1st METS

Large Vibrations on a Centrifugal Compressor Caused by High Windage Heating on a Flexible Coupling

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Root Cause Analysis and Solutions

Yves Bidaut and Urs Baumann

Business Unit Oil & Gas

MAN Diesel & Turbo Schweiz AG

OUTLINE

- Background
- Description of the trains
- Findings
- Root Cause Analysis
- Actions
- Measurements after modifications
- Lessons learnt / Conclusion

Background

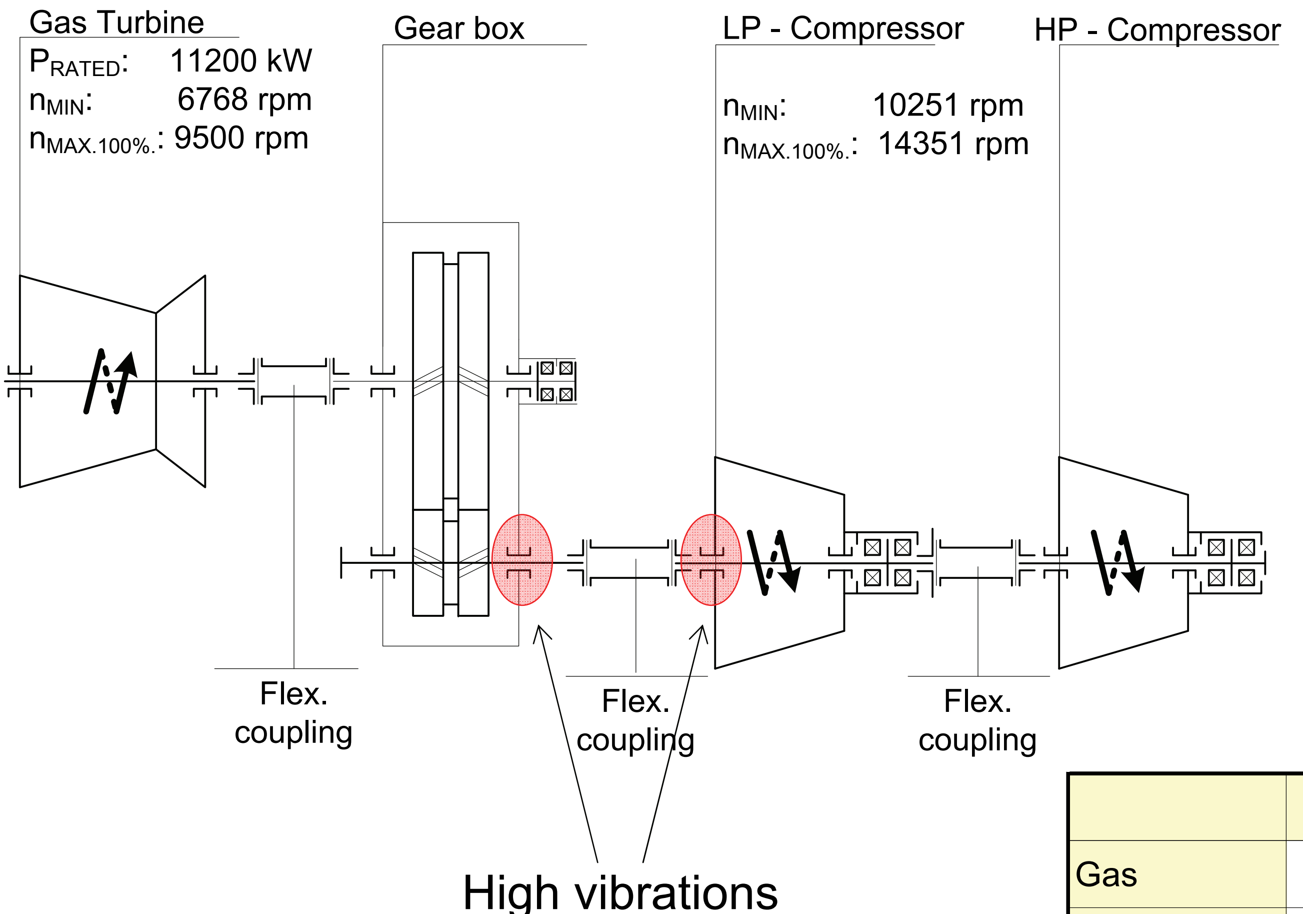
- 2 parallel trains consisting of a Low Pressure (LPC) and High Pressure (HPC) compressors were supplied for an offshore reinjection application near the coast of Angola.

- During the commissioning on site large lateral vibrations were observed at both units on the Bearings “Drive-End” of the Pinion and “Drive-End” of the LPC.

- Several balancing runs of the trains on site were necessary to operate both units and allow for injection gas.

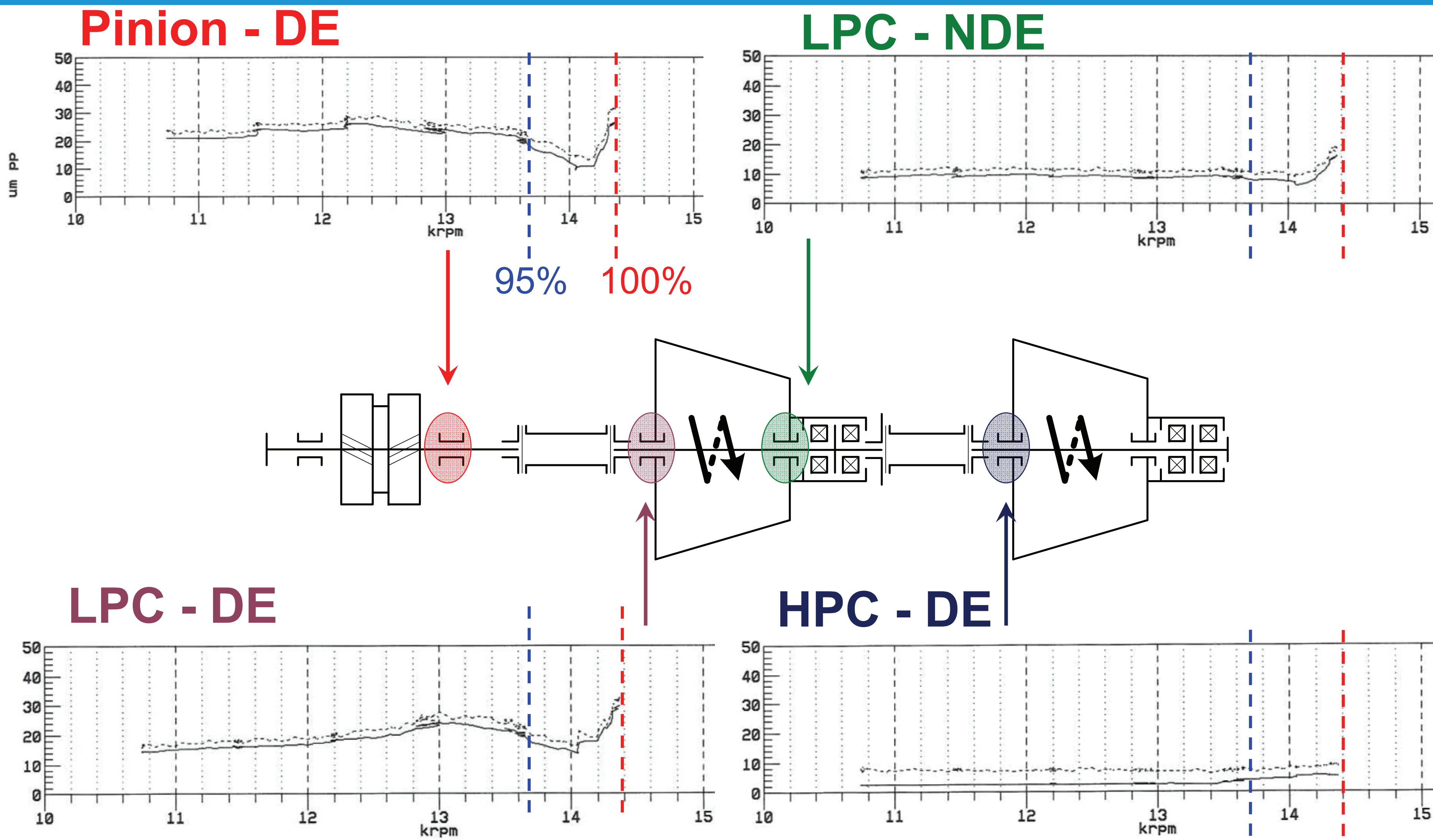
- To avoid repeated field balancing (if coupling or rotor must be removed/reinstalled during future maintenance) the coupling and oil system needed to be re- designed.

Train Arrangement , Compressors



	LPC	HPC
Gas	Natural	
p_s (bara)	20.5	116
p_d (bara)	118	323

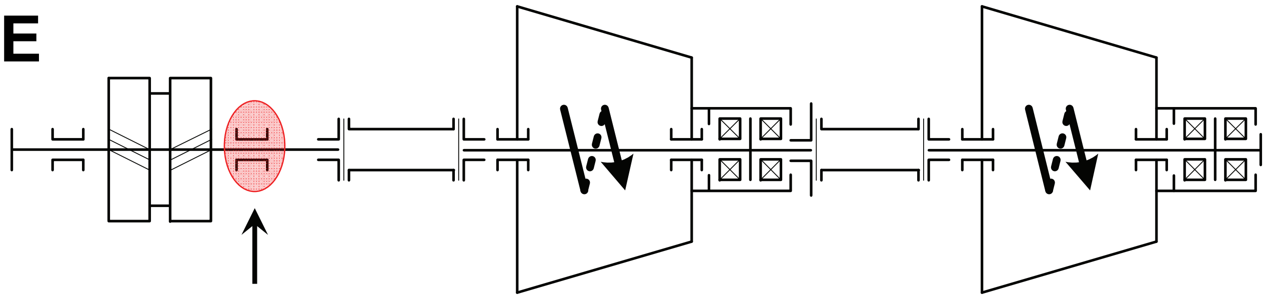
Findings – Lateral Vibrations

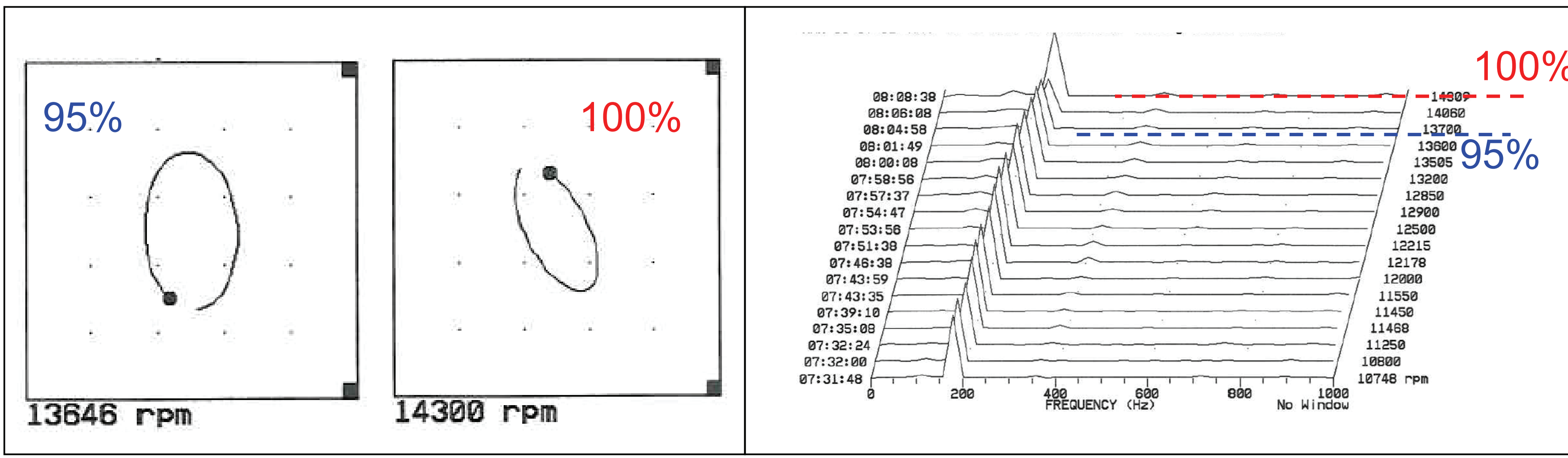


→ Important increase of vibrations above 97% speed

Findings – Lateral Vibrations

Pinion, DE





Orbit

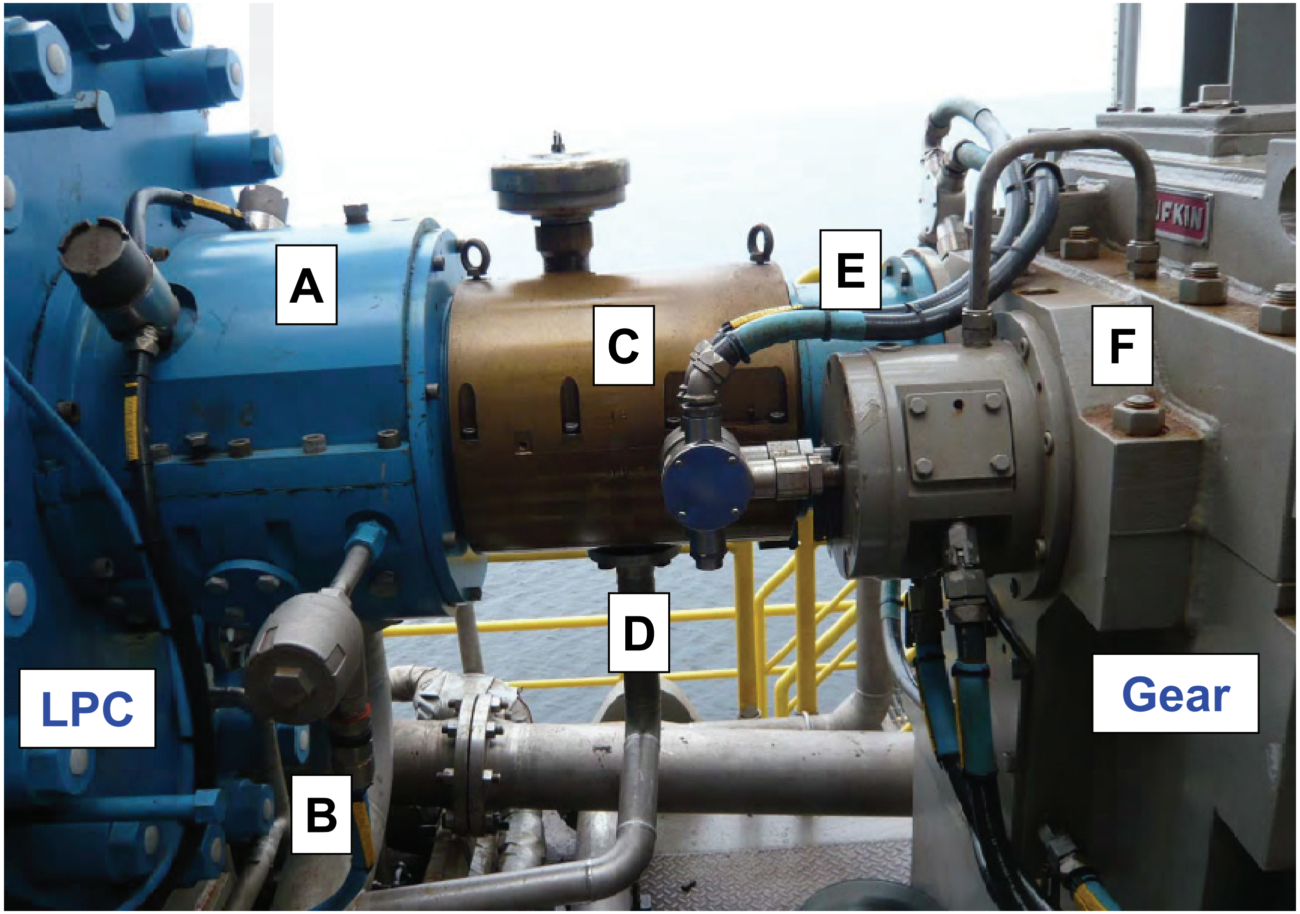
→ Phase change

→ Resonance in Speed range?

Waterfall -Diagram

→ No sub-synchronous

Findings – Coupling Guard Temperature



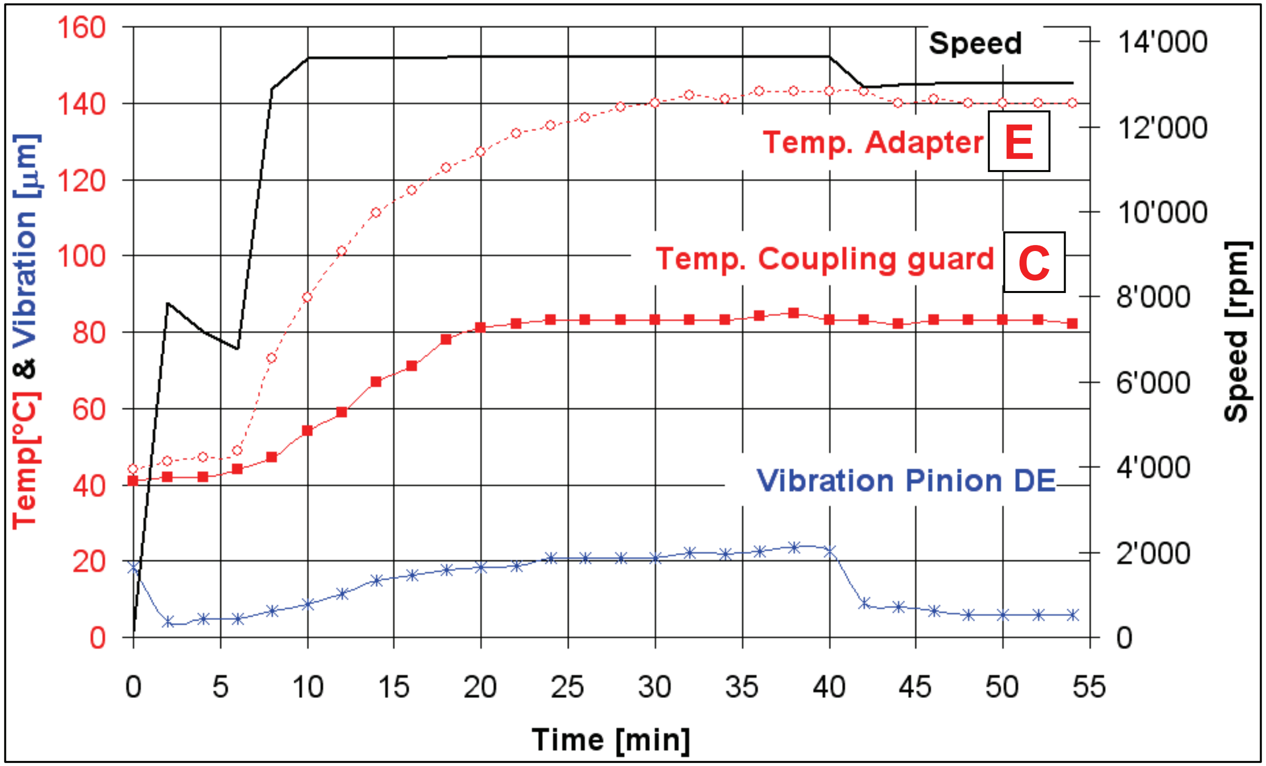
Point n°	Train A	Train B	
A	84	77	°C
B	72	64	°C
C	101	88	°C
D	83	84	°C
E	136	126	°C
F	69	72	°C

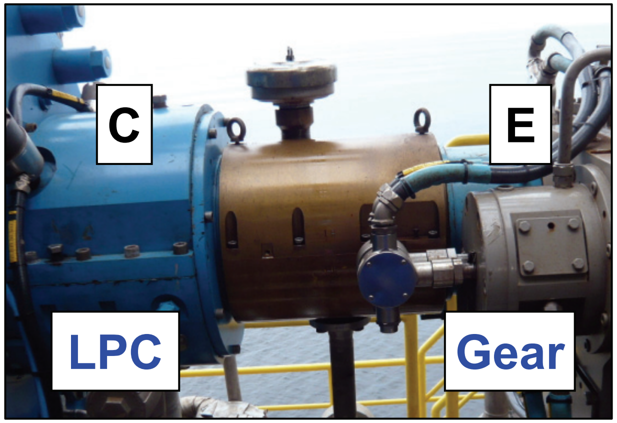
Temperatures @ 94 % - Speed

→ Too high temperature on adaptor Pinion / Coupling guard

Findings – Coupling Guard Temperature

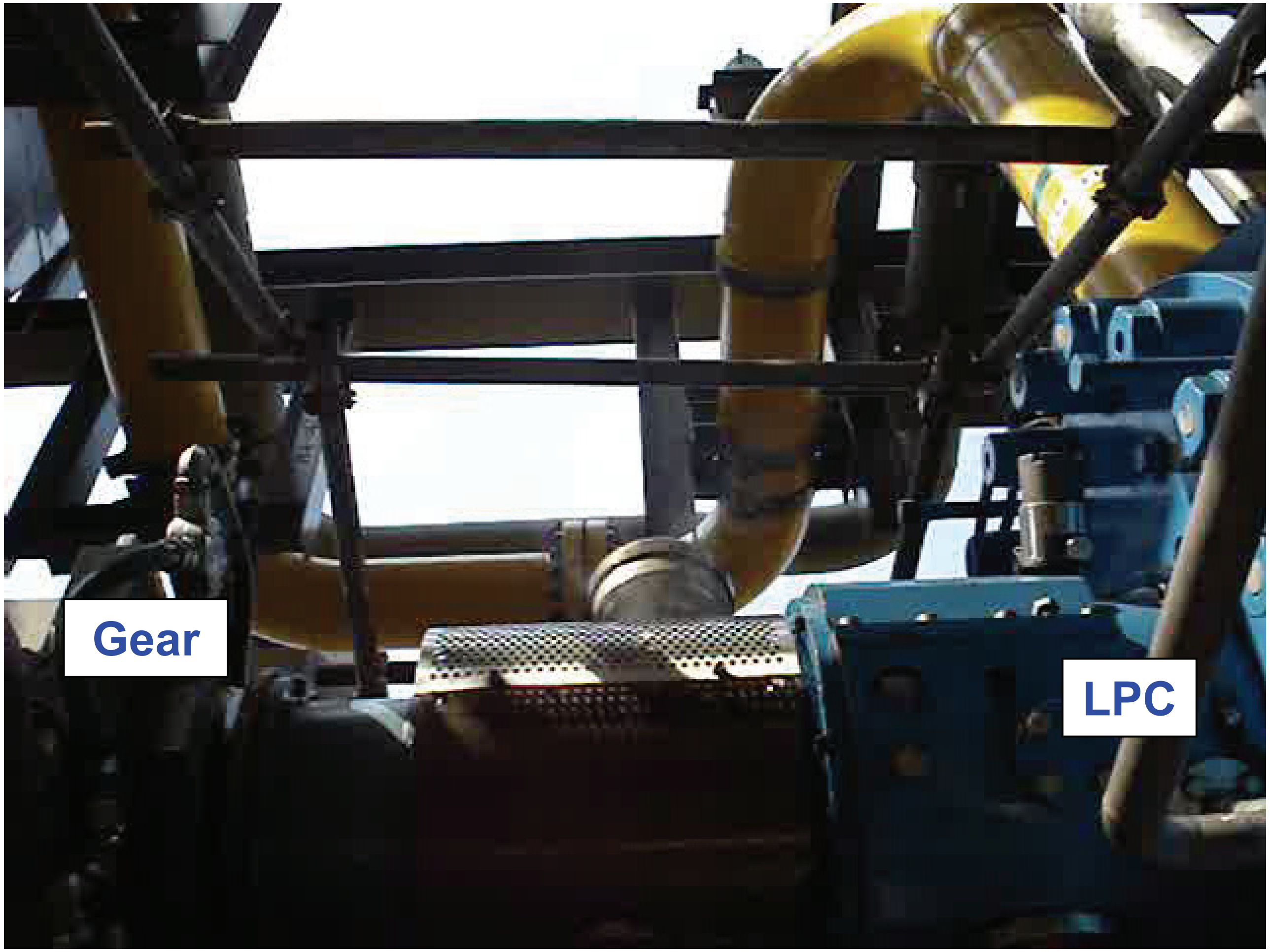
- Speed hold at maximum continuous for 30 minutes





- Vibrations increase as coupling becomes hotter

Findings – Cooling Flow into coupling guard ?



→ Oil – mist comes out from breather !

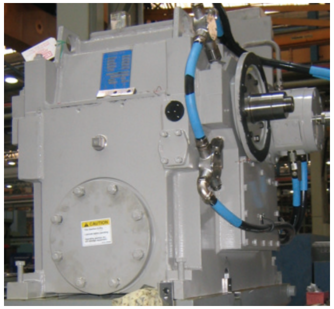
Findings - Summary

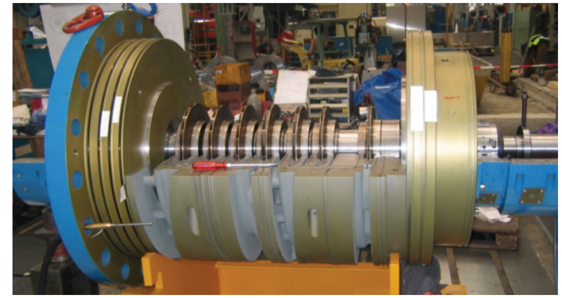
- Both trains (Train A & Train B) show similar behavior.
- Important increase of vibrations at Pinion DE & LPC DE above 97 % Speed.
- Important phase shift in operating range showing a resonance
- High Temperature at Coupling guard at 100% Speed.
- Vibrations increase as coupling becomes hotter at speed.
- No cooling air into the coupling guard.

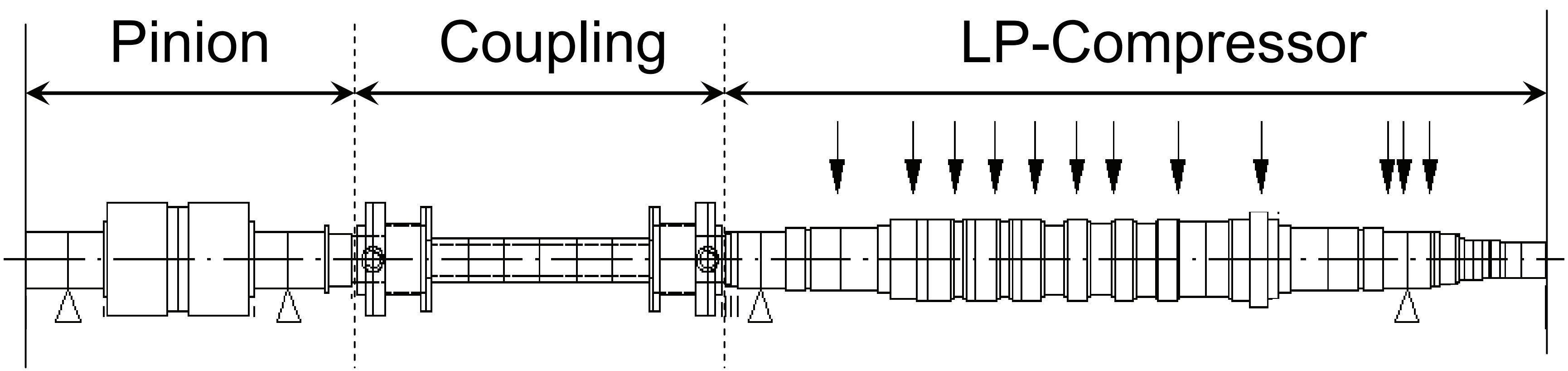
Analyses – Root Cause Analysis

- According to API 617 a lateral analysis of each single compressor was previously performed by the compressor supplier. Also the gear supplier had calculated the lateral vibrations on the pinion according to API 613.
- No resonance was shown in either the compressor supplier's rotor study of the LPC nor of the pinion supplier's on the pinion.
- To determine if the observed phase-shifting corresponds to any resonance a lateral analysis of the high speed shaft system consisting of pinion, coupling and LPC was performed.

Lateral Analysis of High-Speed Train



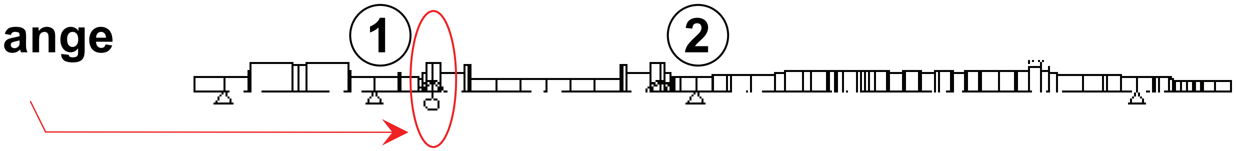




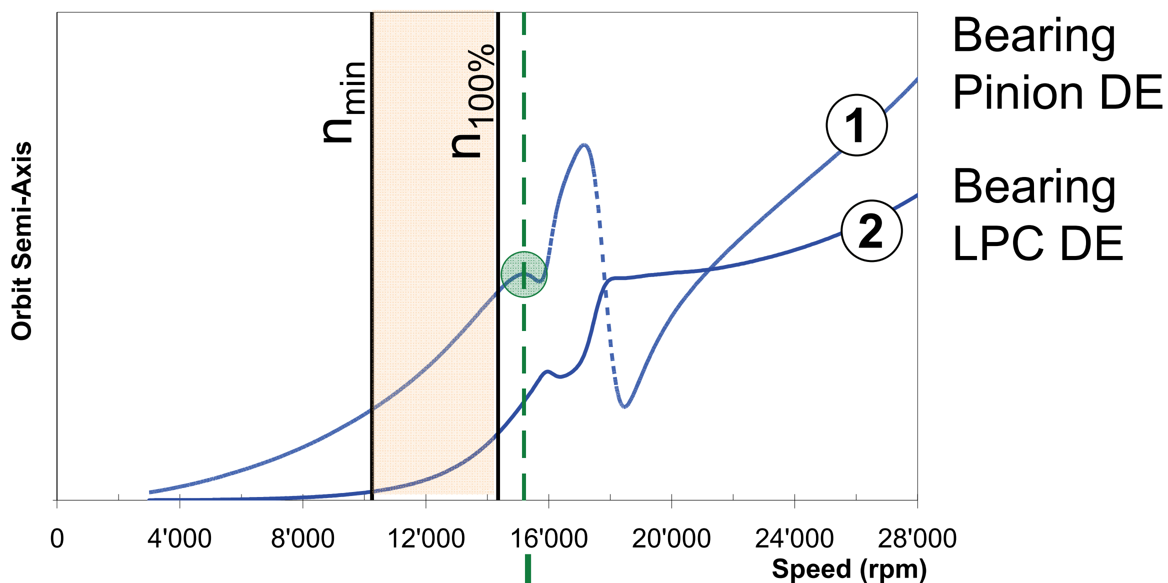
Rotordynamical Model

Lateral Analysis of High-Speed Train

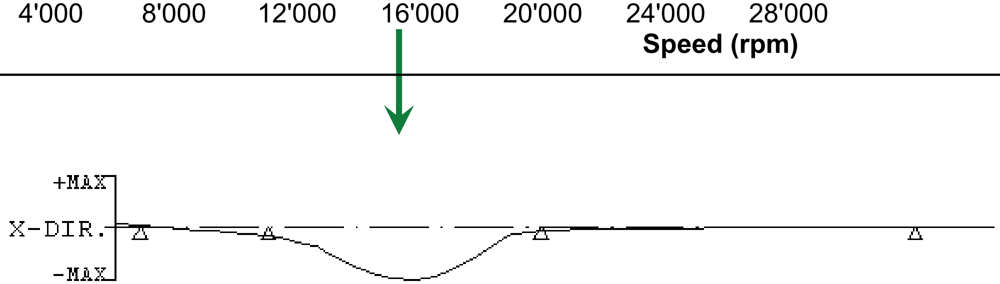
Unbalance set at coupling flange



Unbalance Response Plot



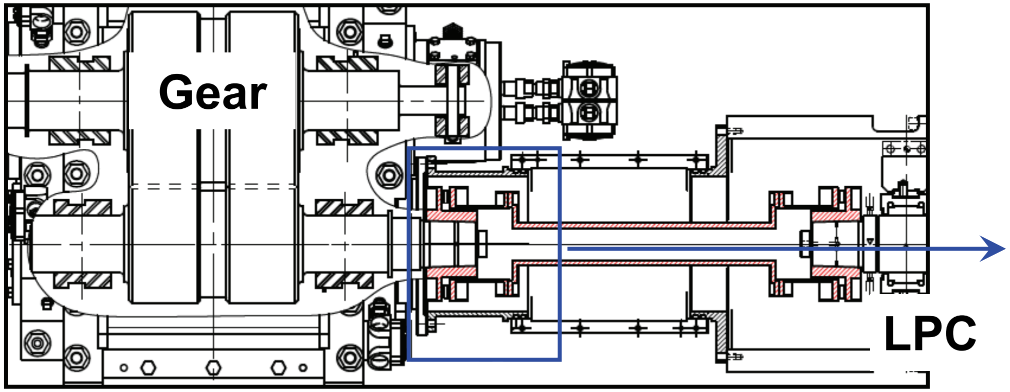
Mode Shape @ resonance (15,200 rpm)

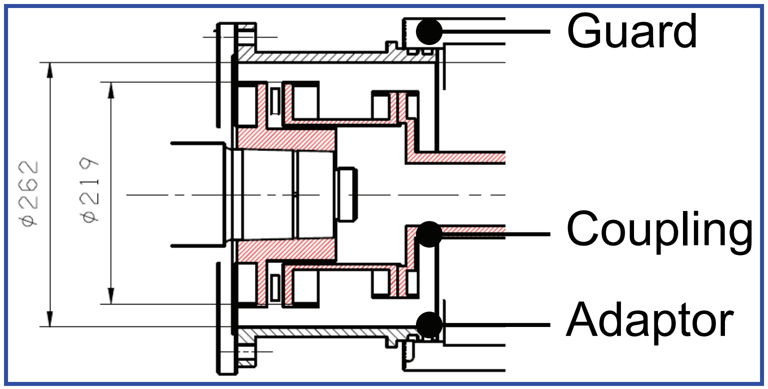


- Resonance corresponding to overhang mode near $n_{100\%}$

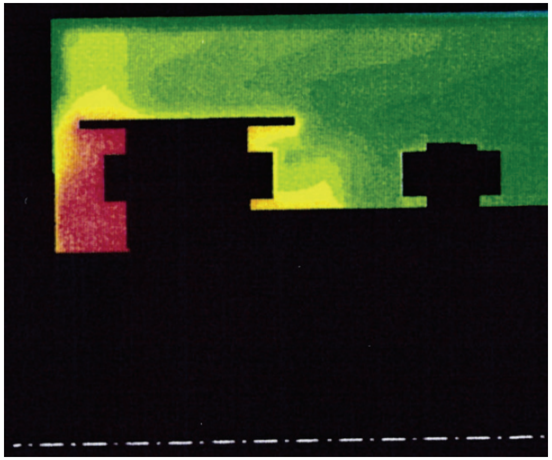
Analyses – Temperature at coupling

- Restricted space between flange (rotating part) and adaptor/guard + high circumferencial speed at flange (165m/s) → high windage heating generated.





- This leads to a high temperature at the guard and coupling (including the flexible element) itself and thus to an unbalance in the coupling.



Static Temperature distribution (typical) between coupling and guard

Summary of the Root Cause Analysis

- The lateral analysis on the high-speed train shows a resonance near the operating range. However, with a well balanced coupling, the vibrations remain low.

- Any unbalance at the coupling leads automatically to a high vibration on the bearing DE of the Pinion and of the LPC (difficult to be balanced).

- The coupling is therefore very sensitive to unbalance.

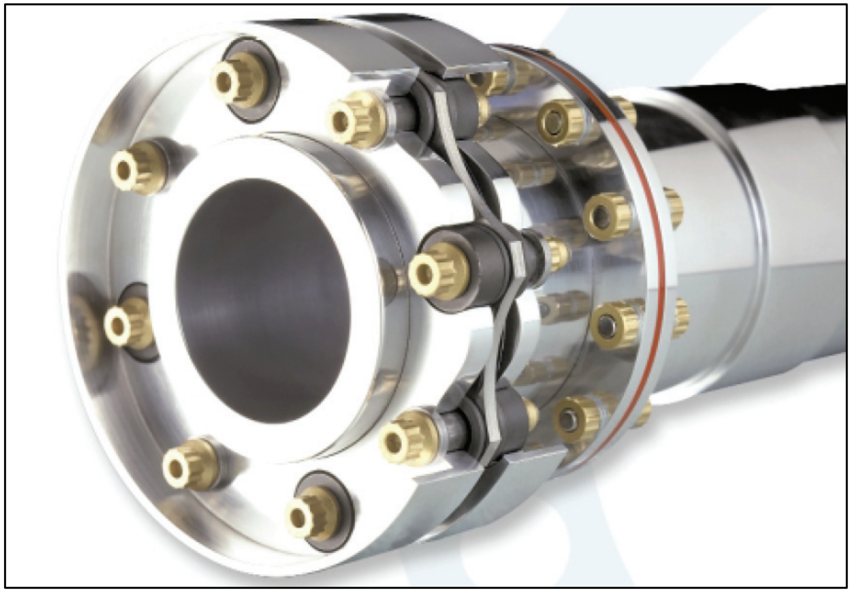
- From the measured high temperature on the guard / adaptor it can be concluded that the coupling runs at a high temperature which produces such an unbalance.

Actions

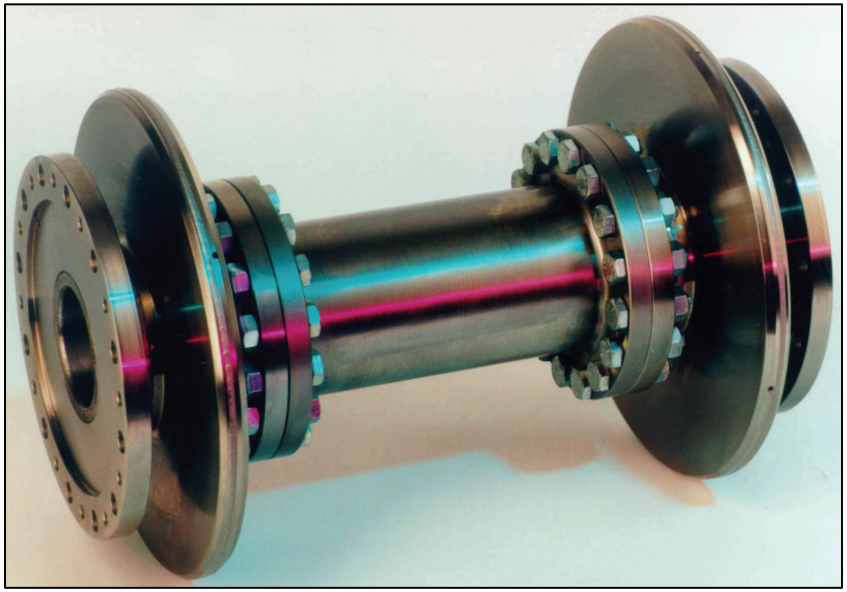
1. Change the coupling to get
   - lighter overhang mass → shift the resonance
   - less windage heating → avoid / eliminate unbalance

2. Include a ventilation system on the Lube oil reservoir to provide cooling flow into the coupling guard.

Action 1 – New Coupling



Previous (flexible disk)

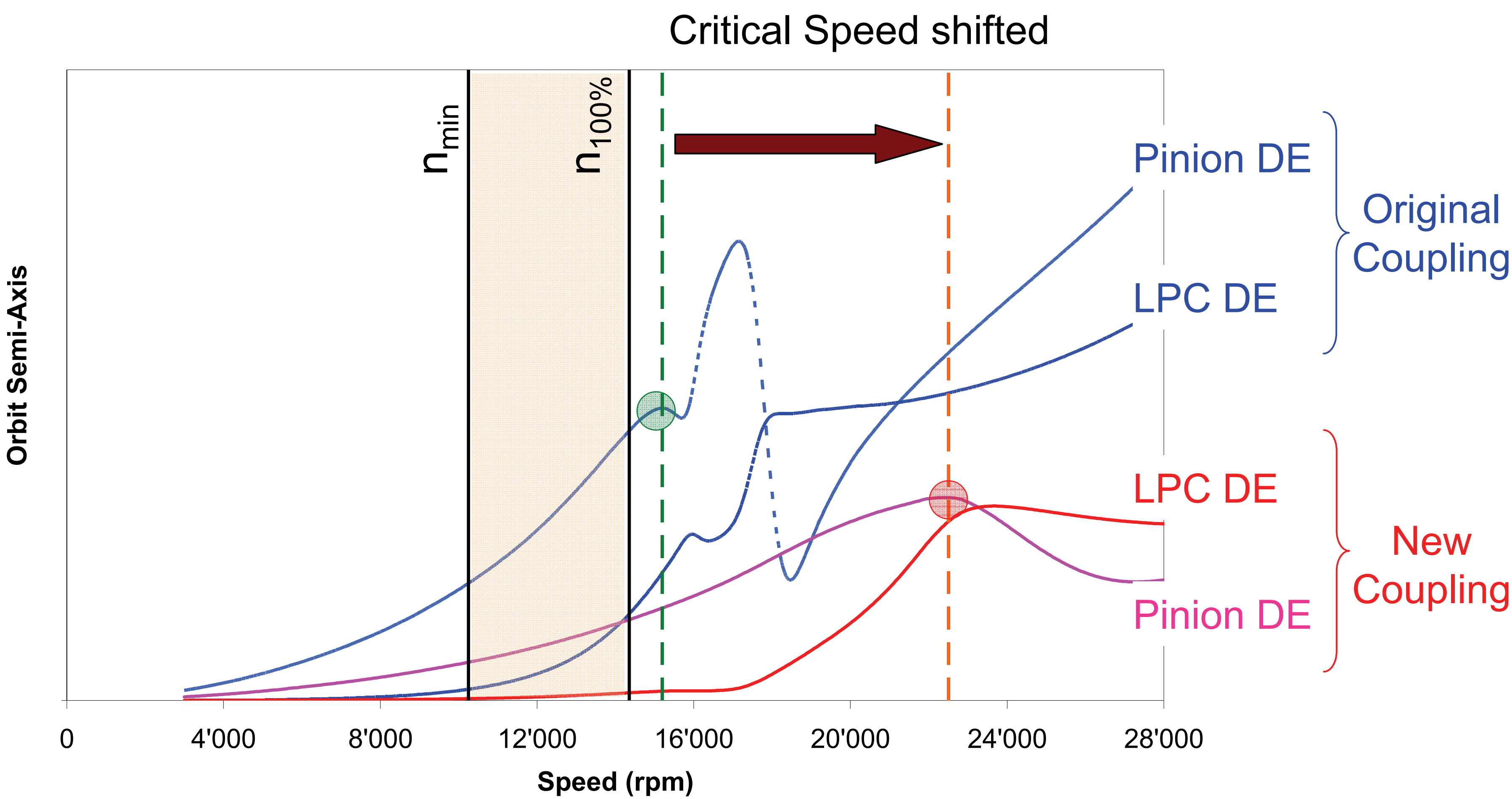


New (diaphragm)

→ Considerable reduction of windage heating power

→ Reduction of coupling mass ≈ 50%

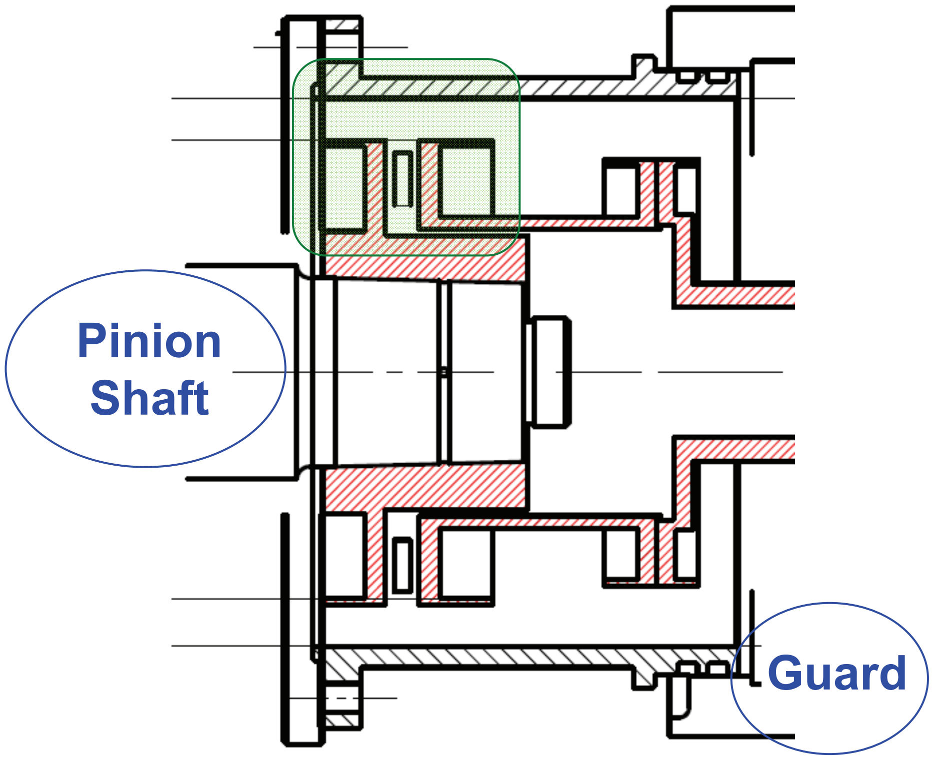
Action 1 – New Coupling – Consequence on Critical Speed



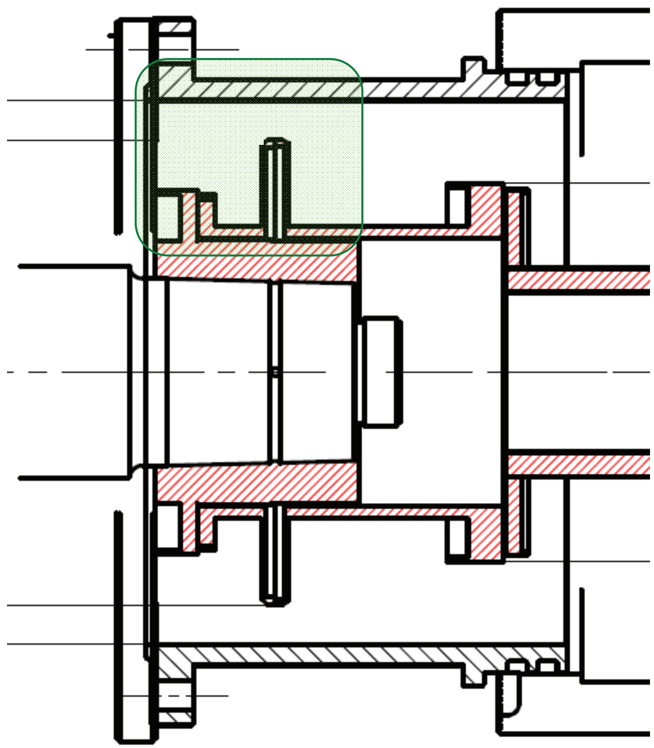
→ Thanks to the new coupling the critical speed is shifted from 15,200 rpm up to 22,500 rpm

Action 1 – New Coupling

Original (flexible disk)



New (diaphragm)

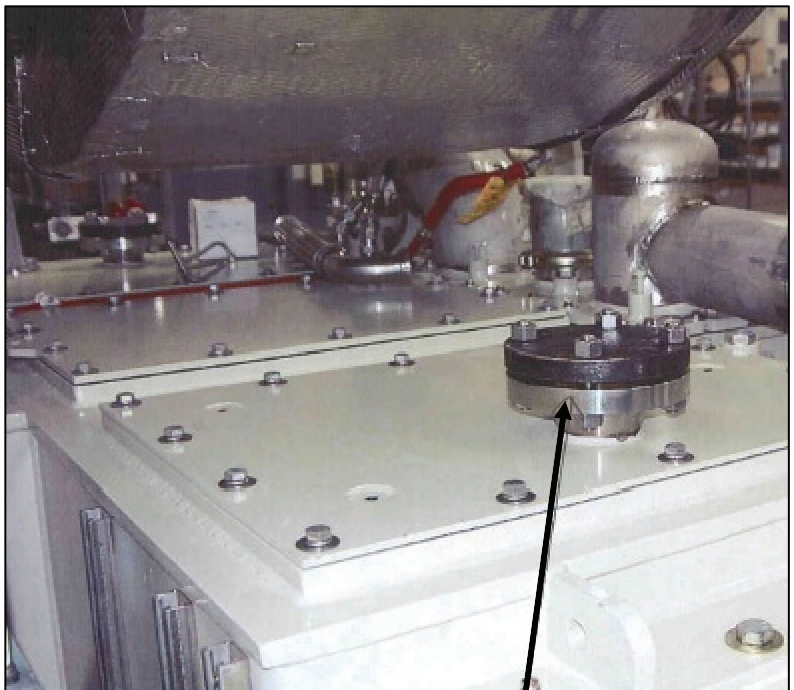


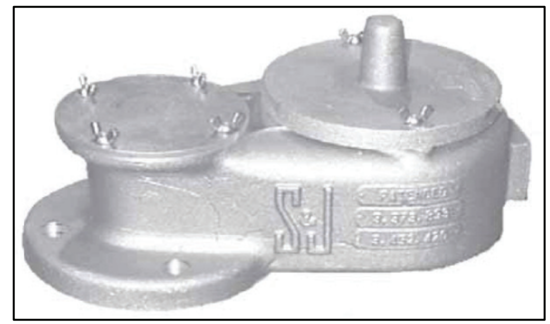
→ New coupling generates less windage than the original one (smooth diaphragm surface, bolts on smaller diameters)

→ More space between flange and adaptor

Action 2 – Active suction device on oil system

- An assembly of fan/blower and vacuum valve is mounted on the LOS. A demister-ventilator is put on the Lube Oil Reservoir.





Vaccum relief vent

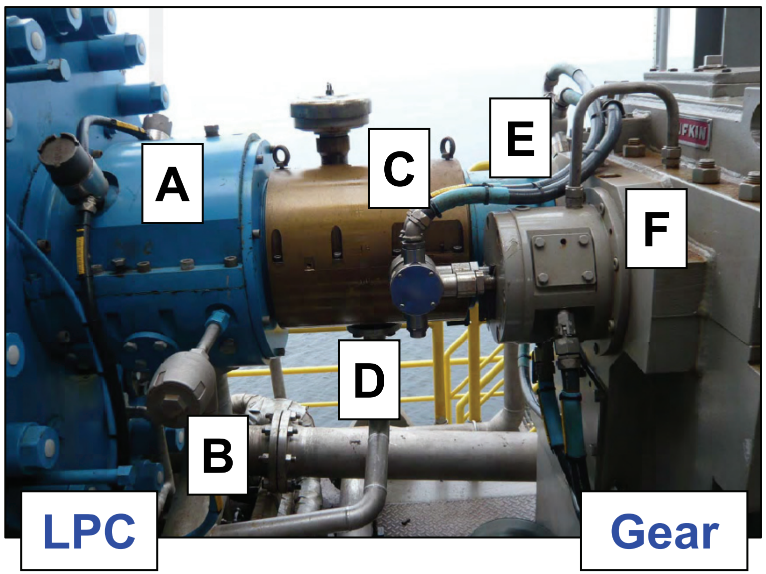
Flange of lube oil tank where the valve has to be mounted

Summary of actions

Original		Modifications
Original disk, flexible shim pack 24.5 kg	Coupling Pinion- LPC Type Half Weight	New diaphragm 13.8 kg
	Critical Speed	
15‘200 rpm AF = 3.4	Pinion Overhung	22‘500 rpm AF ~ 2.5
	Temperature	
> 2000 W > 130 °C to be expected	Heat Production Expected Guard Temp. Thermal Sensitivity (unbalance)	< 1500 W < 100 °C unlikely
	Oil Pressure in LOS	
positive		negative (assembly of fan & vacuum valve on LOS)

Measurements after modifications

- After replacement of the coupling the compressors were started up.

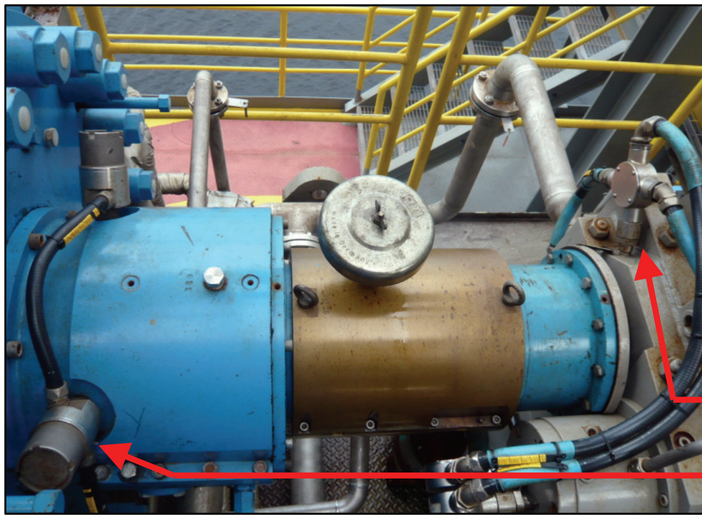


Point n°	Train Original A	Original B	After modifications A	After modifications B	
A	*84*	*77*	72	69	°C
B	*72*	*64*	59	57	°C
C	*101*	*88*	62	67	°C
D	*83*	*84*	61	64	°C
E	***136***	***126***	**83**	**78**	°C
F	*69*	*72*	59	62	°C

- Both units are now running with reduced coupling guard temperatures.

Measurements after modifications

- Also the vibrations were measured.



	Original		After modifications	
Date	*05.2008*		10.2009	
Speed	*13687 rpm*	*14202 rpm*	13281 rpm	14290 rpm
	94%	*99%*	93%	100%
Max. vibration (unfiltered)				
LPC DE	*9*	*16*	7	8
Pinion DE	*22*	*23*	16	17

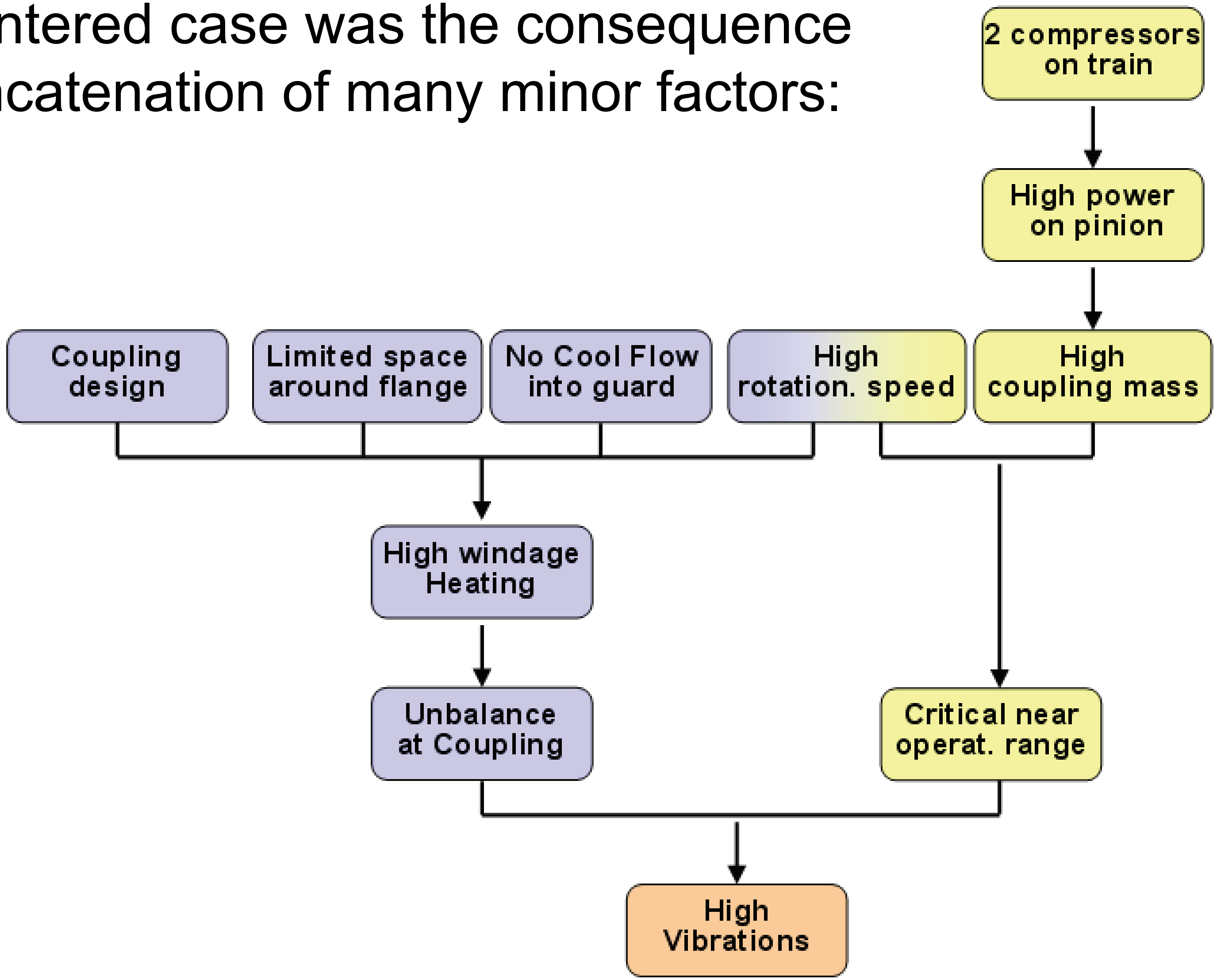
Reached after several balancing runs on site (Original)

Without balancing run (After modifications)

- All shafts are now running with good vibration levels.
- A balancing run is not necessary any more.

Lessons learnt / Summary

- The encountered case was the consequence of the concatenation of many minor factors:



Lessons learnt / Summary

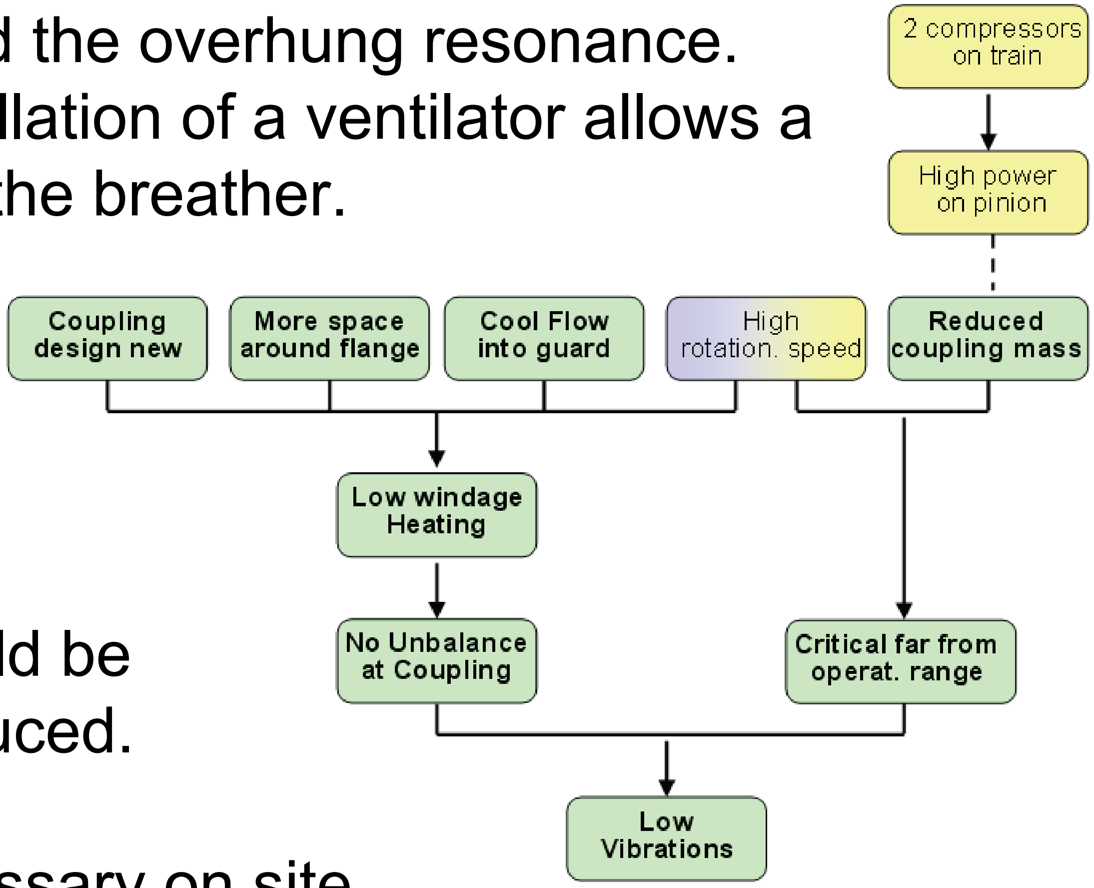
- For such configurations a standard Lateral Analysis (according to API) is not sufficient. A train lateral analysis including the coupling itself shall be performed (in order to determine the correct pinion critical speeds).

- In case of a resonance near or at the operating range due to the overhang mode the pinion DE and coupling are very sensitive to any unbalance.

- Especially the high windage heating produced by the flexible disk coupling inside the coupling guard can lead to an additional unbalance.

Lessons learnt / Summary

- To eliminate both negative factors (heat + resonance) the original flexible disk coupling was replaced by a diaphragm type coupling which reduced the heat production and shifted the overhung resonance. Furthermore the installation of a ventilator allows a positive flow through the breather.



- Thus the vibrations could be considerably reduced.

- No balancing was necessary on site.

Thank you !

Questions ?