40th TURBOMACHINERY SYMPOSIUM

CASE STUDY

‘BALANCE INSTABILITY AND VIBRATION ON A 6 MW INDUCTION MOTOR ROTOR’

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Induction Motor at Test Stand

Stabilizer Overhead Compressor

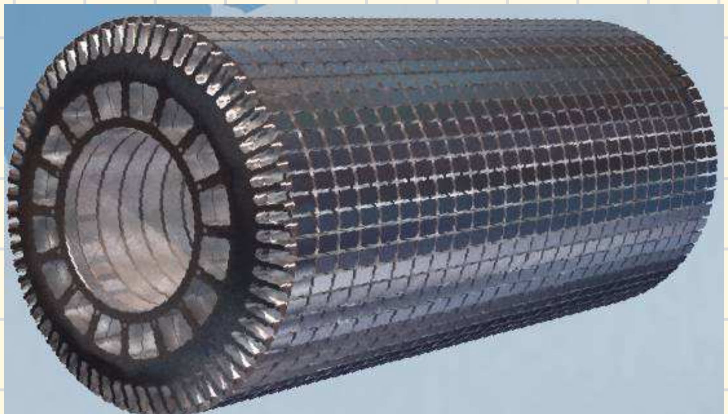
- Centrifugal compressor (with ‘side stream’)
- Two stage compression used for mixing vapor/gas from ‘stabilizer’ column into feed gas stream
- Speed increasing gearbox
- 6 MW induction motor driver with variable frequency drive
- Large variation in inlet flow
- Complicated control system
- No spare compressor

Induction Motor Driver

- 6 MW induction motor
- 6.6 kV 3 Ph 60 Hz
- Coupled with variable frequency drive (VFD)
- Motor designed per API 541 and IEC (hybrid standard)
- Routine and complete run tests including heat run test, unbalance response test, mechanical run test, over-speed test etc.

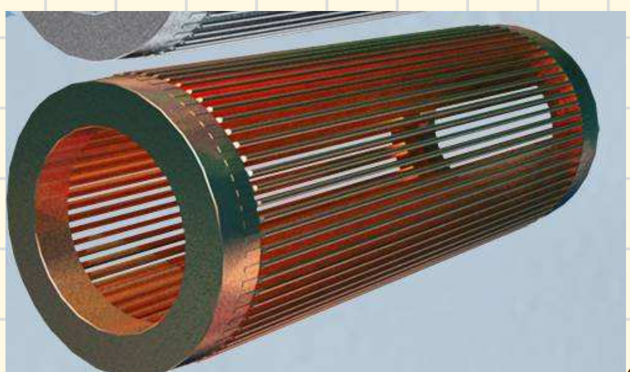
Motor Design: Squirrel Cage Induction Rotor

Rotor core
(Laminated steel)



Spider shaft
(Homogenous forged steel)

Squirrel cage
(Copper)

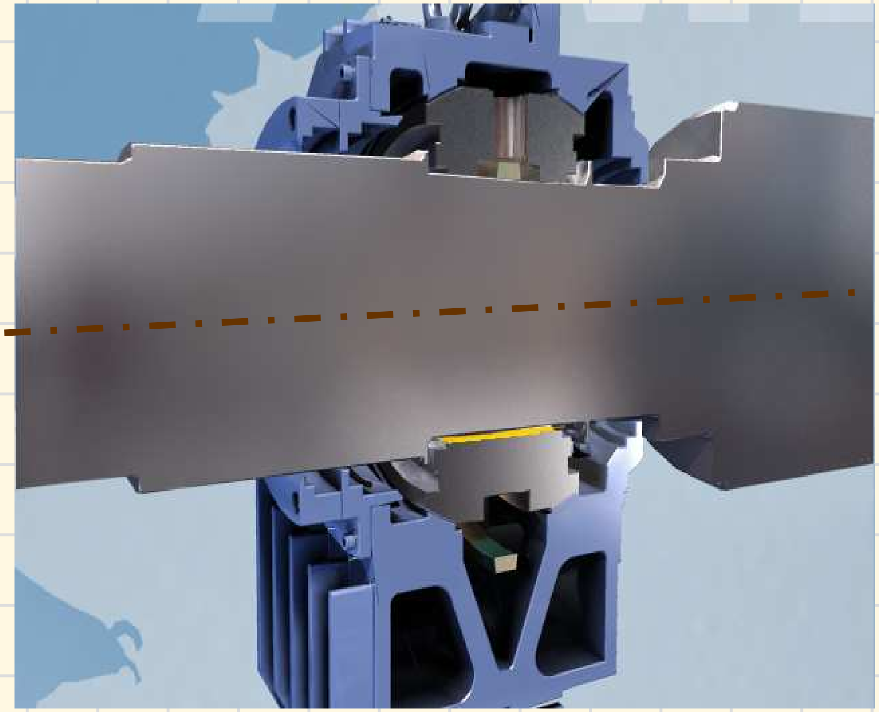


Rotor assembly AND

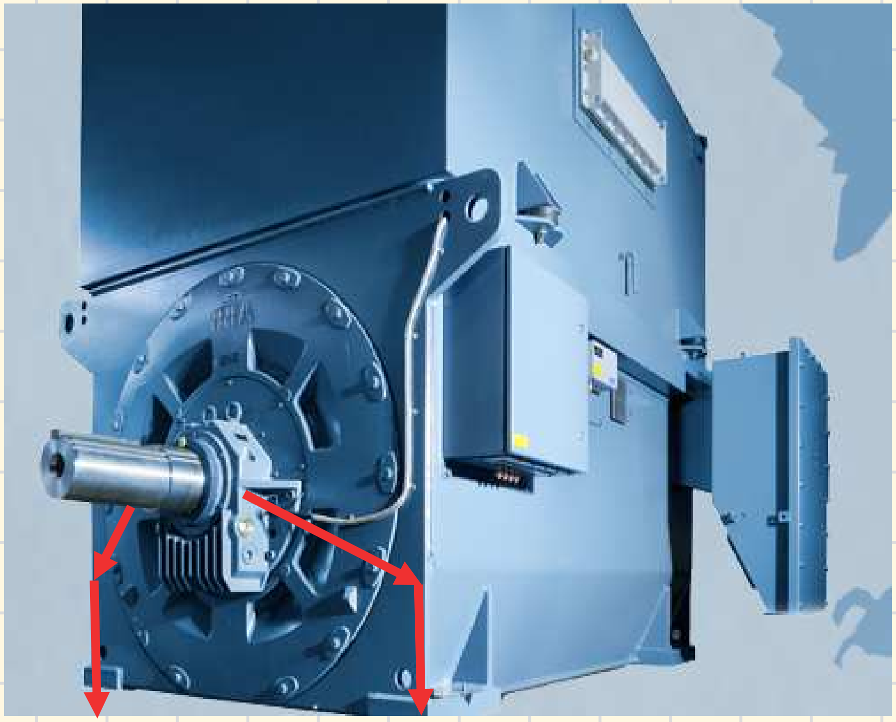
Complete rotor

The sheet laminations are shrunk on to the rotor shaft and compressed in axial direction

Motor Design: Sleeve Bearings and Stiffness Chain

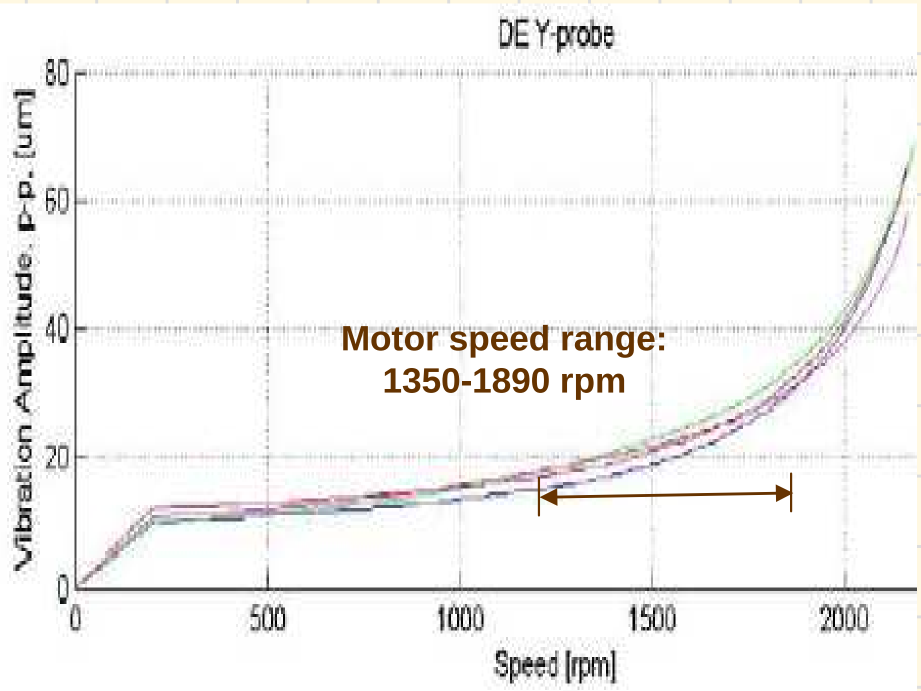


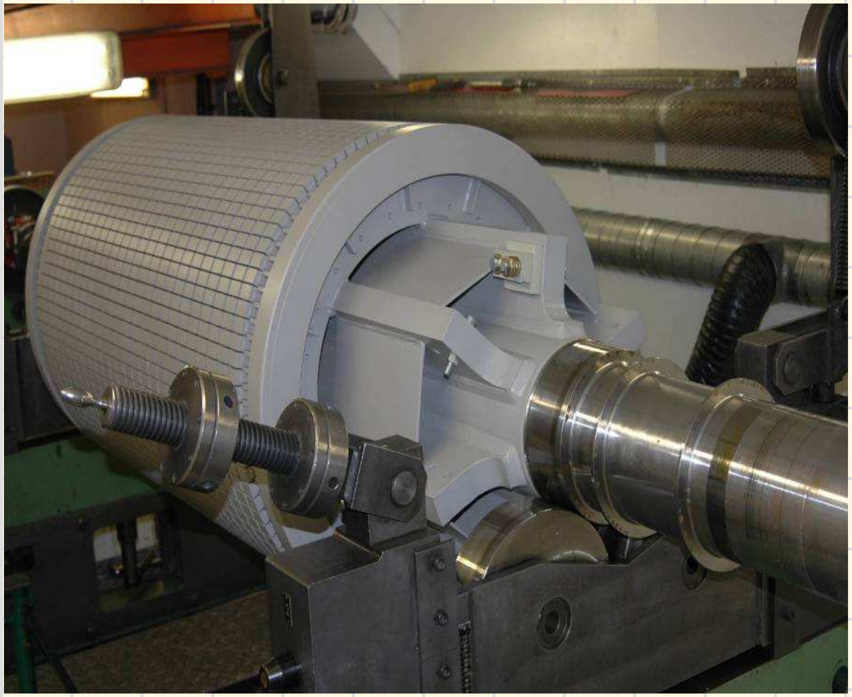
Sleeve bearings with
oil film for damping and stiffness



Stiff shaft design with
unbalance force pathway

Separation Margin and Balancing

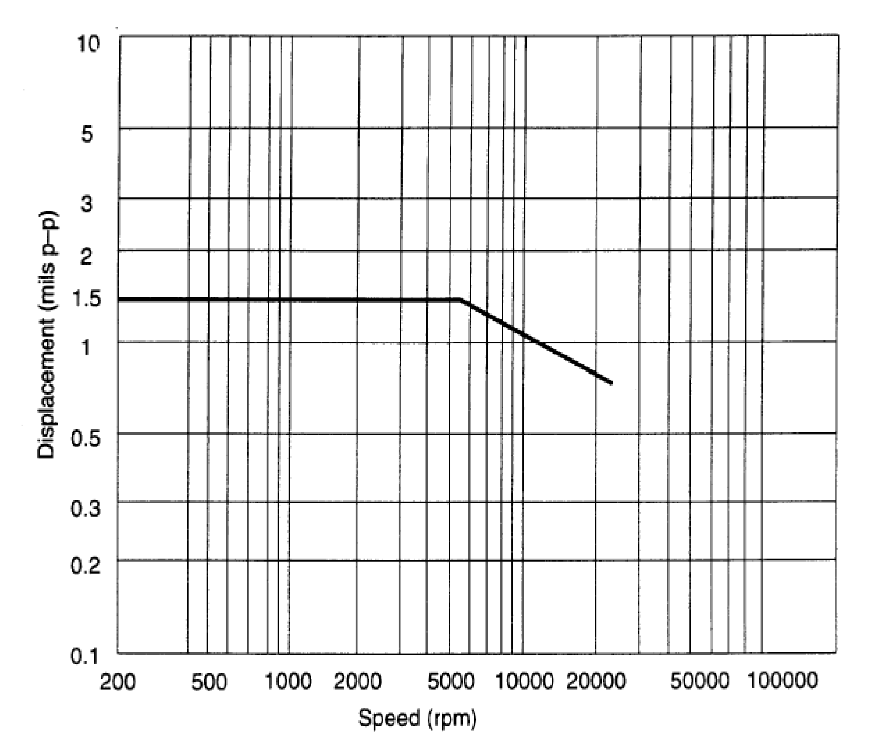


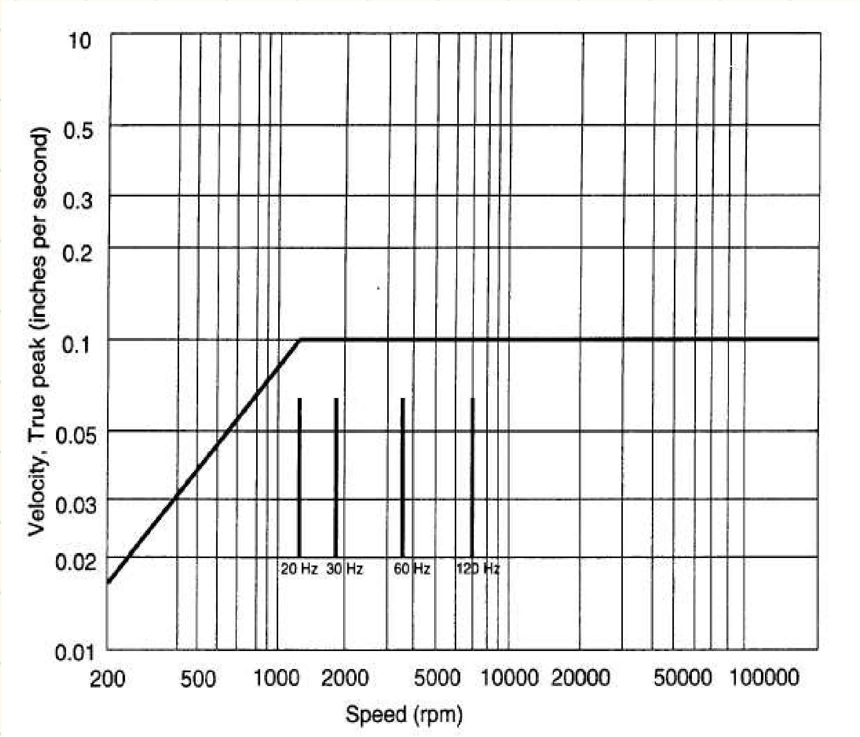


Normally 4 pole motors are run below first critical speed with sufficient separation margin (sub-critical operation)

2-plane balancing at reduced speed is often sufficient for sub-critical operation

API 541 Vibration Requirement





Shaft vibration limits

(Relative bearing housing using non-contact probes)

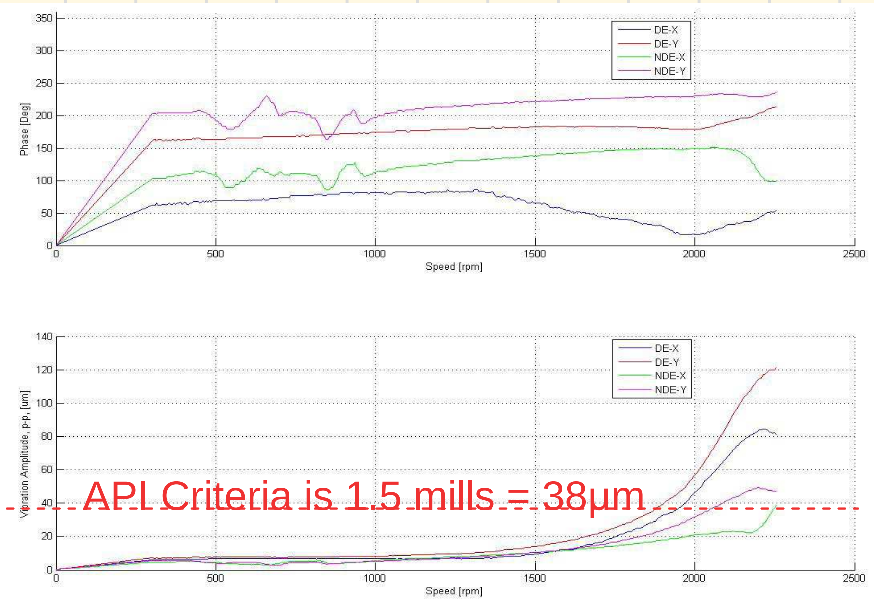
Bearing housing vibration limits

(Using bearing-mounted velocimeters)

Factory Acceptance Test (FAT)

- High vibration levels during over-speed test
- Vibrations above normal for the machine type at running speed (1800 rpm)
- High vibrations during over-speed test led to bearing failure

Factory Acceptance Test Results



Bearing Vibrations during Overspeed Test

Failed NDE Bearing during 4 hour Mechanical Run Test

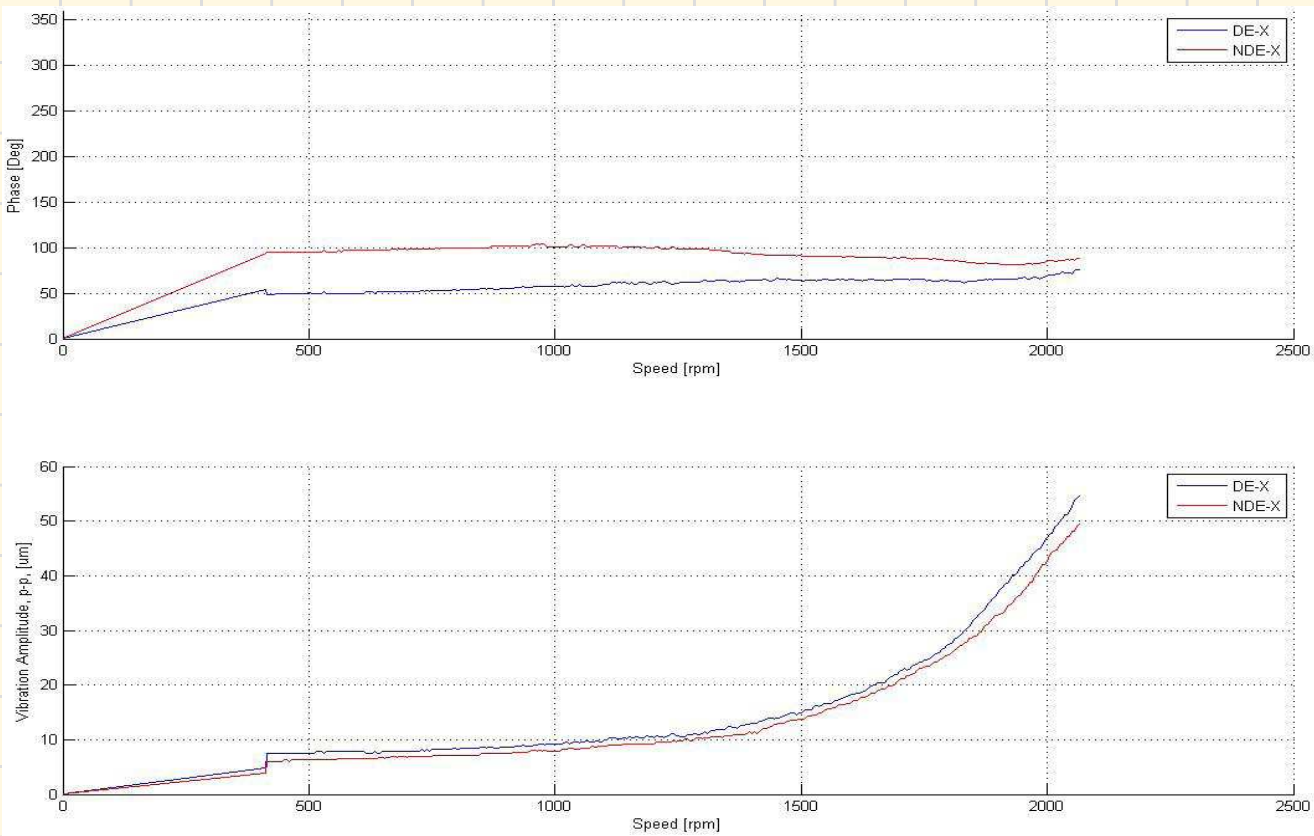
Investigation After FAT

- Assumption:
  - The vibrations are caused by unbalance in the rotor due to initial settlement during the first heat run and/or over speed test
- Decisions
  - Residual Unbalance Check → Re-Balance at Low Speed (1000 rpm) → New Test
- Result
  - Vibrations still not meeting the requirements

FAT Results After Re-Balancing

	FAT		After Re-balancing		
Balancing plane	Residual unbalance [kg mm]	Residual unbalance mass [g]	Residual unbalance [kg mm]	Residual unbalance mass [g]	API 541 requirement residual unbalance mass [g]
DE	33	117	2	6.2	7.8
NDE	47	169	1	2.1	7.8

Residual Un-Balance After Re-Balancing



Bearing Vibration Results After Re-Balancing

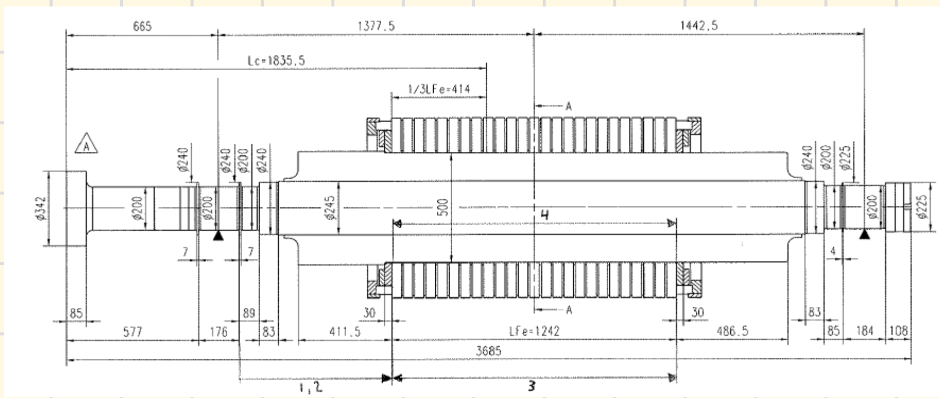
More Investigations…

- Assumptions:
  - Other effects than only settling.
- Decisions:
  - Check balancing state again, this time at different speeds
- Findings
  - The balancing state at 1000 rpm had changed again
  - Balancing state was also changing with speed
- Conclusions
  - Unbalance of the rotor was not caused by only settlings in the rotor

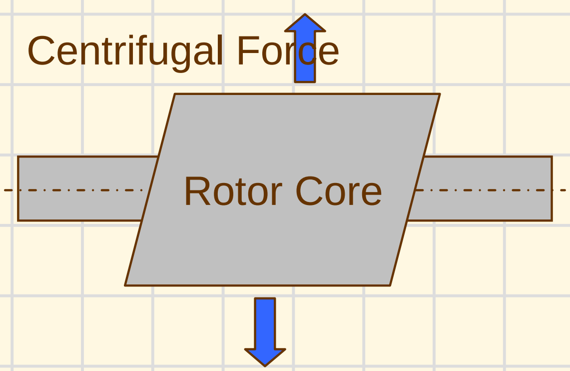
	NDE		DE	
Speed [rpm]	Residual unbalance [kg mm]	Residual unbalance mass [g]	Residual unbalance [kg mm]	Residual unbalance mass [g]
249	7.4	26.3	18.8	67.1
500	3.8	13.7	20.2	72
751	1.9	6.7	23.2	82.7

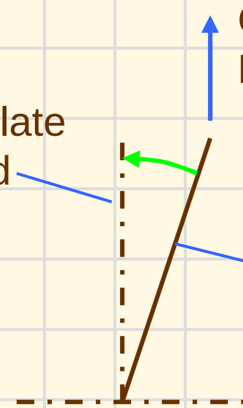
A Theory Was Formulated…

- Measurements showed that individual sheets in the lamination were skewed/buckled
- Centrifugal force acts to 'straighten' the sheet metal plates which could lead to changed balancing state



Rotor core measurements





Corrective Actions

- Attempt to recompress the rotor core lamination to make it perpendicular to the rotor centre line
- Result:
  – Improved vibration but still not meeting requirement, balancing state still changes with speed
- Conclusion:
  – Recompression not working due to high friction between rotor core and spider shaft

Rotor Core Compression

‘Press-rings’

‘Pull-rods’

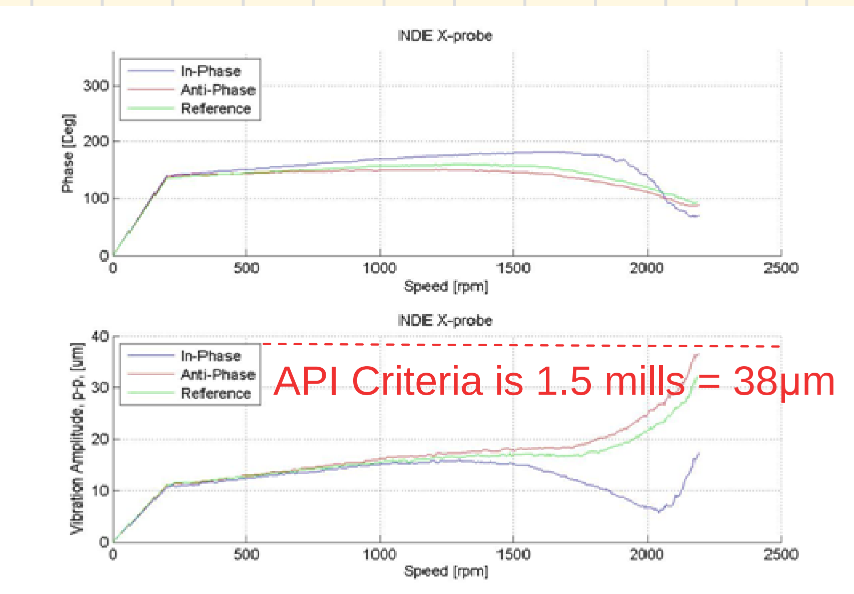
After recompression:

	NDE		DE	
Speed [rpm]	Residual unbalance [kg mm]	Residual unbalance mass [g]	Residual unbalance [kg mm]	Residual unbalance mass [g]
249	20.2	72.1	17.1	61.2
500	19.7	70.5	20.1	71.7
750	17.4	62.1	22.3	79.8
1000	14.4	51.3	25.1	89.7

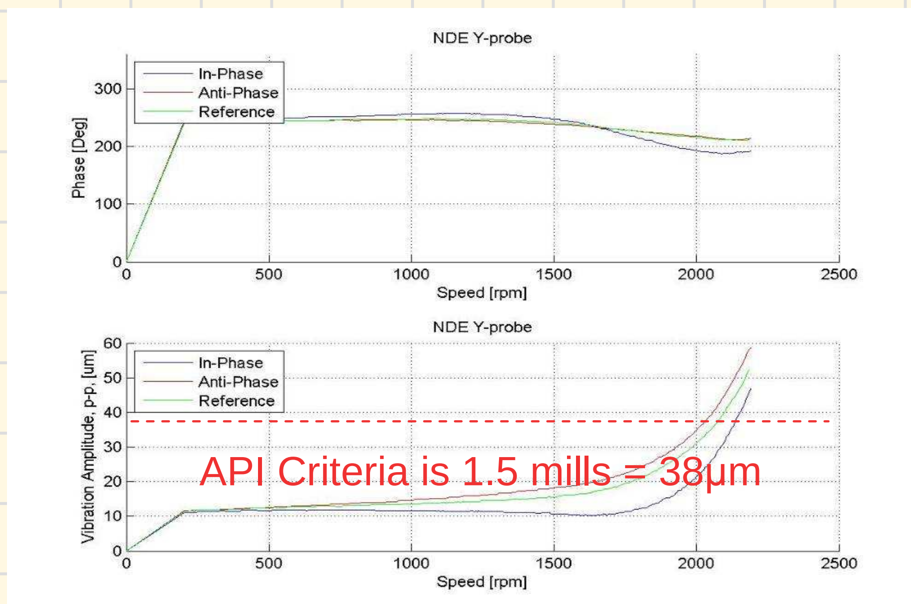
	Balancing @ 1000 rpm		
Balancing plane	Residual unbalance [kg mm]	Residual unbalance mass [g]	API 541 requirement residual unbalance mass [g]
DE	1	4.8	7.8
NDE	2	7.6	7.8

Test After Operating Speed Balancing

- Solution for the problem:
  - Balancing of rotor at full speed (settling effects within balancing)
- Results
  - After full speed balancing vibration levels are within required limits
- Forced unbalance tests for final verification



NDE X-direction



NDE Y-direction

FAT: Residual Unbalance Test Per API 541

- The residual unbalance in the rotor was found to be above maximum allowable residual unbalance
- It was now decided that a new rotor should be manufactured

	DE	NDE	Comment
Jourral Static Load [kg]	2410	2010	
Max Continuos Speed [rpm]	1800	1800	1300 rpm is used as Nmc in the protocol
Radius Correction Flane [mm]	280	280	
Max allowable res. Unbalarce [gmm]	8502	7091	
Calculated res, unbalance in rotor [gmm]	10747	725E	

Root Cause Analysis Findings

Problem:

High vibrations bearing failure → Balancing state changes with speed → Skewed/buckled sheet metal plates

Analysis:

Insufficient compression of rotor core due to malfunction in the cooling process of rotor core during manufacturing process

Resolution:

Manufacturing of new rotor with changed manufacturing process for the core shrinking

Resolution: Manufacture New Rotor

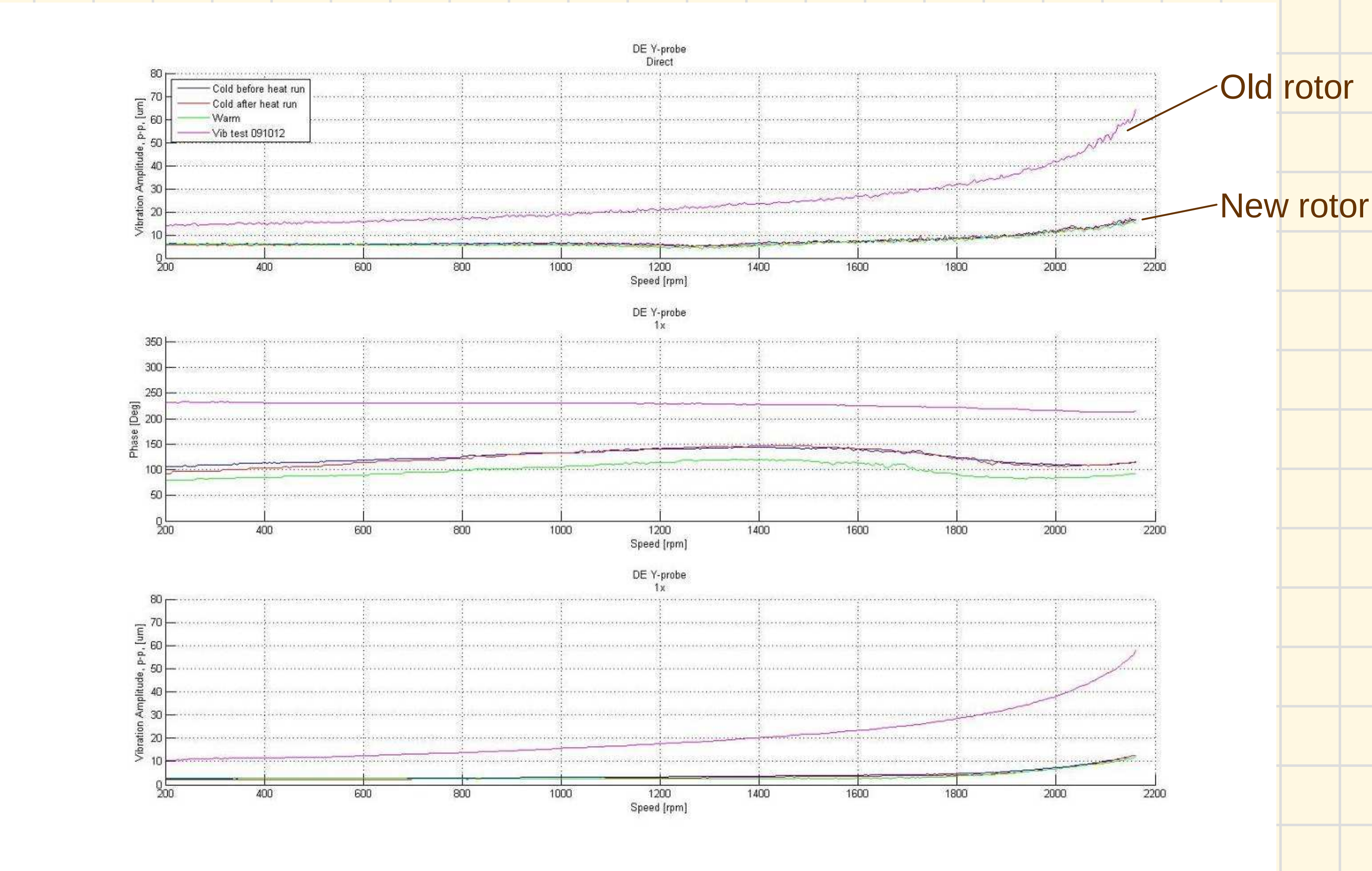
- New process for shrinking the core onto the shaft:
  - Cooling from the top down to get axial pressure on the entire length of the rotor core

Rotor core cooling

Fans to cool ‘Top Part’ of rotor core

‘Insulation’ around bottom part of rotor core

New Rotor: Residual Unbalance & Vibration Tests



CONCLUSION

- It is very difficult to correct a rotor after a distorted cooling or skewed lamination fit on the rotor core
- Trial and error attempts to diagnose and repair this type of rotor problem can be very time consuming and without guarantee of success.
- In a schedule oriented environment, it is important to have all the necessary resources involved to quickly determine if the problem can be corrected and a quality machine assured. Sometimes it may be necessary to move in parallel in attempting to repair the rotor and preparing to manufacture a new rotor.