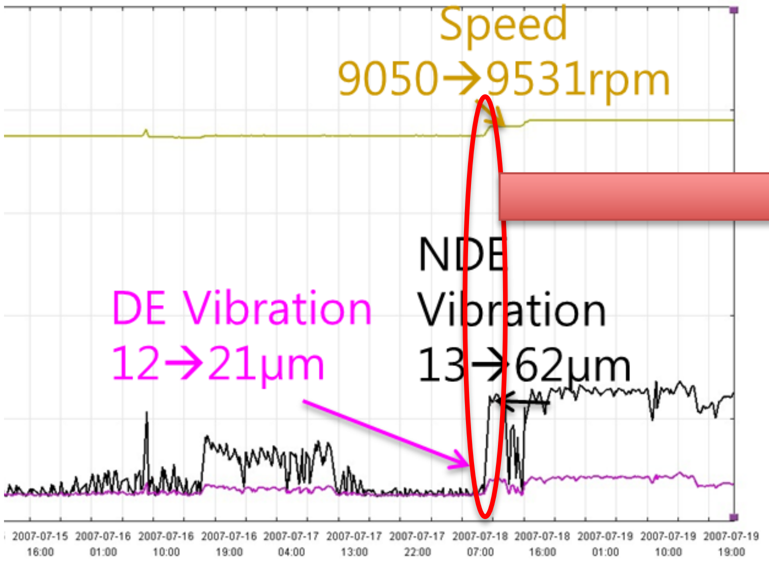
Unexpected high mole weight(low hydrogen purity) which is almost twice higher than design occurred during initial start-up. The higher mole weight can lead higher destabilizing force than design expected. (higher cross coupling)

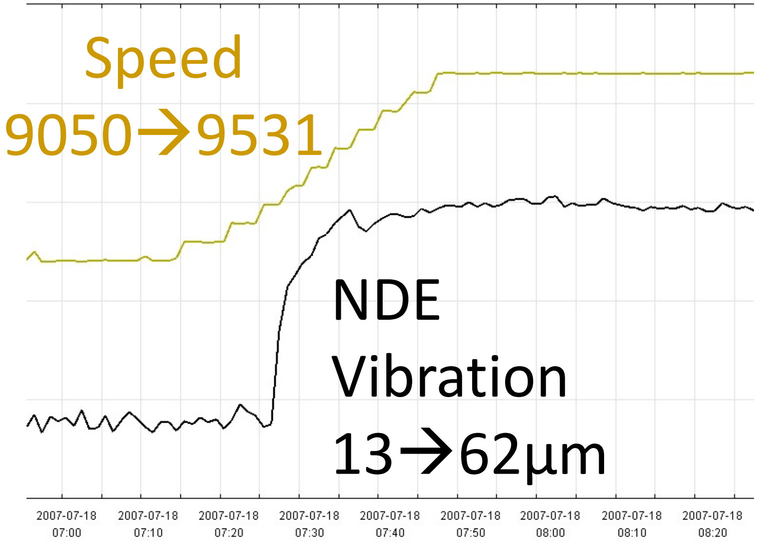
Contents		Design	Actual
Gas Composition	Water Vap.	0.1	0
	H2S	<50ppm	13.4
	H2	87.65	72.13
	C1	9.85	13.41
	C2	1.75	3.6
	C3	0.44	0.63
	IC4	0.1	0.19
	NC4	0.11	0.11
	IC5	0	0.04
	NC5	0	0.02
	C6+	0.2	0.26
	N2	0	9.61
Mole weight		4.34	8.09



Addition to higher mole weight, vibration amplitude increased as speed increased.

→ Log Dec decreases as speed increases





3. Troubleshooting - ④ Bearing Design & ⑤ Any Looseness

Low

④ Bearing Design

The radial bearing of the compressor is tilting pad bearing. Tilting pad bearing generate very little destabilizing cross coupled stiffness. So possibility of Oil Whirl caused by bearing is low.

⑤ Any Looseness

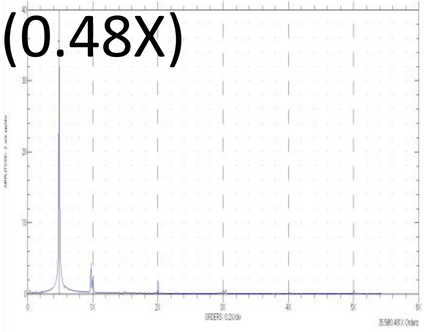
All base & support bolt tightness was check and was properly tightened. Bearing clearance was in design based on the shop assembly report. So possibility of sub-synchronous vibration caused by looseness is low.

	Design	Assembly Record
DE side(mm)	0.15~0.20	0.17
NDE side(mm)	0.15~0.20	0.18

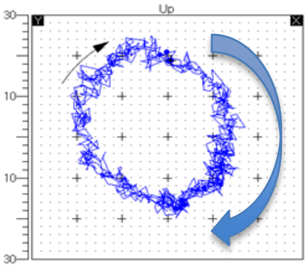
Conclusion

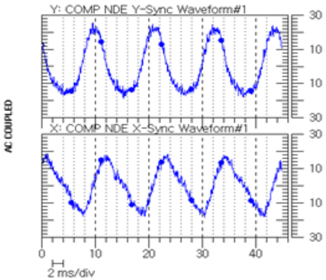
Vibration Analysis

- Sub-synchronous (0.48X)



- Orbit form(circular) and Precession(forward)





Fluid Induced Instability

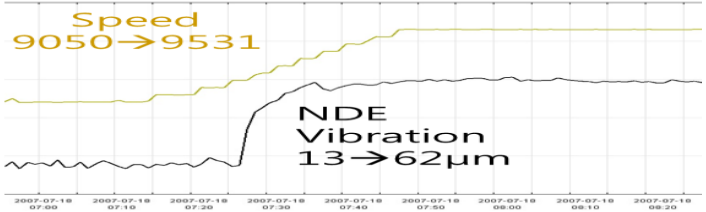
Destabilizing force

- Higher MW

Design : 4.34

Actual : 8.09

- Higher speed → higher gas momentum→ high vibration



Gas Whirl

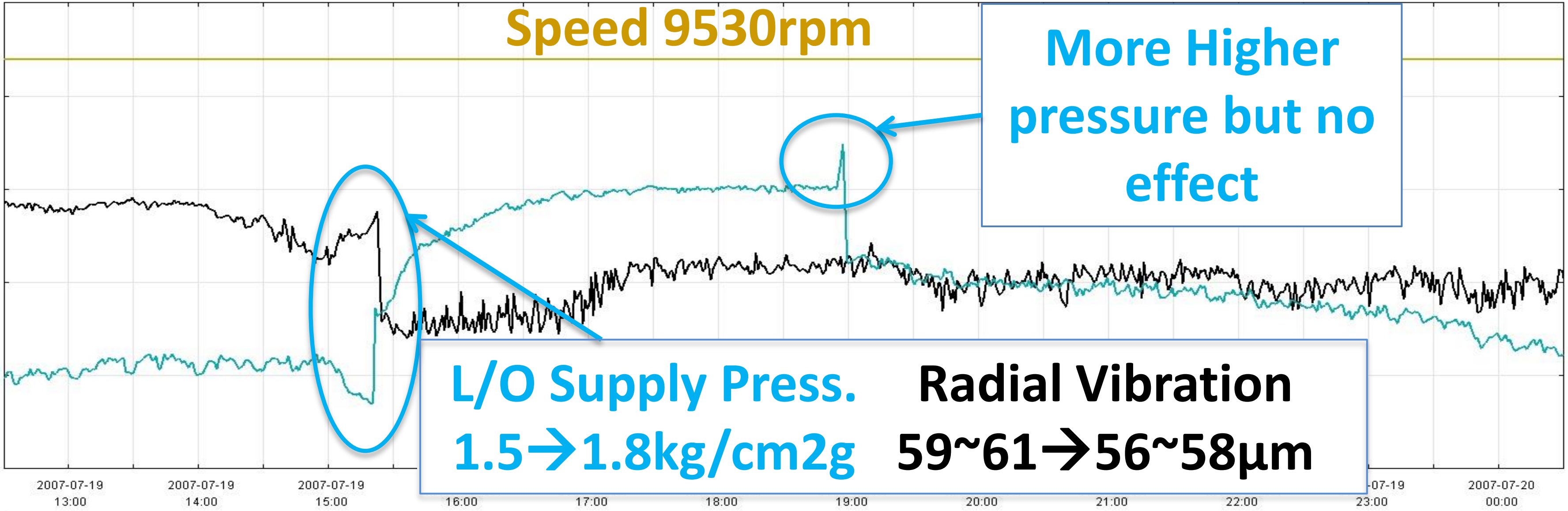
4. Solutions and Results

On-Stream

(1) Increase lube oil supply pressure

Higher oil pressure increase radial stiffness[1]. When oil pressure increased 1.5→1.8kg/cm2g(21.3→25.6 psi), vibration decreased but effect of decreased amplitude is little.

[1]: Agnieszka Muszynska, 2005,“Rotordyanmics”, section 4.14.4



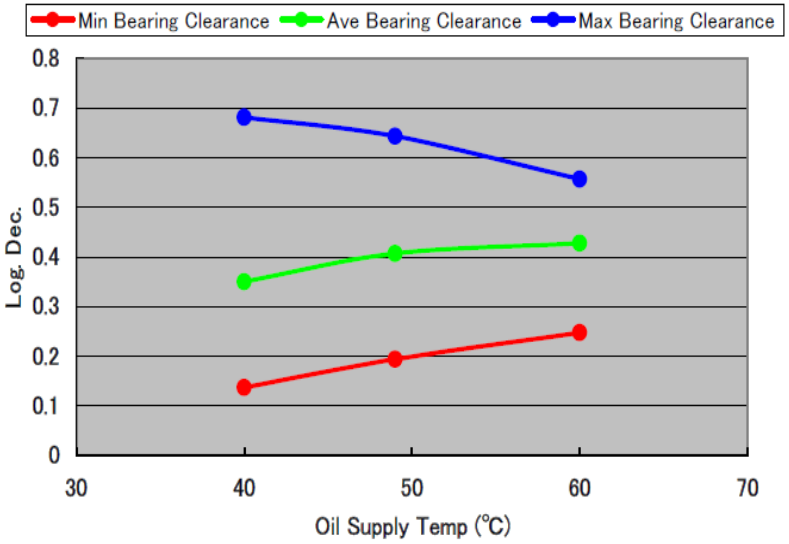
4. Solutions and Results

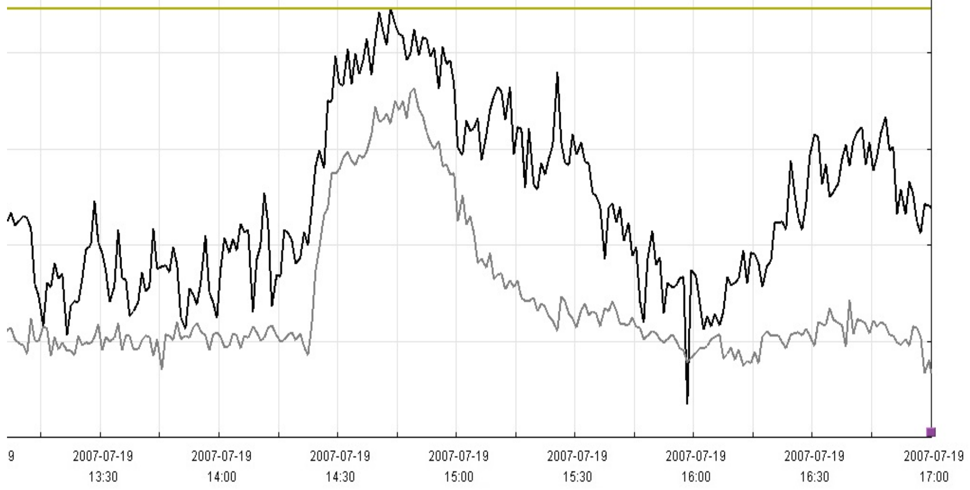
(2) Increase lube oil temperature

Base on stability analysis, increasing oil temperature should increase log dec. (Bearing clearance was average clearance based on shop assembly result) But increasing lube oil temperature made worse vibration.

L/O Supply Temp. 44→49℃

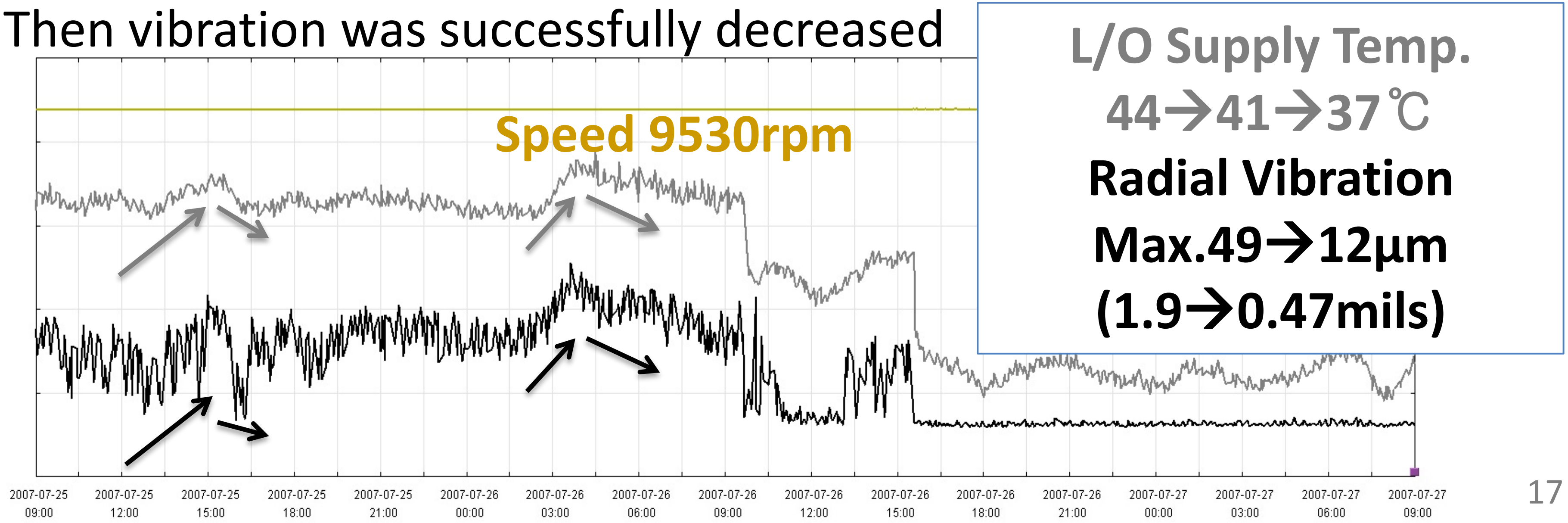
Radial Vibration 62→69μm(2.4→2.7mils)





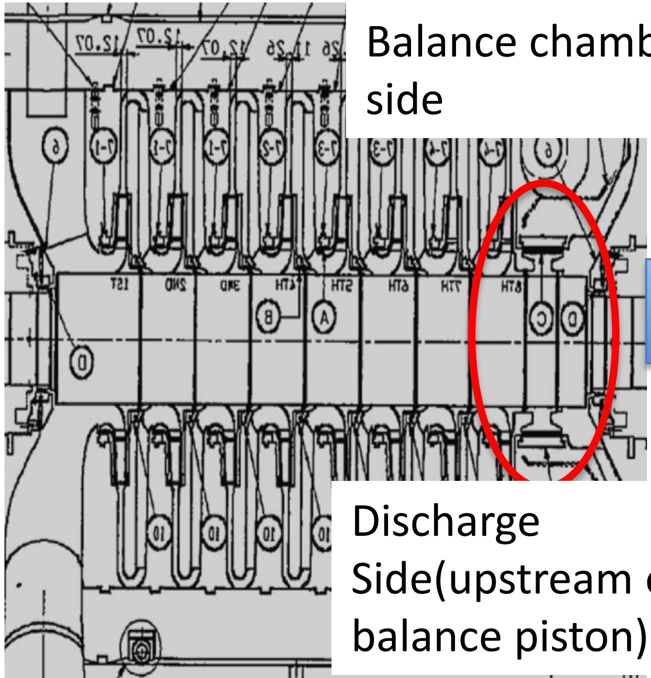
(3) Decrease lube oil temperature

Base on stability analysis, increasing oil temperature should increase log dec. but increasing oil temperature didn’t work.
The lube oil temperature was decreased to increase oil damping.
(Oil temperature and vibration showed directly related trend also)
Then vibration was successfully decreased



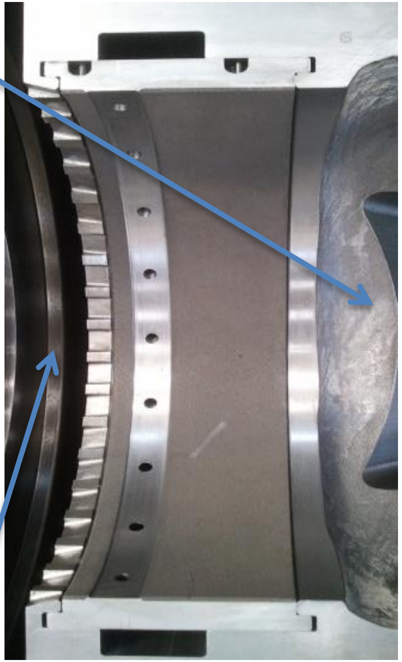
(4) Apply anti-swirl hole and swirl breaker

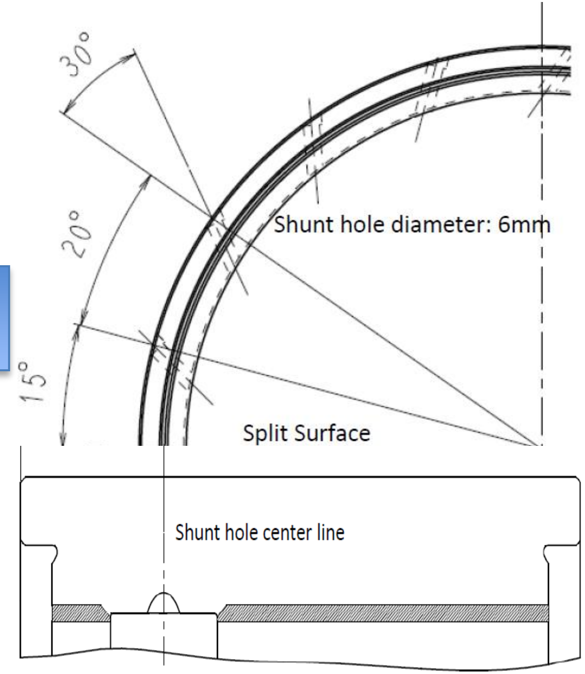
To solve gas whirl, anti-swirl hole were swirl breaker applied during next T/A(2008). And bearing clearance was increased (0.17~18→0.19mm) to increase log dec.



Balance chamber side

Discharge Side(upstream of balance piston)

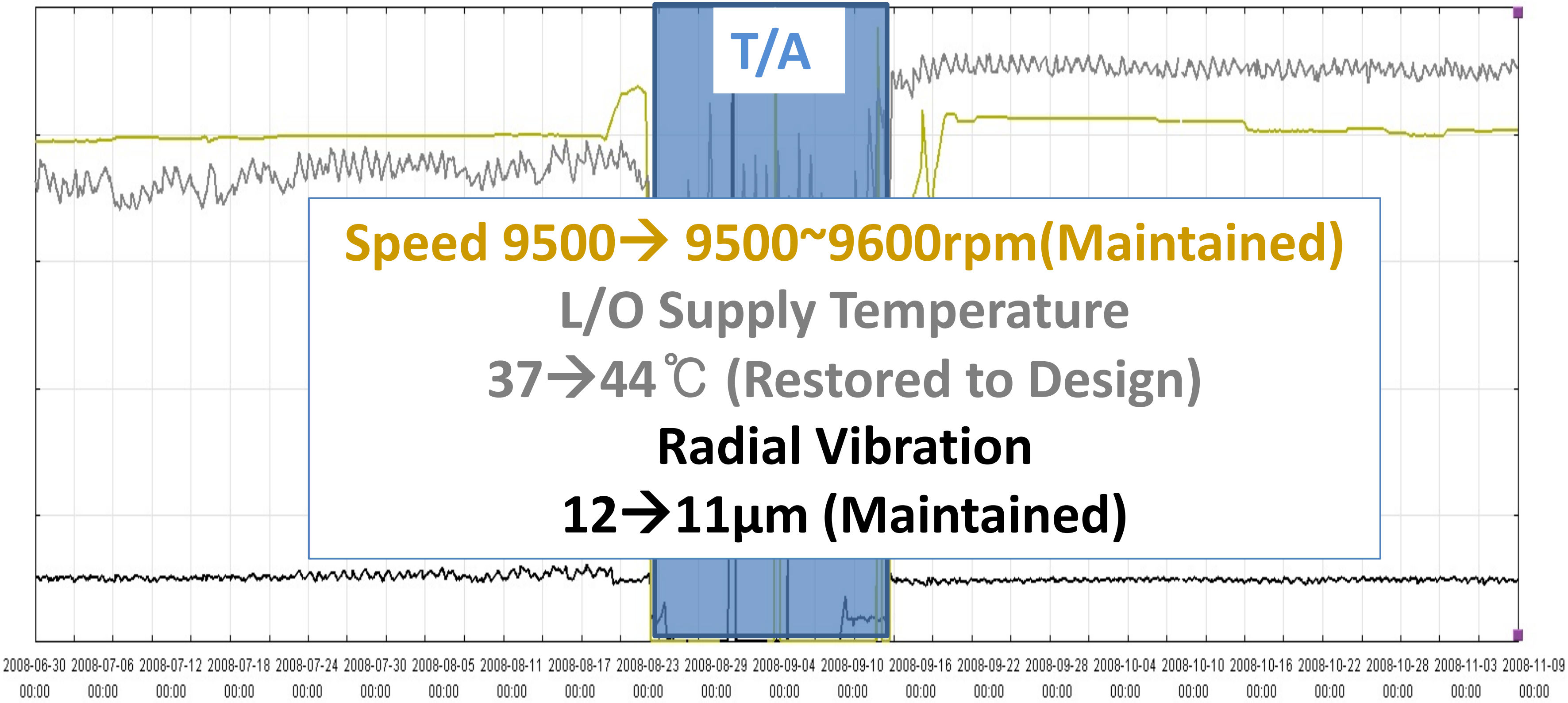




4. Solutions and Results

T/A

After apply above countermeasure, compressor has been operated stably with oil temperature back to design



5. Lessons Learned

- **Changing lube oil supply temperature**

Decrease lube oil temperature to increase damping. For this case, it was effective but based on stability analysis increasing oil temperature is effective to increase log dec. so temperature changing should be tested in both directions (i.e. both increasing and decreasing oil supply temperature)

- **Changing lube oil pressure**

Increase lube oil pressure to increase stiffness and damping. For this case, it was little effective but increasing lube oil pressure can increase stiffness and damping so it is worth to try

- **Anti-swirl hole**

Technically best solution but on-stream countermeasure is practical best solution