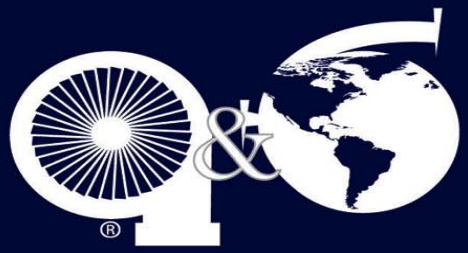

43rd Turbomachinery
30th Pump SYMPOSIA
GEORGE R. BROWN CONVENTION CENTER
HOUSTON, TX | SEPT. 22 - 25, 2014

COUPLED TORSIONAL-LATERAL ANALYSIS

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TEXAS A&M UNIVERSITY

TEES TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

Outline

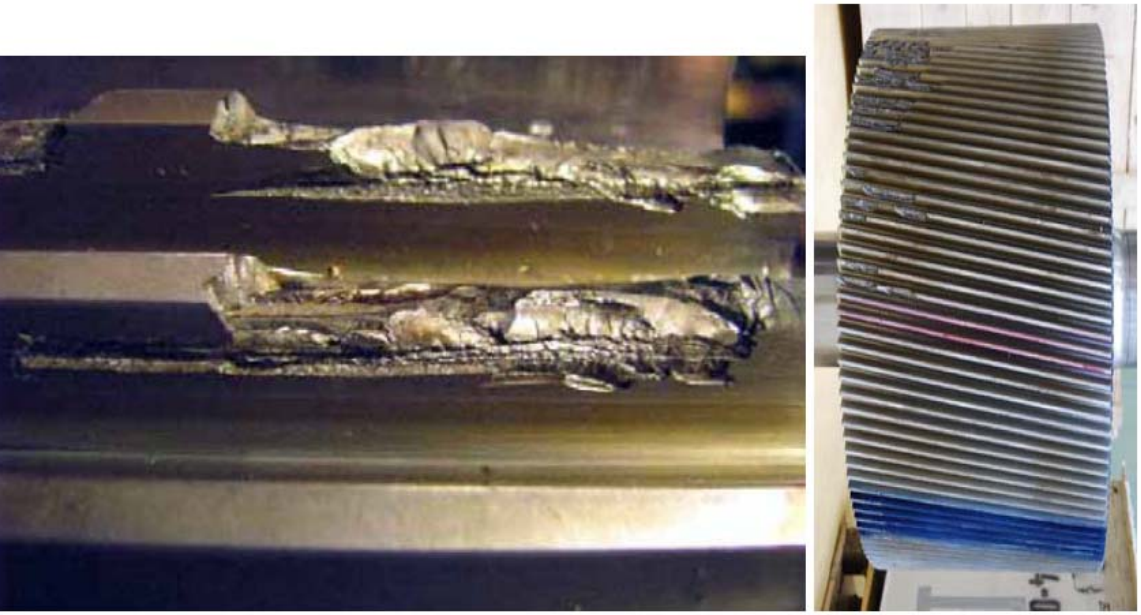
- Background
- Measurements on gear casing
- Calculations
  - Static
  - Dynamic
- Comparing measurements
- Discussion

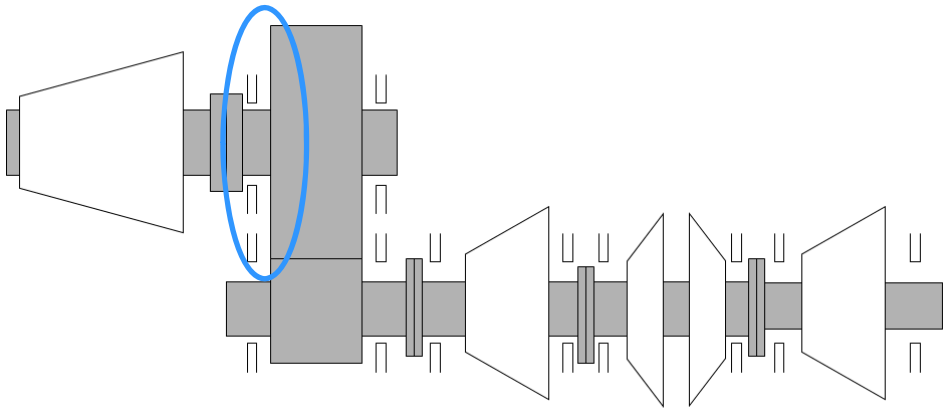
Background

- North sea platform production modification
- Two compressor trains were upgraded from 18 MW -> 21 MW
- Main modifications:

Property	Modified	Original
Power [MW]	21.30	18.25
Speed in [rpm]	3600	3600
Speed out [rpm]	10718	10894
Module	5.6	6.4
Z1	44	38
Z2	131	115
Type	Single helical	Single helical

Background





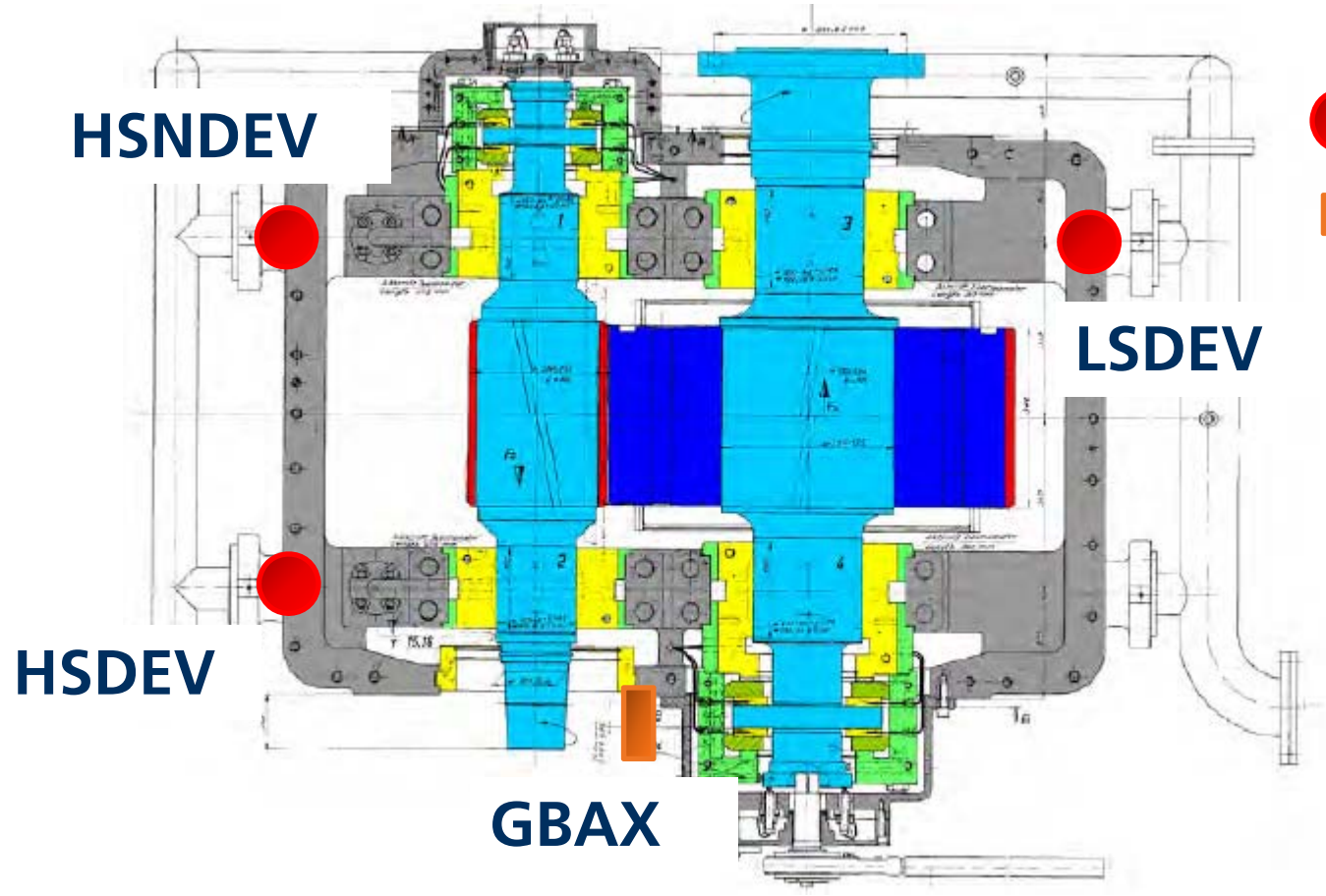
Problems encountered:

- Two consecutive gearbox failures within few weeks after commissioning
- ~ 500-1000 operating hours before failure
- Severe gearbox casing vibrations and excessive noise levels recorded
- Turbine side on bull gear experienced fractured teeth and cracks on the load surfaces

Actions taken:

- Full RCA initiated. This concluded poor final grinding as primary cause of failures
- Contributory causes had to be investigated as part of the RCA
- Torsional/Lateral vibration analysis was initiated by LRC as part of the RCA

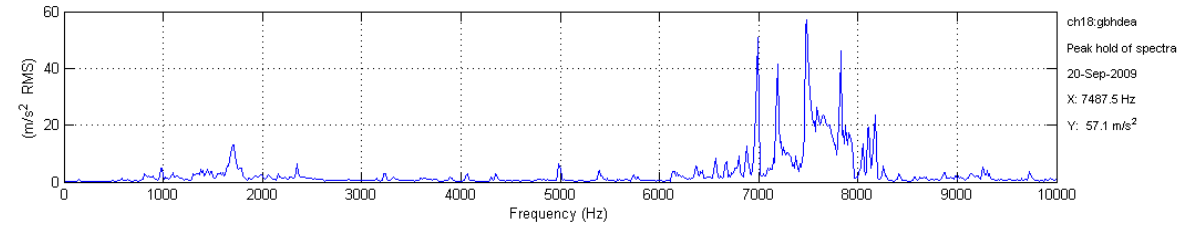
Measurements

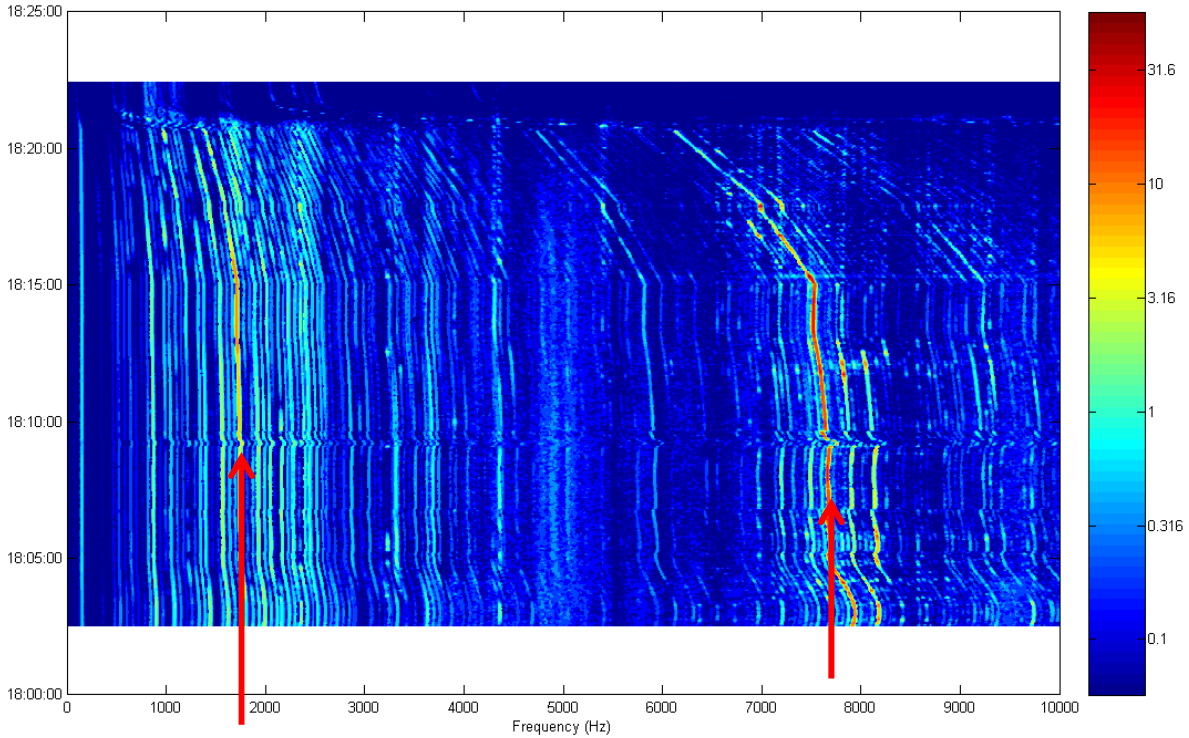


Vertical accelerometer

Horizontal accelerometer

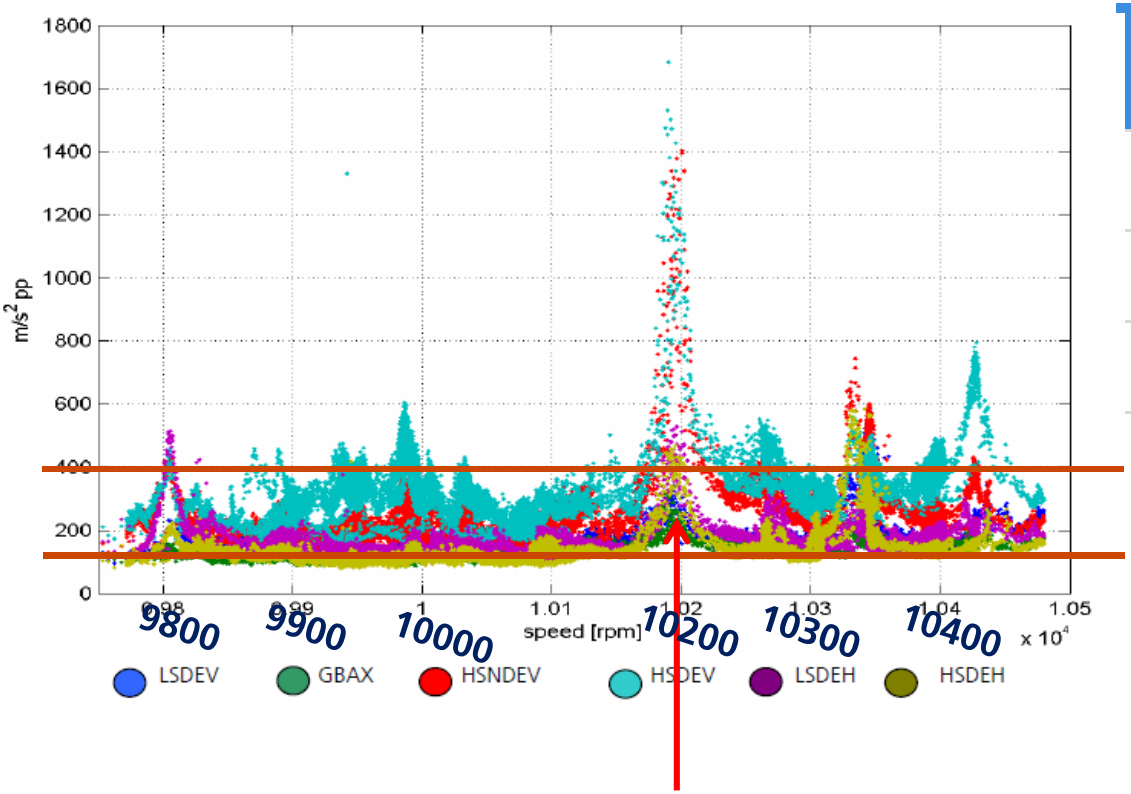
Measurements





~1700 Hz **Gear mesh frequency (7000-8000 Hz)**

Measurements



LRC

API

Requirements

API613 5th Ed.	Velocity (RMS)	Acceleration (P-P)
Frequency range	10 – 2500 Hz	2500 – 10 000 Hz
Overall	2.9 mm/s	8 g (~80 m/s²)
Discrete frequency	1.8 mm/s	-

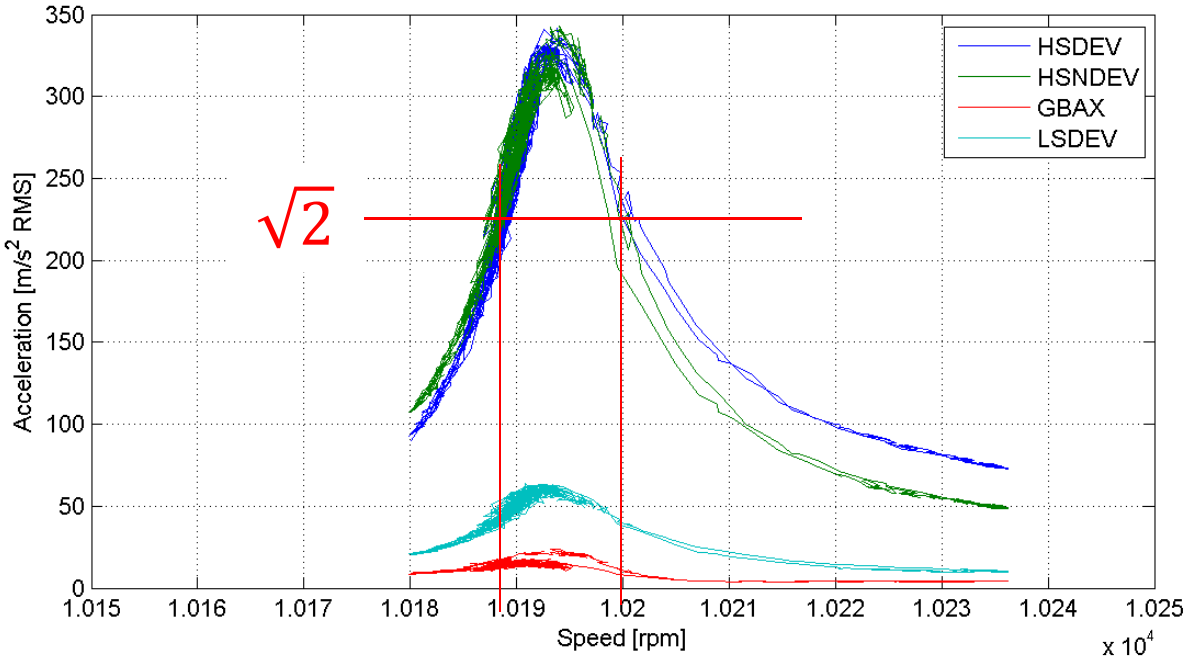
10200 rpm = GMF @ 7480 Hz

Levels up to 1600 m/s² (~160 g) p-p

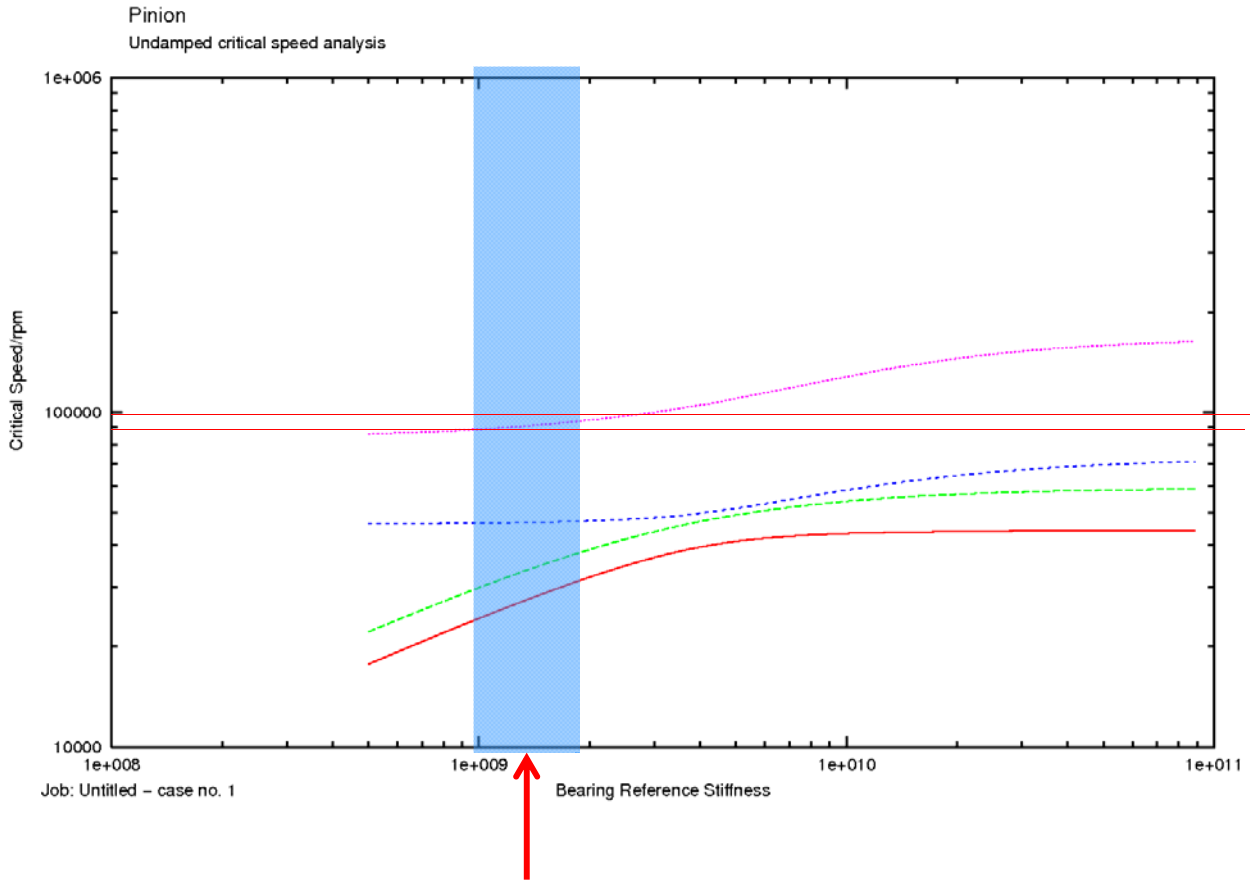
Measurements

Amplification factor
Q ≈ 700

44X filter applied on signal



Pinion mode excitation



88000 – 97000 cpm
(1470 – 1620 Hz)

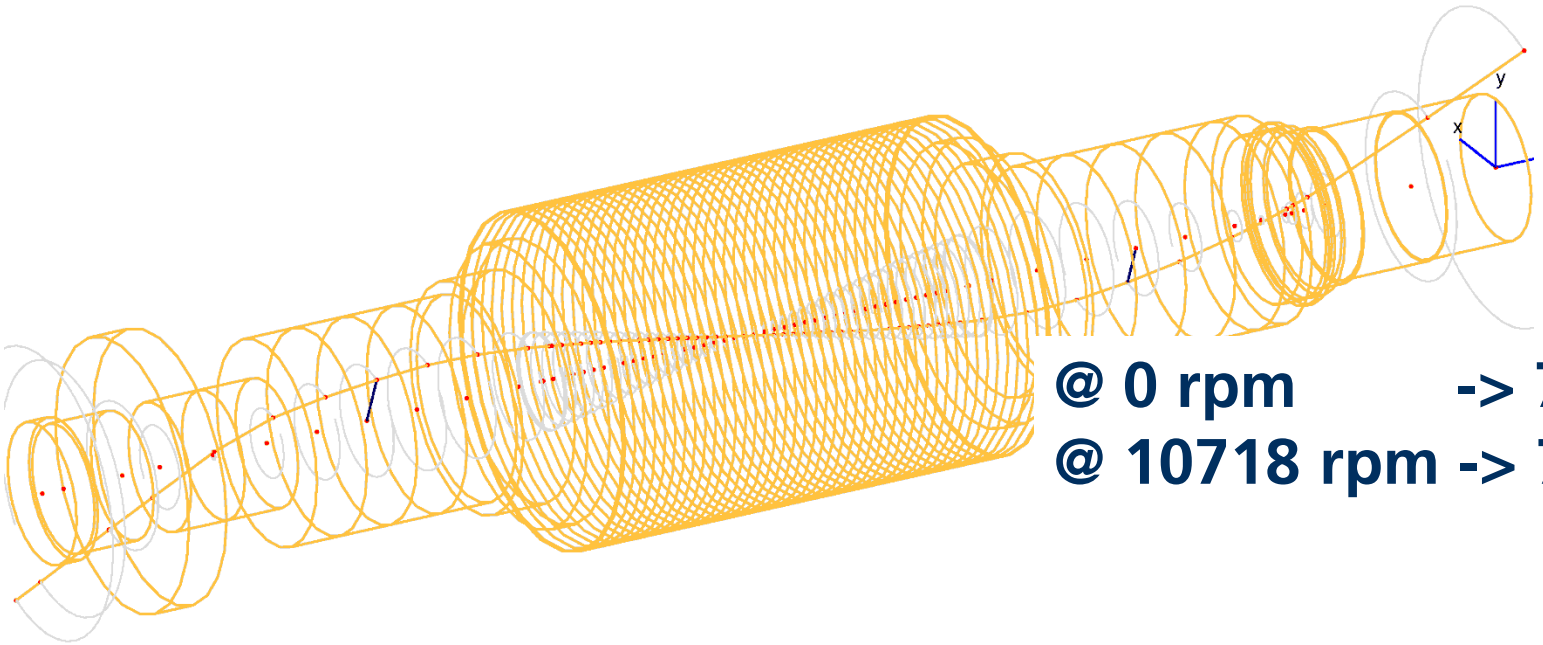
Bearing stiffness range
~1 – 2.5 E+9 N/m
(~6 - 14 E+7 lb/in)

1X = 10 718 rpm
8X = 85 744 rpm
9X = 96 462 rpm
10X = 10 7180 rpm

Pinion mode excitation

Pinion

Damped eigenvalue analysis
elements, nodes , mode no. 8: 1313.8 Hz, log. dec = -6.149
Speed: 10718 (1)

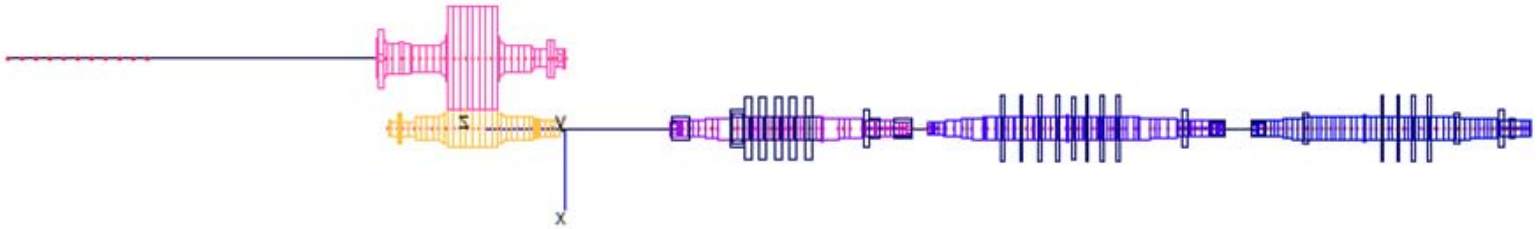


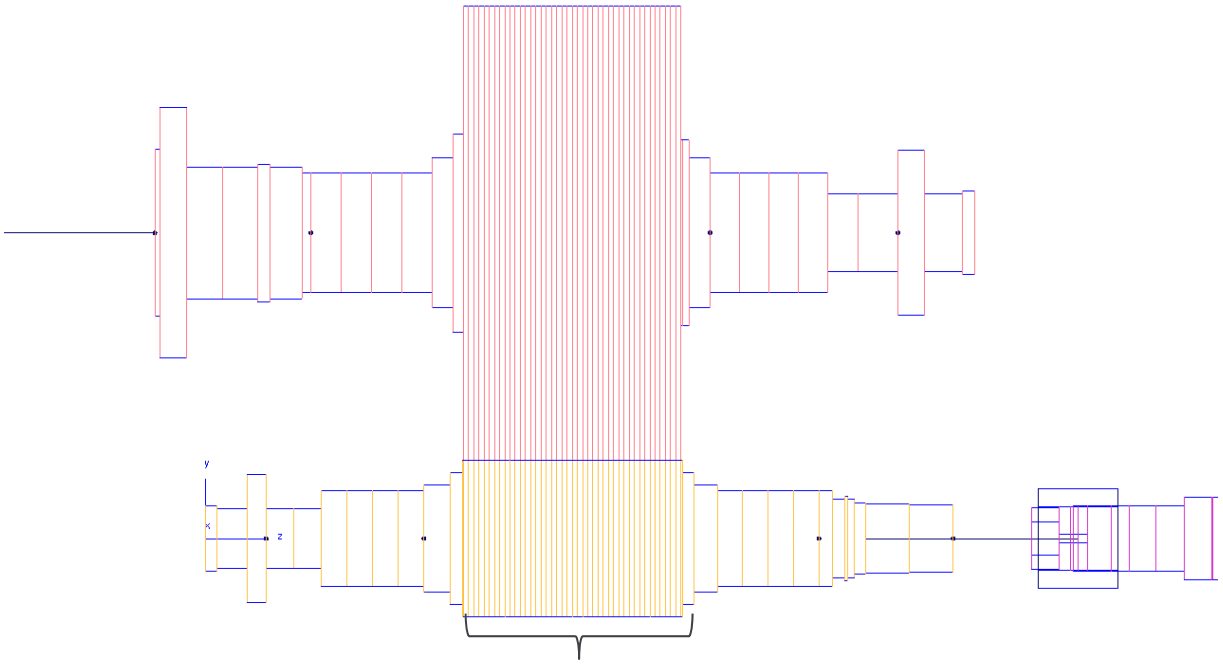
@ 0 rpm -> 77 460 cpm (1291 Hz)
@ 10718 rpm -> 78 840 cpm (1314 Hz)

Untitled - Case no. 1

1X = 10 718 rpm
7X = 75 026 rpm
8X = 85 744 rpm
9X = 96 462 rpm
10X = 10 7180 rpm

Torsional-Lateral Calculations



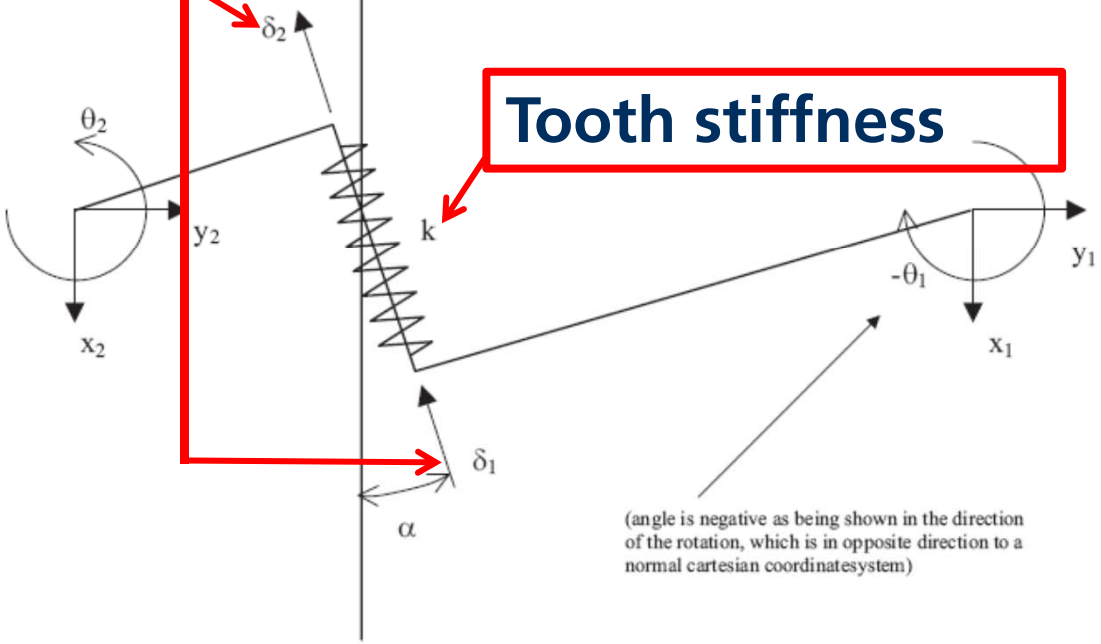


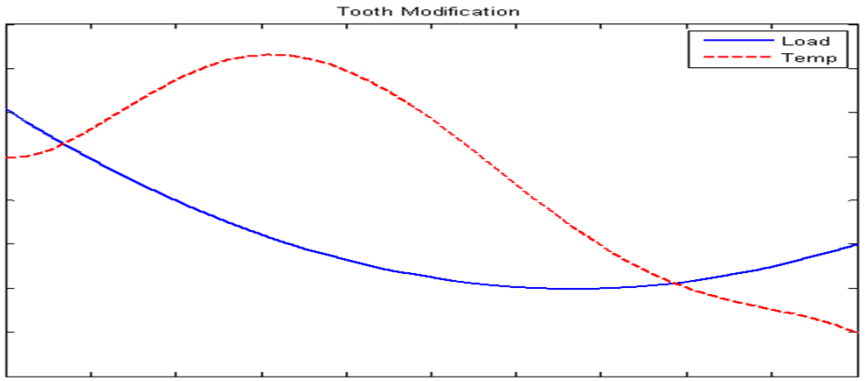
42 Elements

Torsional-Lateral Calculations

Displacement in gear contact

Tooth stiffness



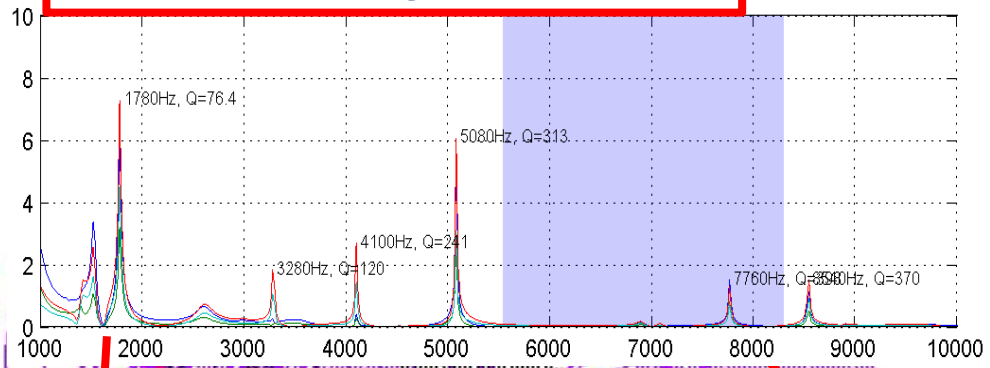


$$\delta_1 = -r_1\theta_1 - x_1\cos(\alpha) - y_1\sin(\alpha)$$
$$\delta_2 = r_2\theta_2 - x_2\cos(\alpha) - y_2\sin(\alpha)$$

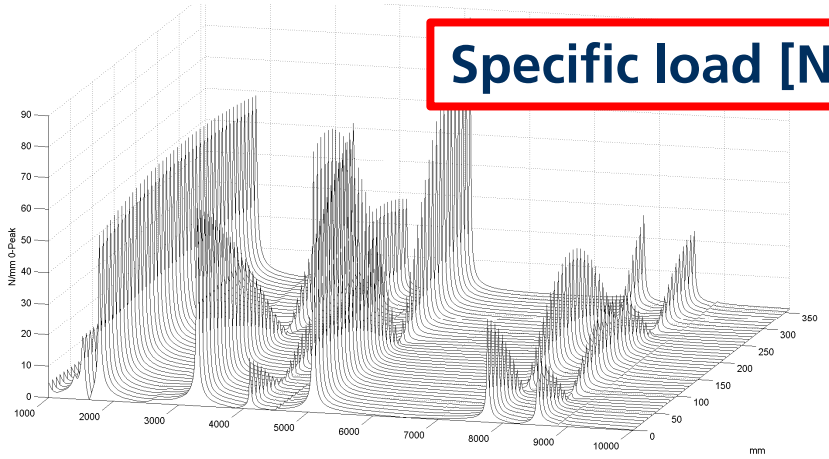
$$P_i = \begin{cases} k(\delta_{1i} - \delta_{2i} - \delta_{ci}) & \delta_{1i} - \delta_{2i} > \delta_{ci} \\ 0 & \delta_{1i} - \delta_{2i} \le \delta_{ci} \end{cases} \quad i = 1..43$$

Results – Dynamic calculations

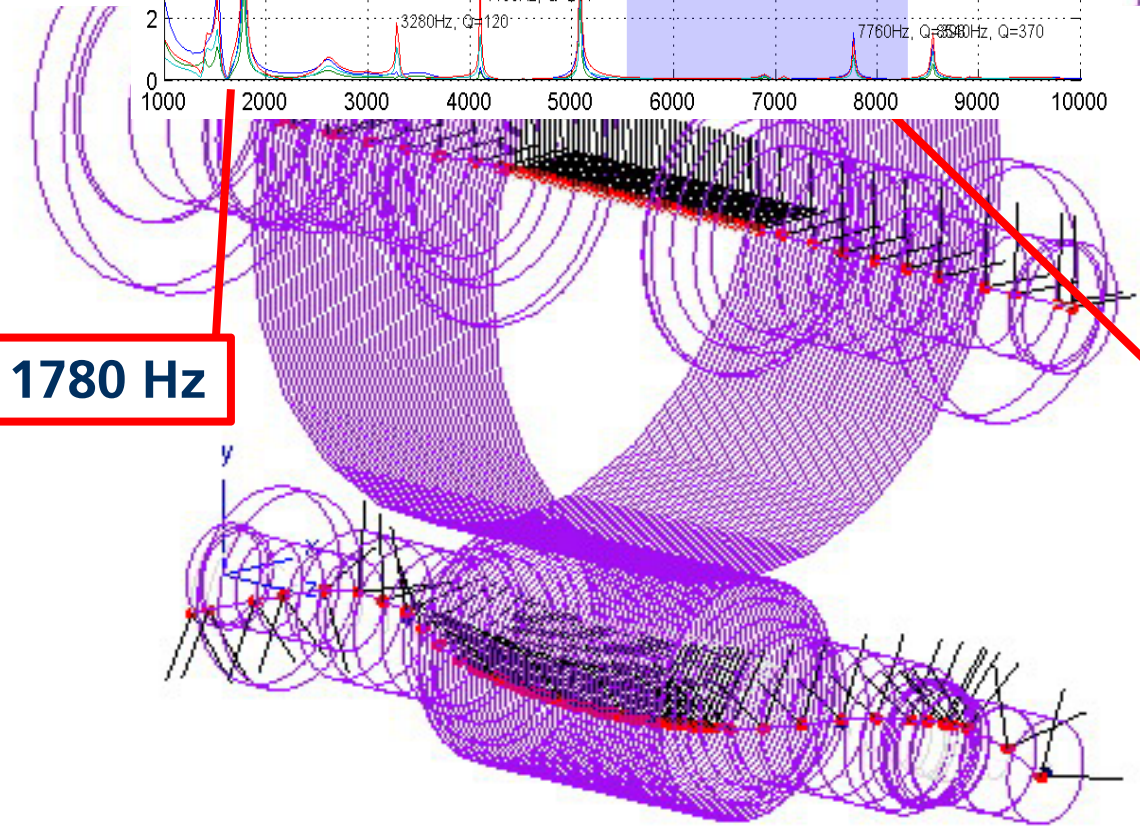
Pinion bearing force [N]



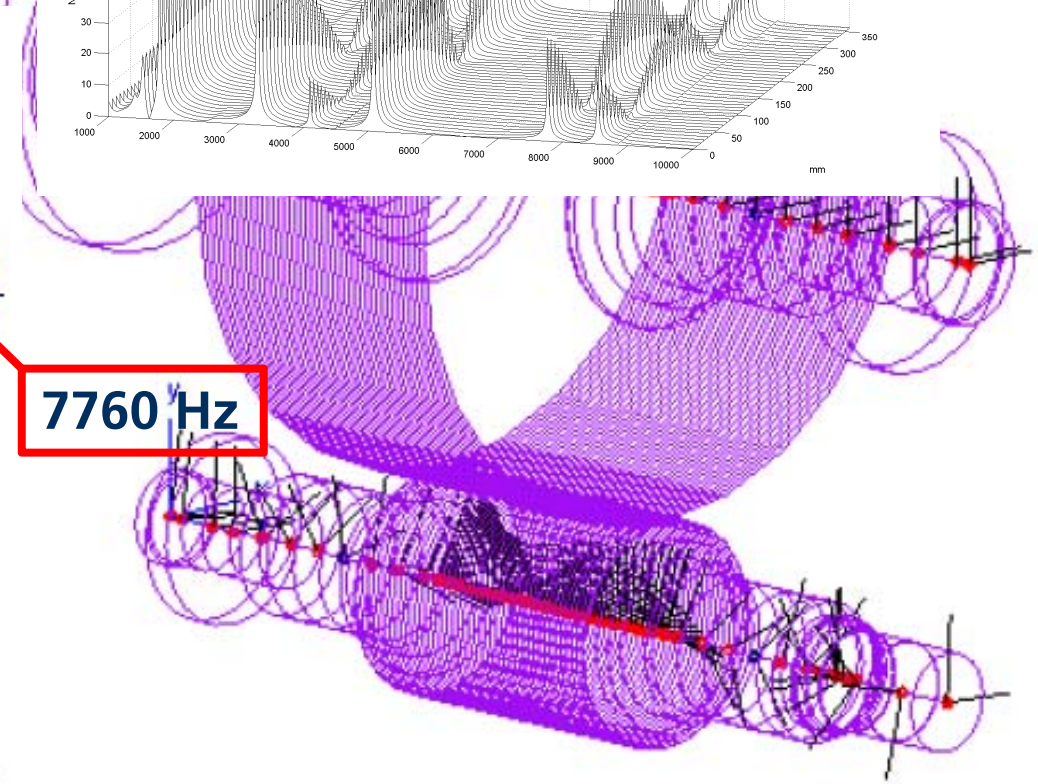
Specific load [N/mm]



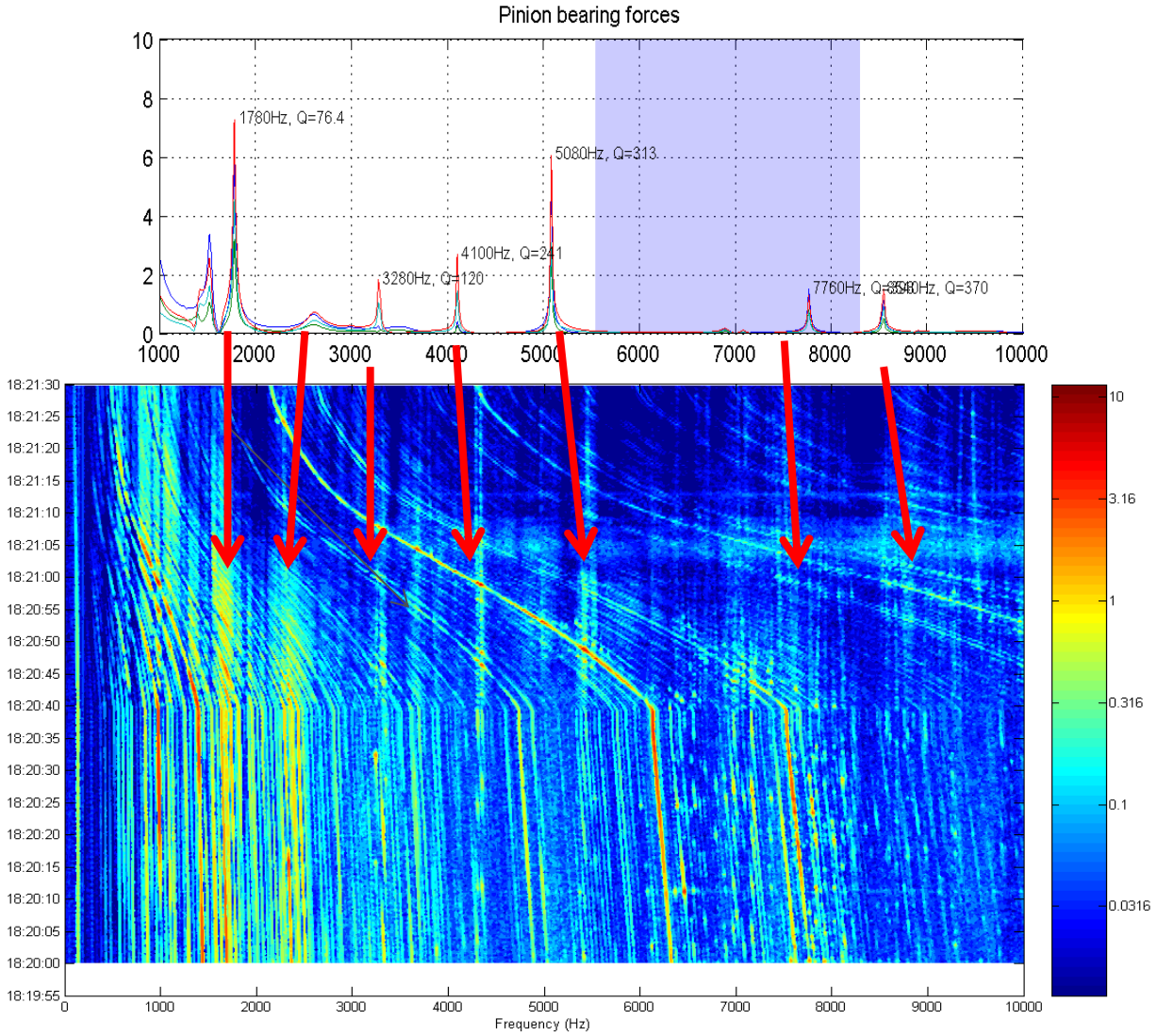
1780 Hz



7760 Hz



Comparing with measurements



Conclusions

- The primary cause of failures was residual stress in tooth flanks from the manufacturing process. Contributory causes (such as torsional/lateral analysis) were investigated as part of the RCA.
- Spare gear set was sent onshore for a second “final grinding” to remove residual stress on the load flanks.
- The presented calculations were tuned with measurements from before and after modifications. The resulting loads were input to load flank fatigue calculations by the vendor.
- Fatigue calculations from before and after the machining could prove that the load flank fatigue life improved with the second grinding.
- Gear boxes are still in operation with no reported issues since commissioning March 2010 and June 2012 for the two trains, respectively.

Questions?