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MARINA BAY SANDS

TURBOMACHINERY LABORATORY
TEXAS A&M ENGINEERING EXPERIMENT STATION

TEXAS A&M UNIVERSITY

imagination at work

Effects of shaft geometric unconformities on the rotor-dynamic behavior in hard coupled equipment

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Authors

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Gianluca Boccadamo is currently Design Engineer in the shaft Line Integration Team for GE Oil & Gas Nuovo Pignone, in Florence, Italy. He is responsible for the requisition tasks and the integrated rotor-dynamic studies. He supports also NPI projects, manufacturing and test department for full speed full load string tests.

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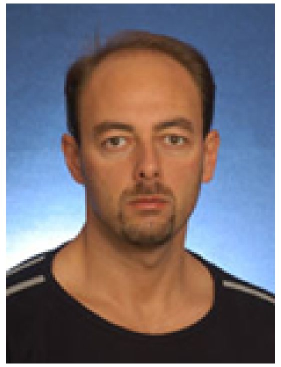

Paolo Agnoletti is currently Design Engineer in the Electrical Engineering Team for GE Oil & Gas Nuovo Pignone in Florence, Italy. He is responsible for the requisition tasks involving electrical machines coupled with Gas Turbine or Compressor. He supports also test department for the load string tests of the machines.

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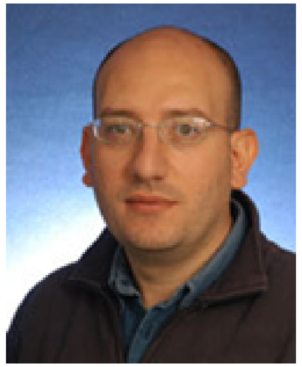


Gaspare Maragioglio is currently the Engineering Manager of the Shaft Line Integration Team for GE Oil & Gas Nuovo Pignone, in Florence, Italy. He is now responsible for technical selection and design verification of flexible and rigid couplings, load gears and auxiliary equipment, with particular focus on the train rotor-dynamic behavior, torsional and lateral.

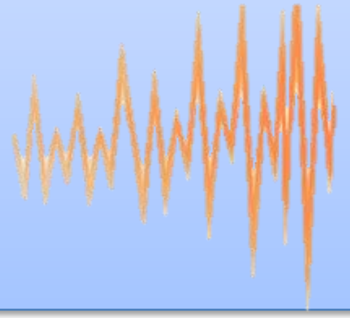
Short Abstract

This case study deals with a 25MW turbo-generator train with a semi-rigid connection between generator and gearbox.
For this application, machine alignment and connection is a key factor for a smooth rotor-dynamic system behavior: both high run-out and high radial vibration can be induced by poor quality of the assembly.
The rotor-dynamics of the train in subject was negatively influenced by a geometrical out-of-tolerance on the generator flange, causing a distortion in the shaft line which introduces a pre-stress on the rotor system.
The aim of this case study is to draw the attention on the importance of system integration especially in presence of semi-rigid assembly, which requires specific design, manufacturing and integration requirements.

Problem Statement

Subject

- 25MW Turbogenerator with semi-rigid connection between Gearbox and Generator
- Unexpected high radial vibration on Generator, even at low speed
- Abnormal vibration detected also on Gearbox LS shaft



Potential Issues

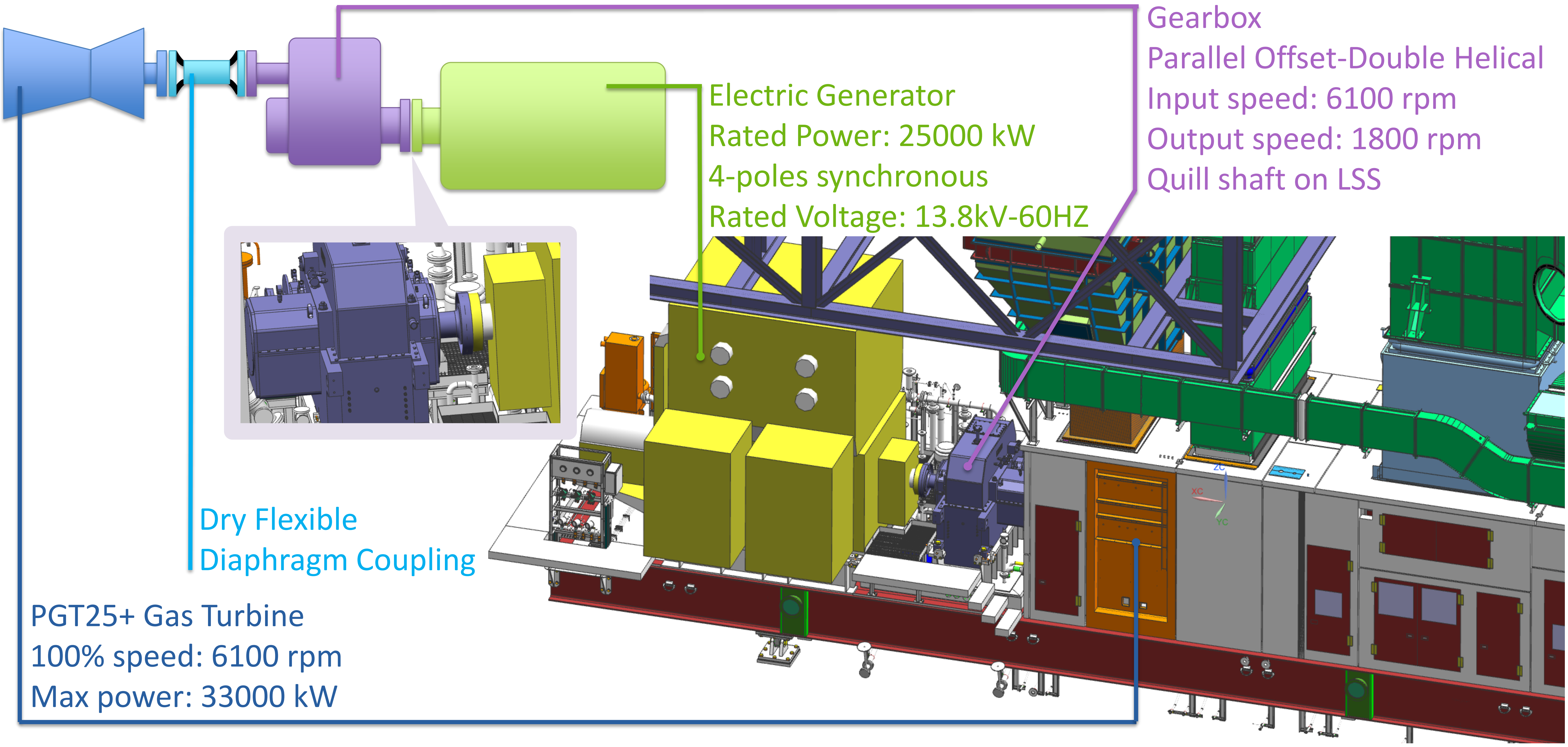
Vibration above the acceptance limits

- Failed string test
- Reduced availability at site

Purpose of the case study:

Draw the attention on the importance of system integration especially in presence of semi-rigid assembly, which requires specific design, manufacturing and integration requirements here discussed.

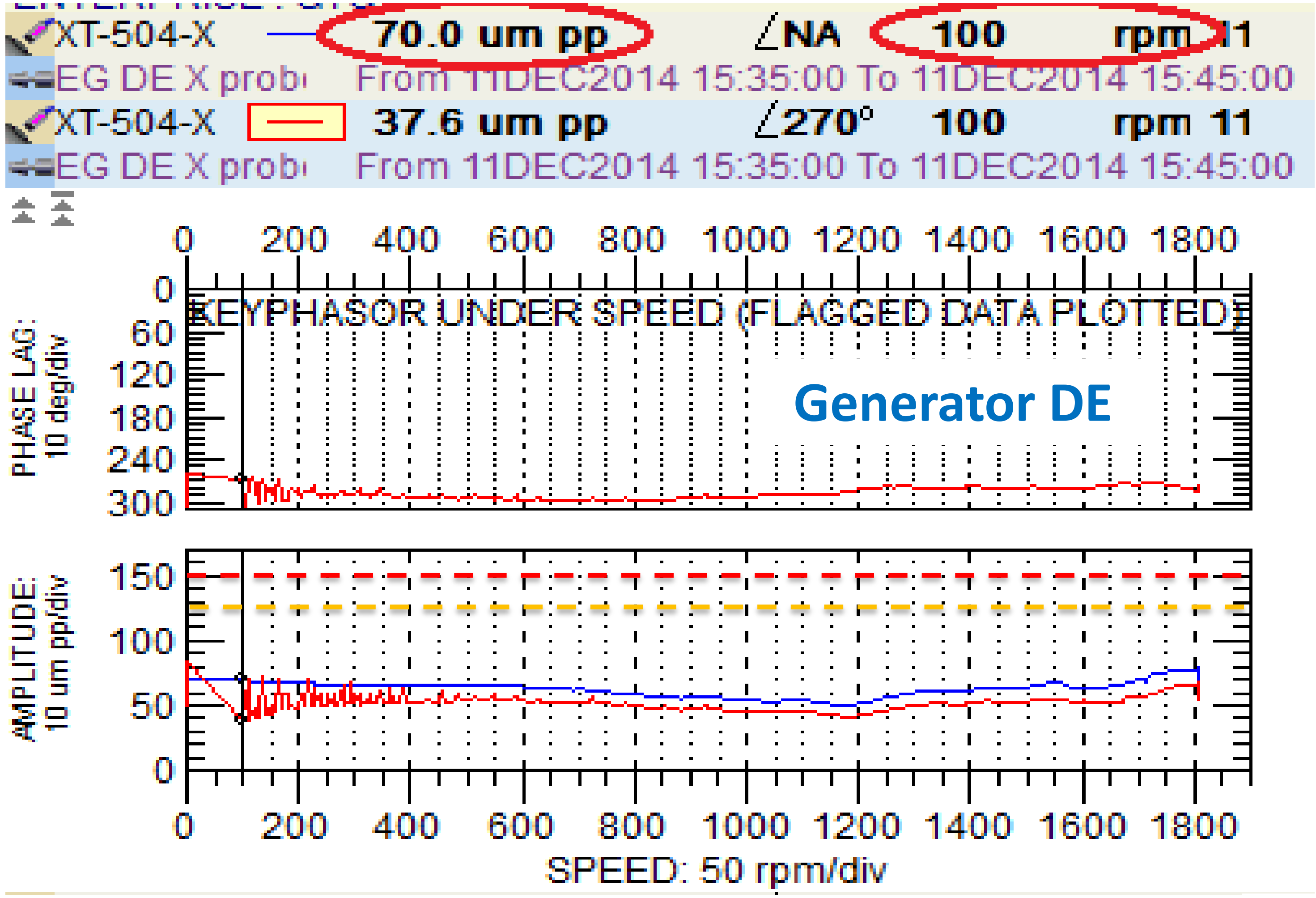
Train configuration & characteristic data

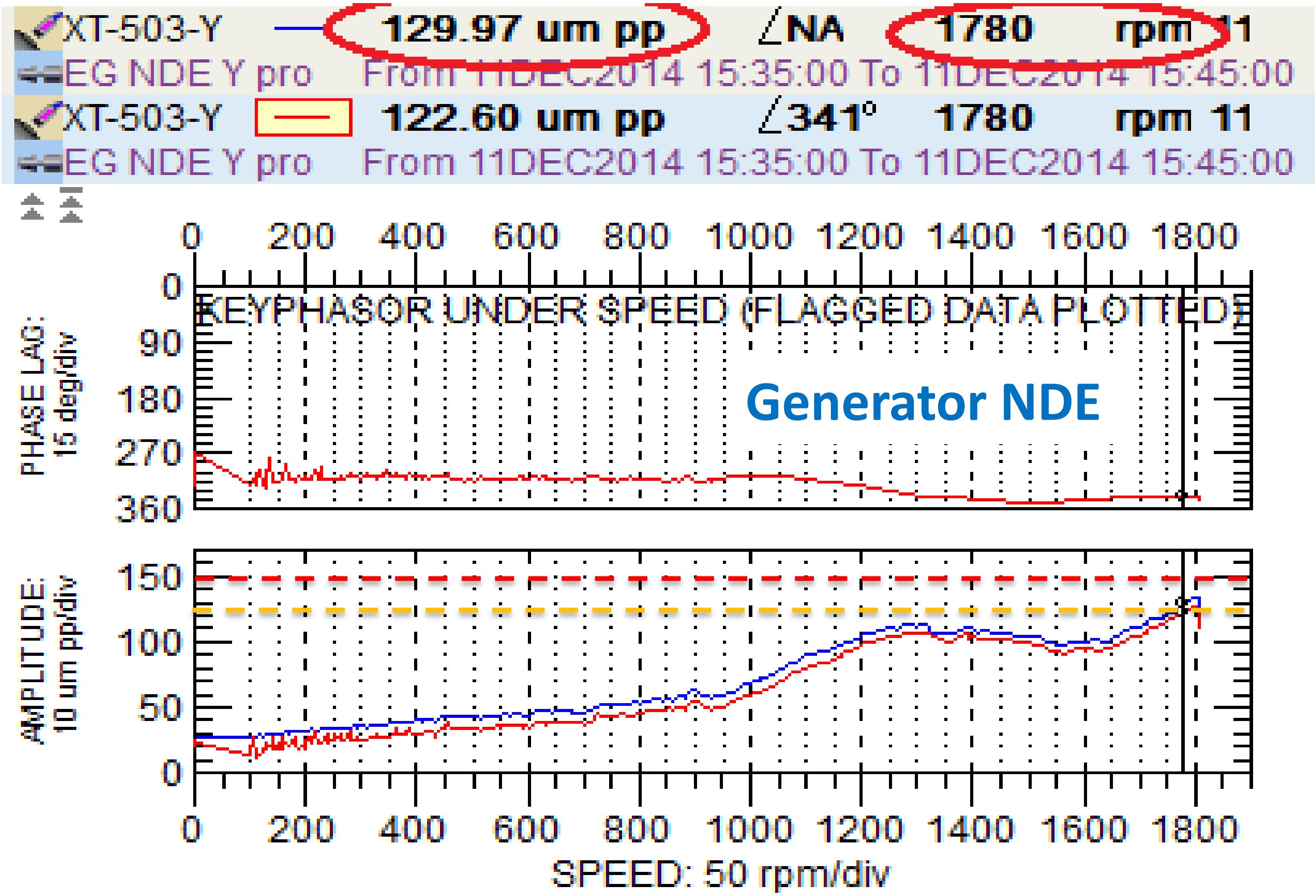


Observed vibration

- Generator shaft run-out ~60micron p-p during slow roll (expected below 30micron) at DE side
- Main component: 1X REV

- Generator high vibrations (~130micron p-p) at NDE side during ramp-up at MCS
- Main component: 1X REV





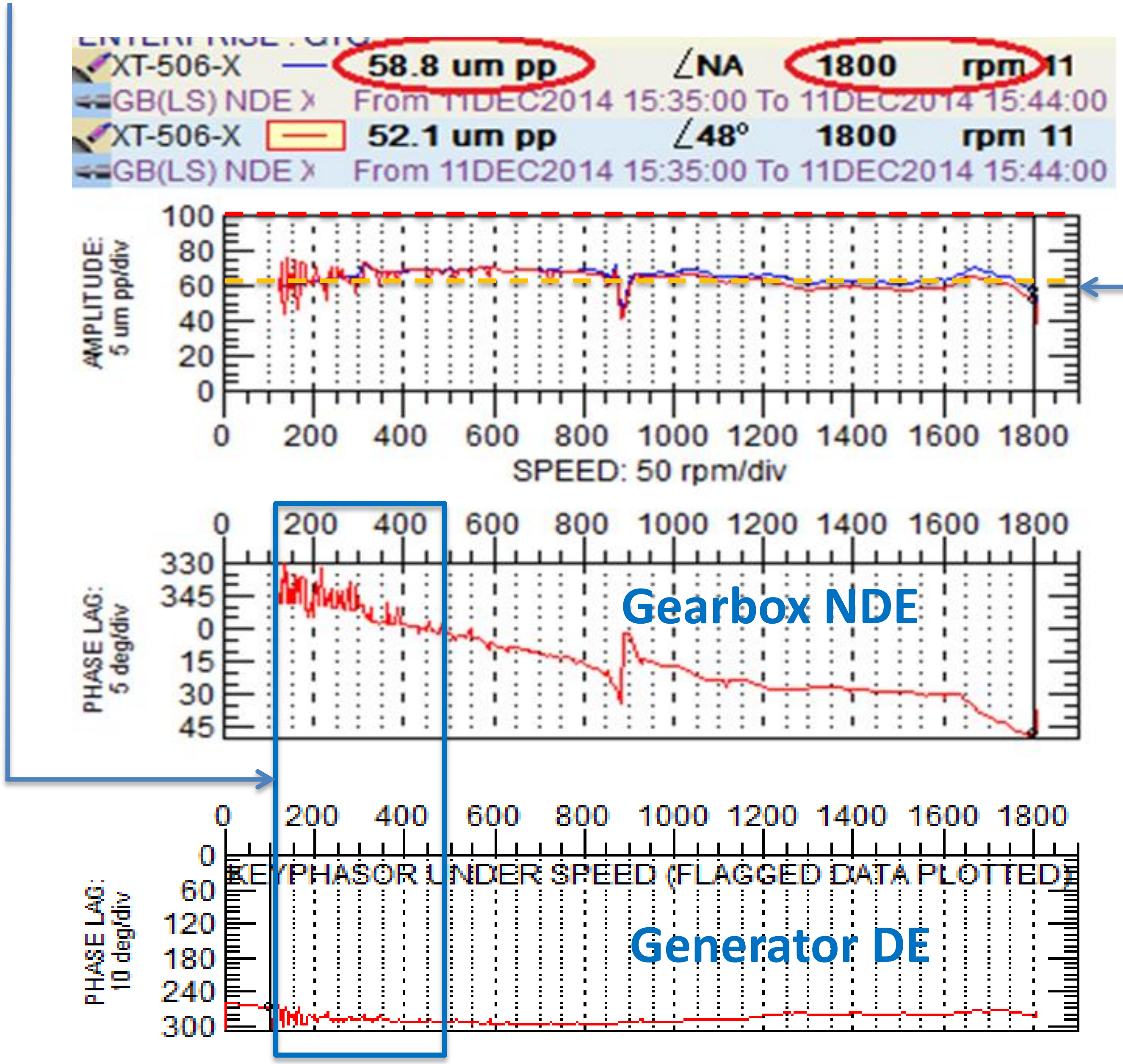
Alarm Level

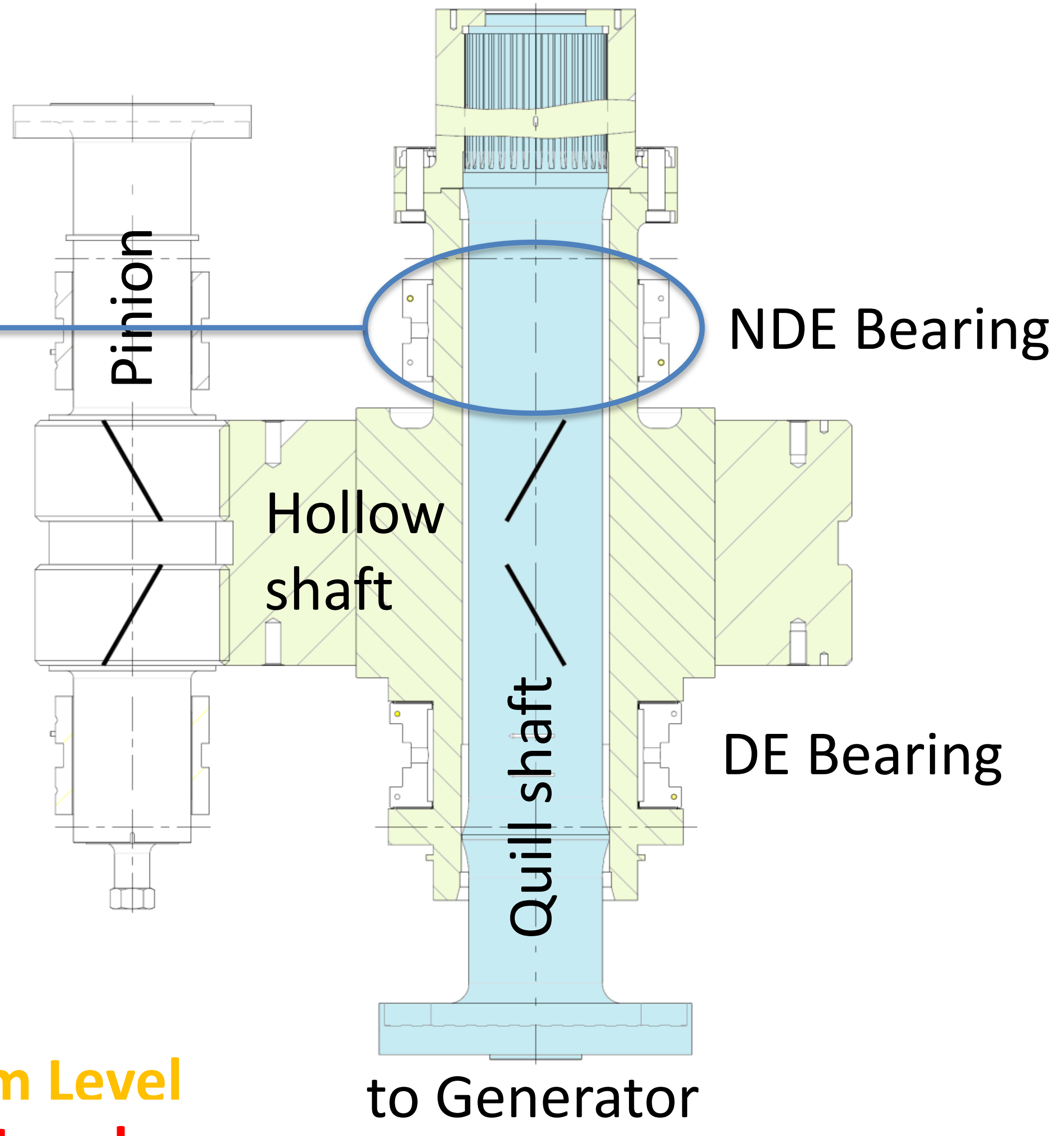
Trip Level

Observed vibration

- Abnormal radial vibrations detected on Gearbox LS shaft NDE side
- Gearbox phase lag at low speed is higher than Generator vibration probes (i.e. Generator peak anticipates Gearbox peak)

This suggests that the issue comes from Generator side



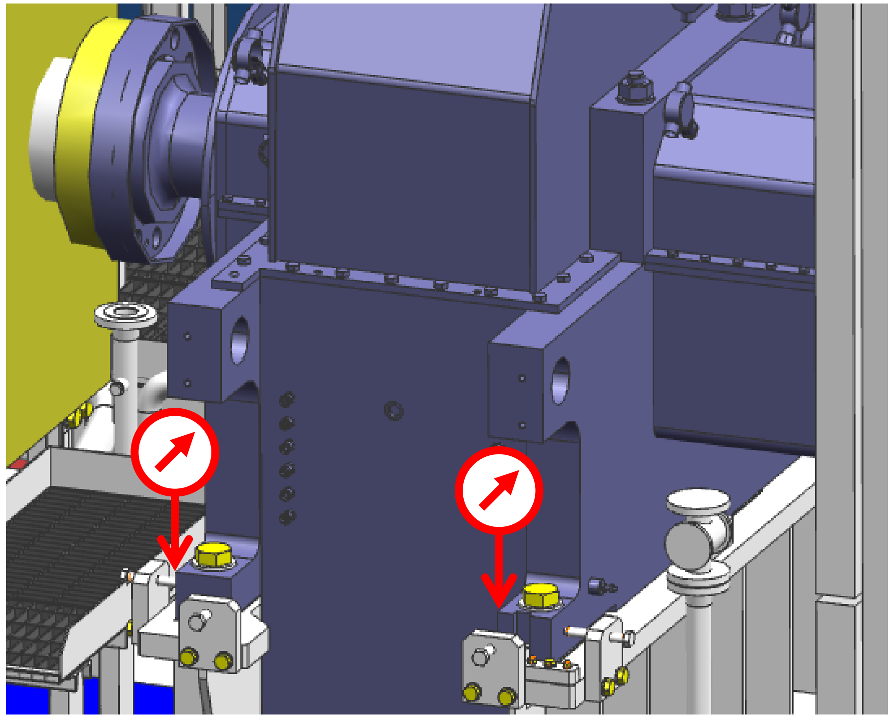


Alarm Level

Trip Level

Checks & Tests performed

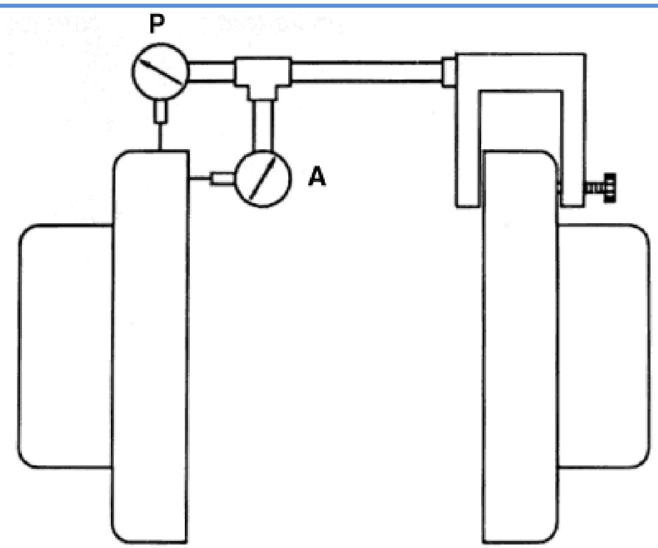
Soft Foot check acting on Gearbox & Generator anchorage bolts



Negligible dial gauge variations when tightening/untightening bolts

OK

Machines alignment check

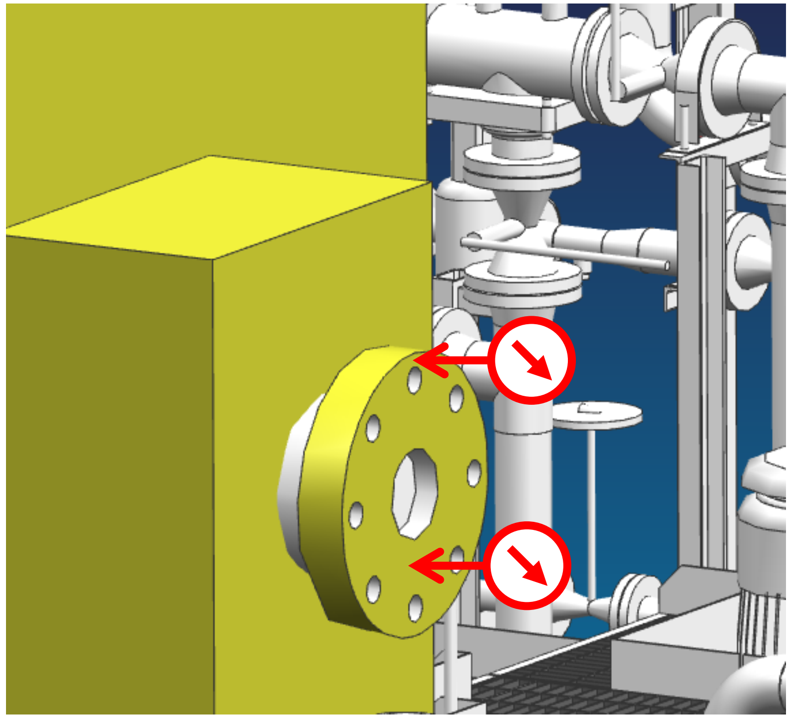


Alignment records depended on Generator/Gear flanges relative clocking

Alignment not repeatable

?

Flange Planarity Measurement

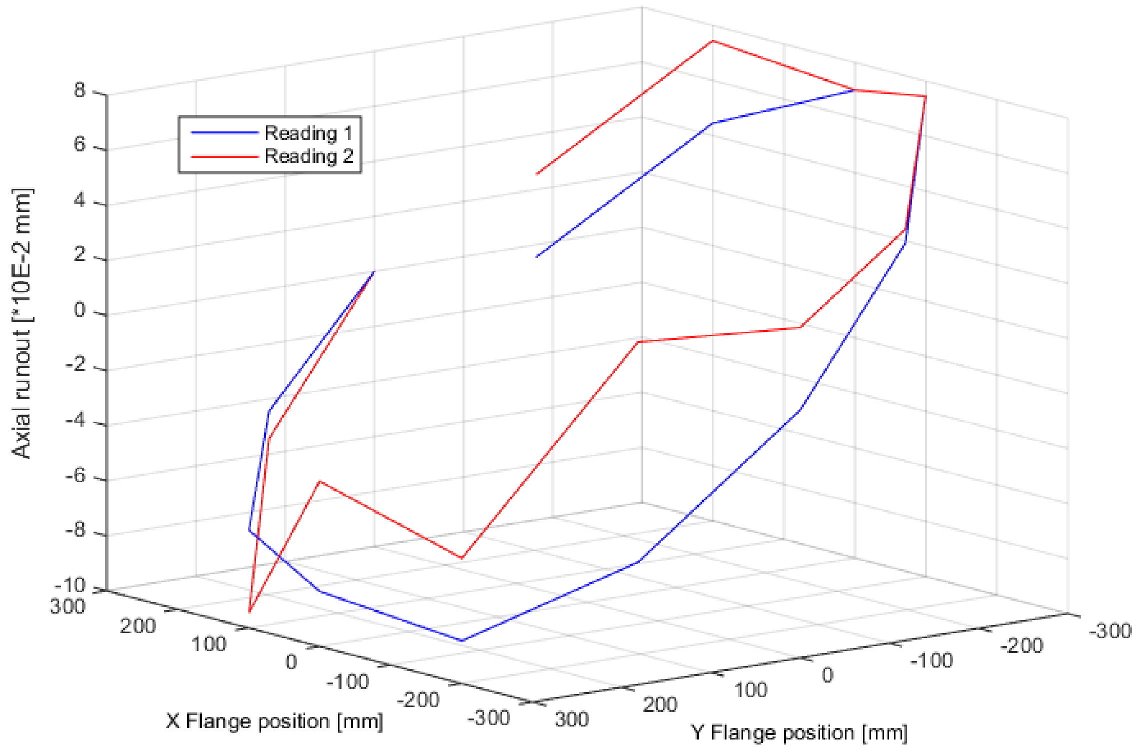


Generator flange planarity out of tolerance

X

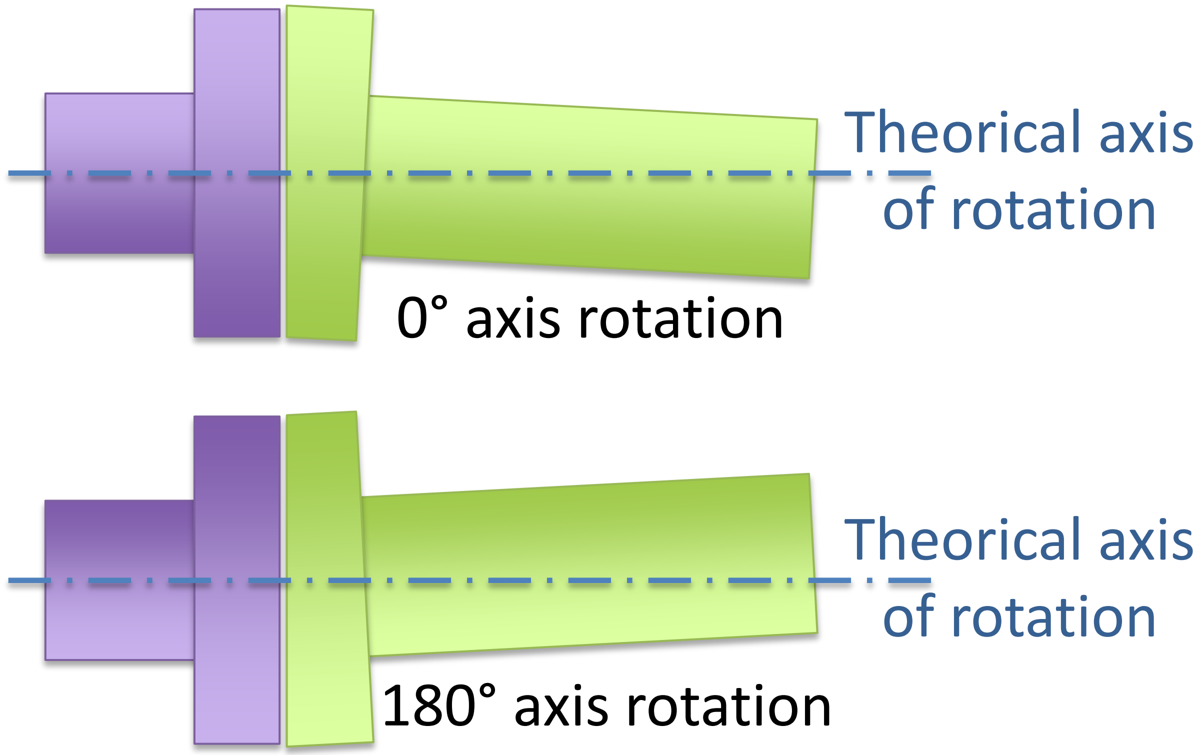
Note. Machines unbalance (typical source of 1X REV vibration) has been initially excluded: vibration trends do not seem to increase significantly with rotor speed

How non-planar flange influences vibration



Max axial run-out tolerance:
Required = 2/100 mm
Measured = 8/100 mm

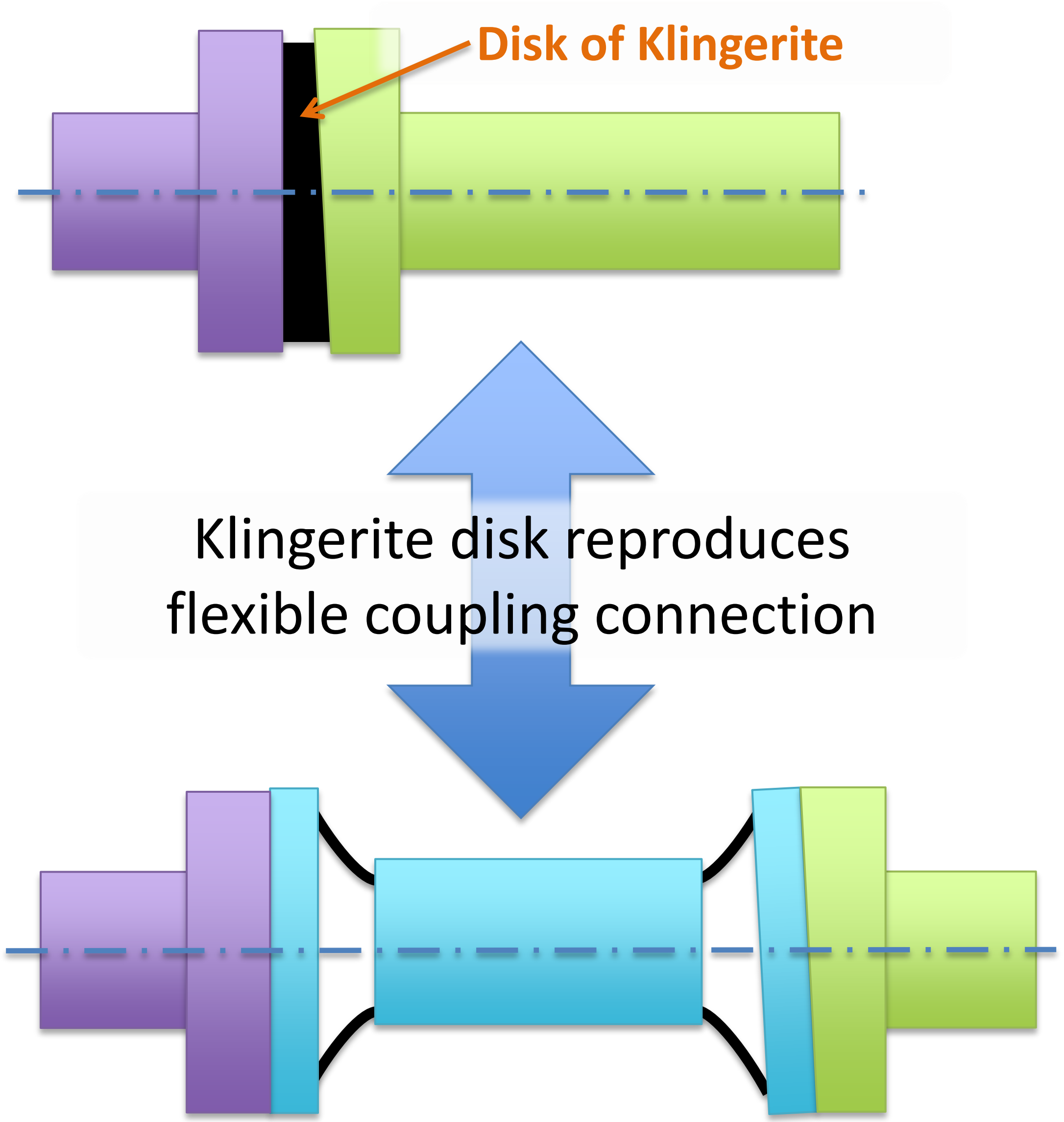
After connection with Gearbox



Especially in semi-rigid connections, flange non-planarity induces a permanent deformation in the shaft line that produces a force status able to alter the predicted rotor-dynamic equilibrium

Hypothesis validation via dedicated test

Additional test performed inserting a soft joint (disk of Klingerite ≈3 mm-thick; Klingerite is typically used for gaskets) between gearbox and generator flanges to prove that the issue is caused by the connection between the two machines



Soft joint features:

1) Lateral rotor-dynamic disconnection (i.e. lateral disturbances are not transmitted between different machines

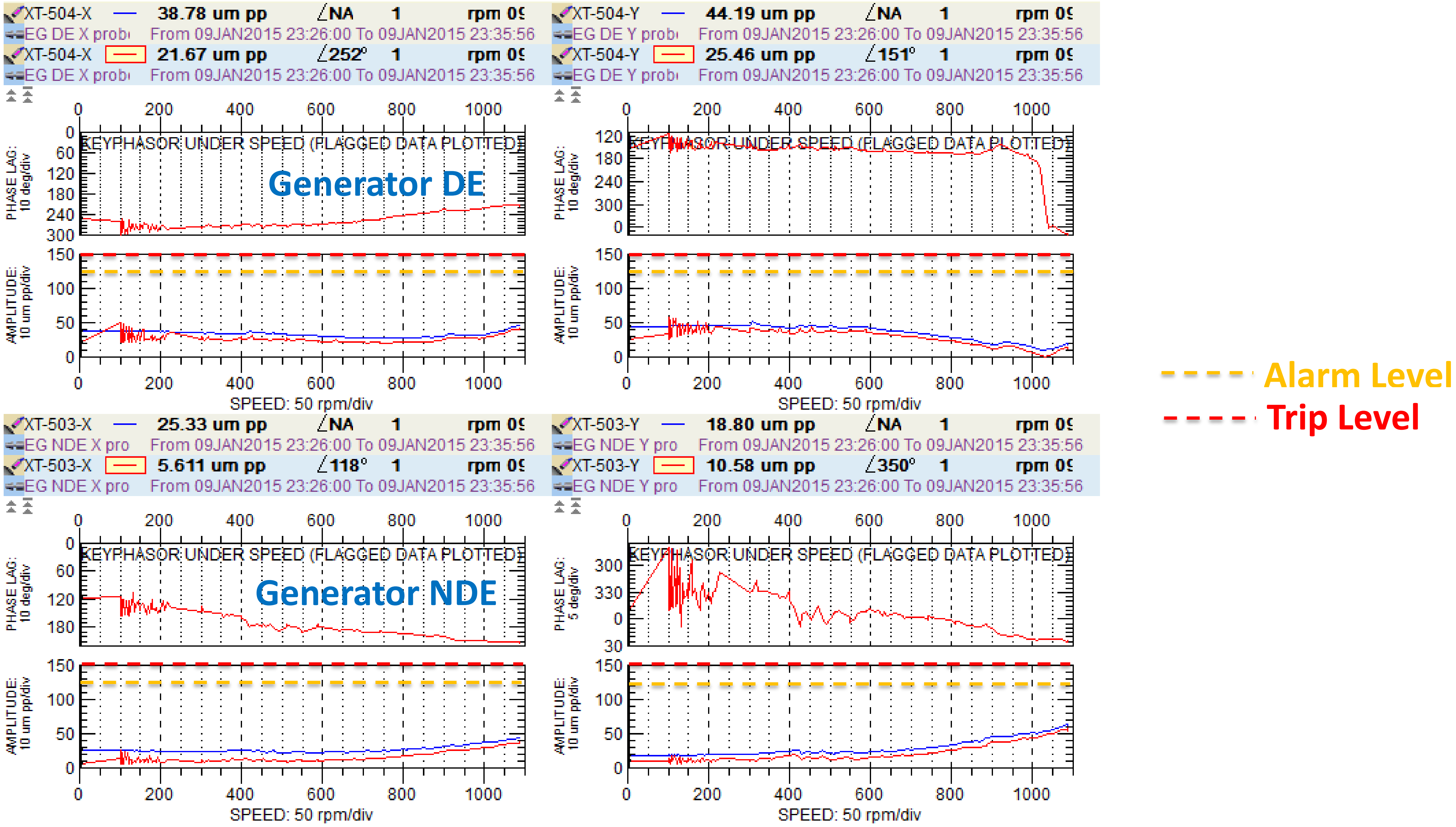
2) Rotor-dynamics is less affected by connection errors (misalignments, flanges manufacturing errors, etc.)

THEN

If the root-cause is the generator flange non-conformity, the soft joint must attenuate its effects on system rotor-dynamics

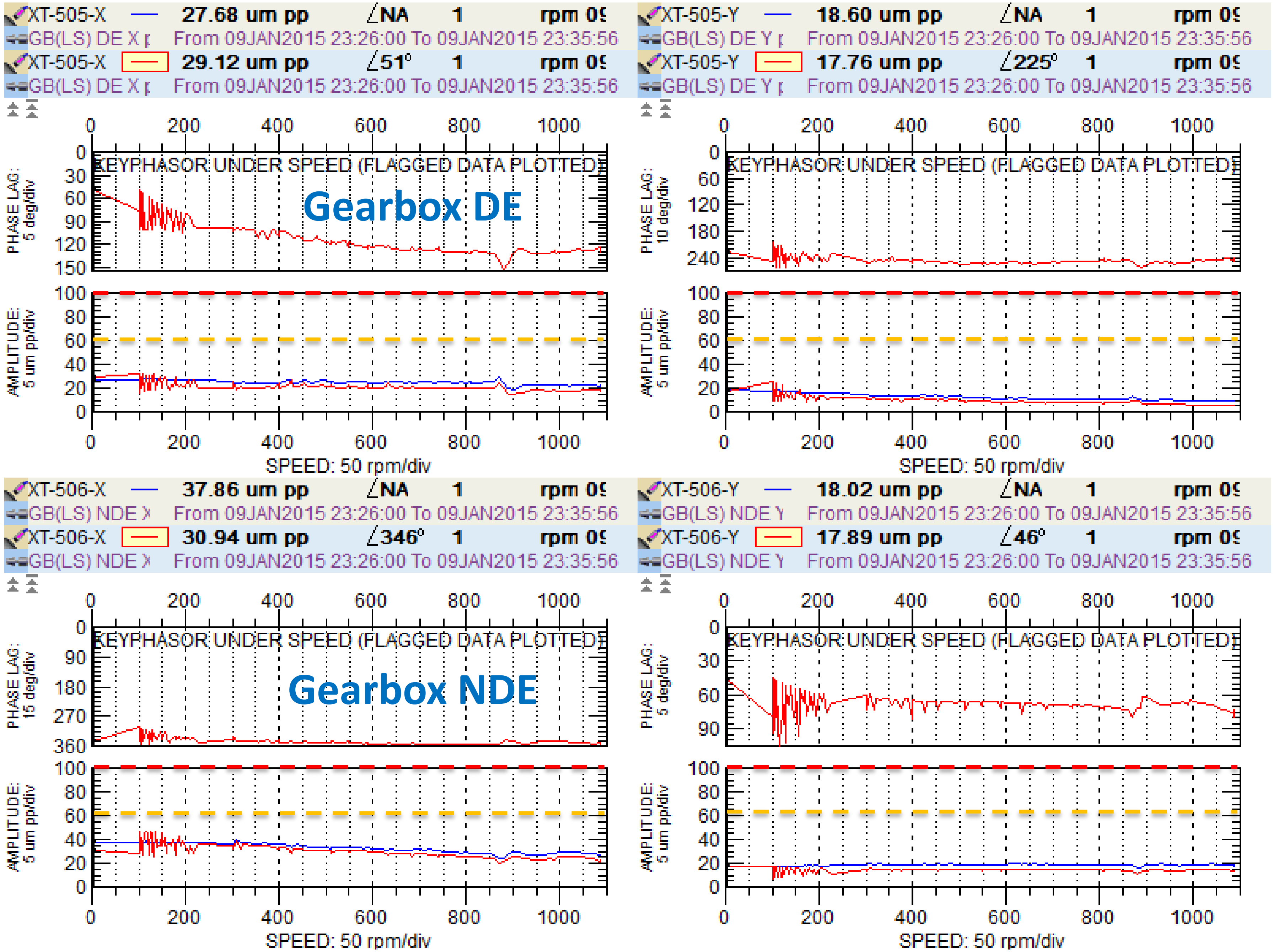
Hypothesis validation via dedicated test

Bode plot of Generator vibration probes with soft joint installed



Hypothesis validation via dedicated test

Bode plot of Gearbox vibration probes with soft joint installed



Conclusions:

In presence of soft joint , radial vibration is dramatically reduced

THEN

The root-cause is the Generator flange non-conformity

Resolution: flange re-machining in situ

The flange deviation was corrected on the field, by the grinding process performed on the generator flange face

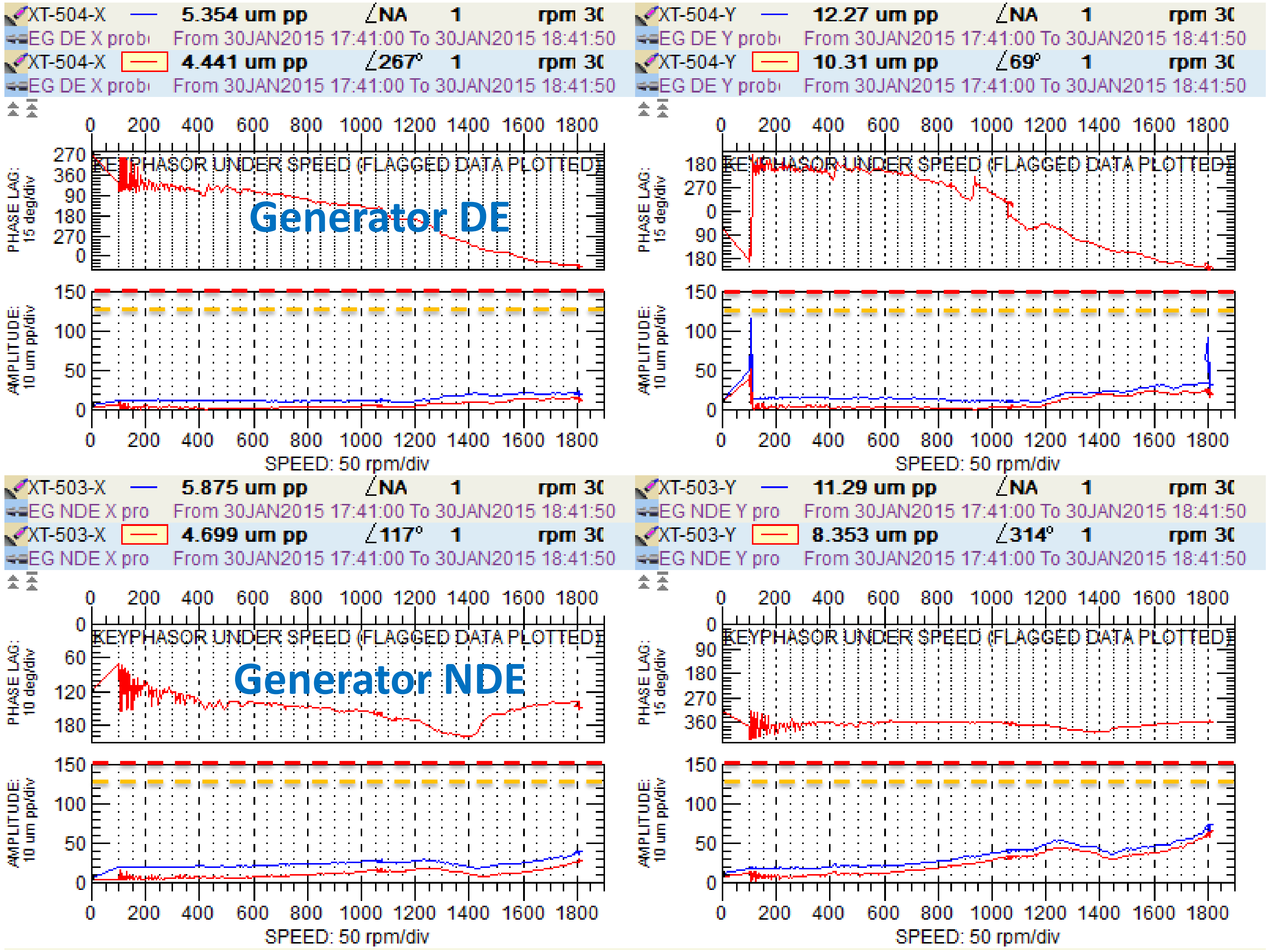
VIDEO

Axial run-out reading with the 3 dial gauges installed and the shaft in rotation was performed after flange machining to confirm the flange flatness

VIDEO

Rotor-dynamics after re-machining

Bode plot of Generator vibration probes



Vibration analysis after flange machining confirms the correctness of the corrective action.

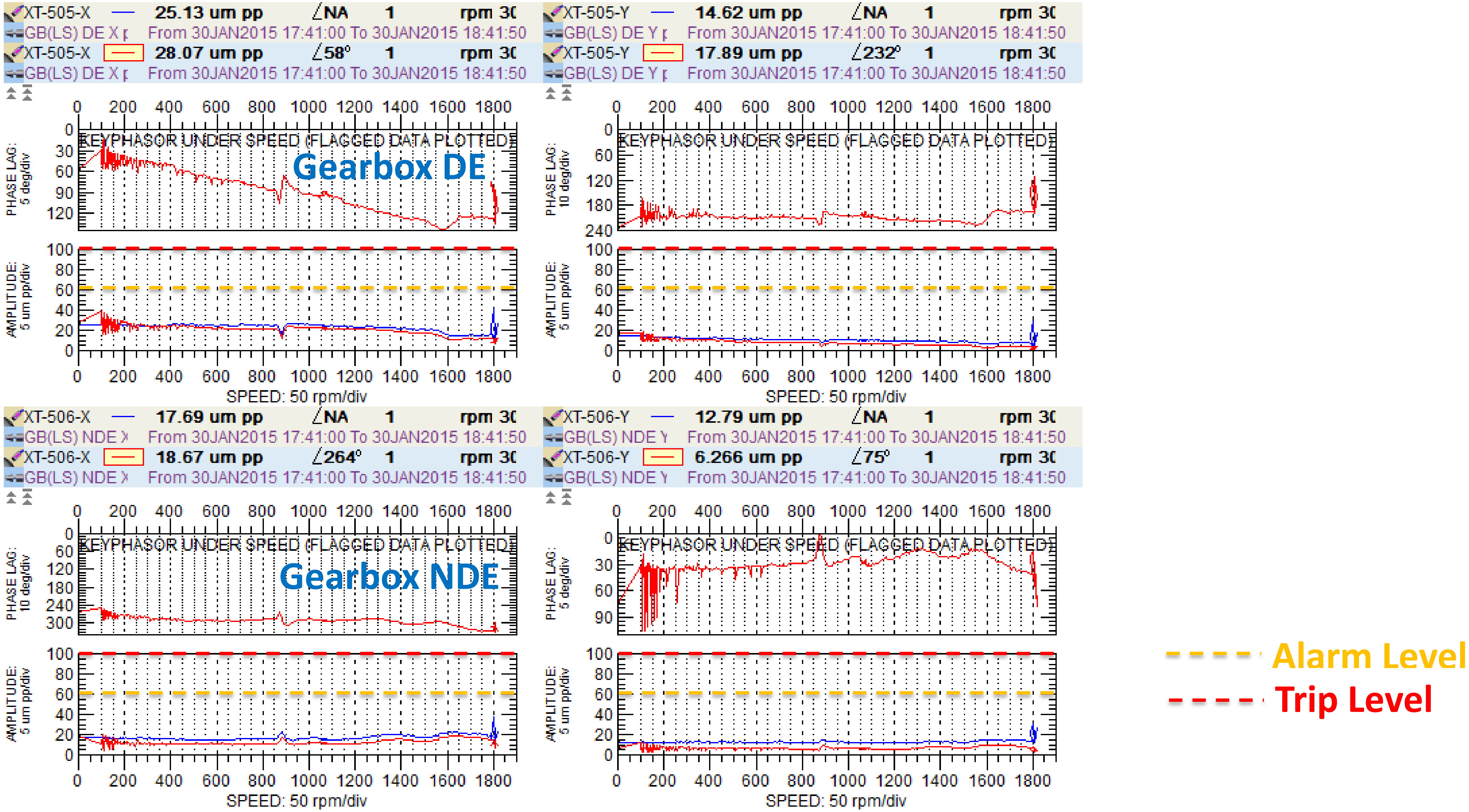
Rotor-dynamic of the shaft line at both FSNL and FSFL condition meets the expected behavior.

Alarm Level

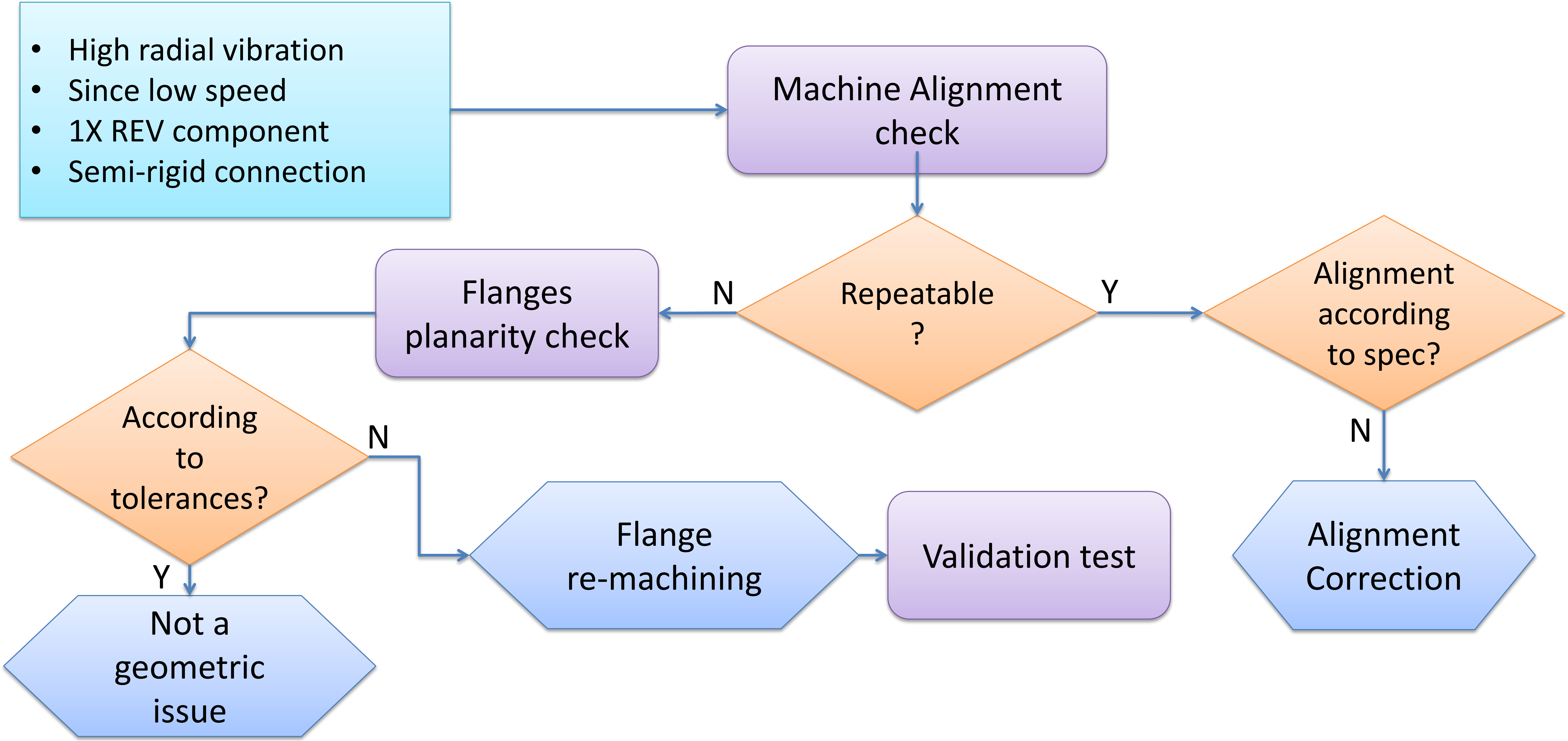
Trip Level

Rotor-dynamics after re-machining

Bode plot of Gearbox vibration probes



Keypoints and basic troubleshooting



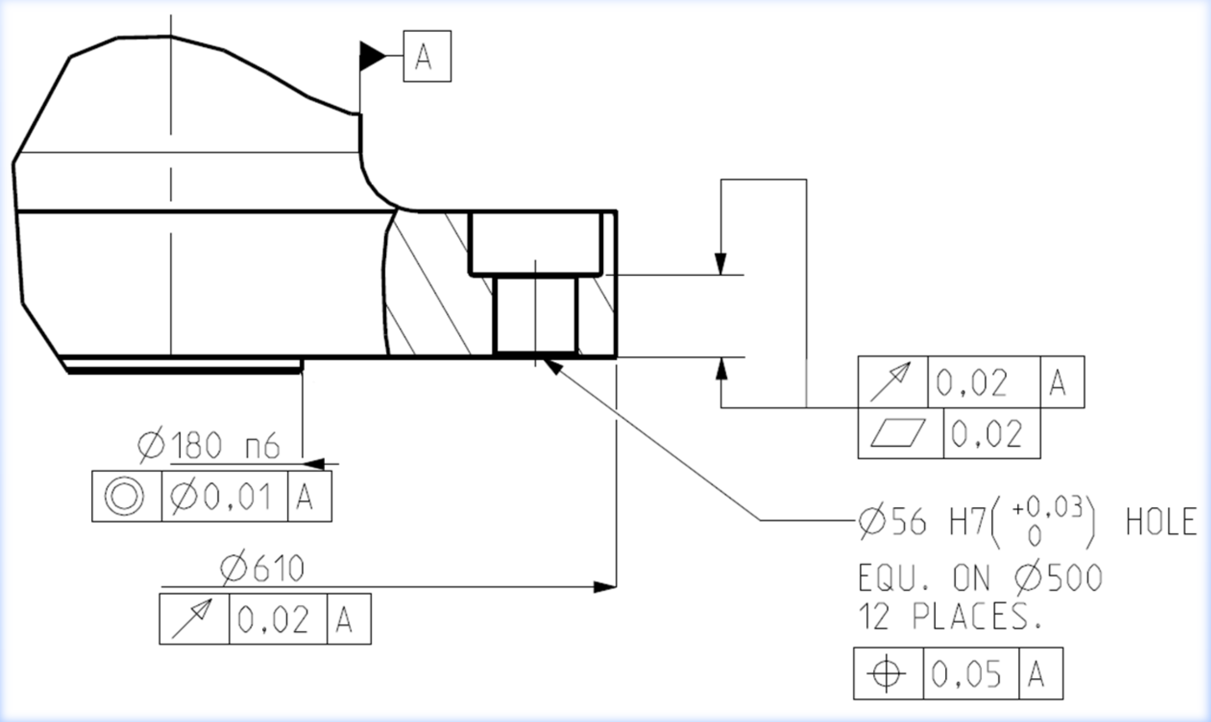
Lessons learnt: Design & Manufacturing

Design

Tight geometric tolerances recommended in case of semi-rigid connection:

☑ Planarity tolerance

☑ Spigot concentricity tolerance



Manufacturing

- Production process was found to be robust: shaft journal grinding to be carried out using the flange as reference to avoid perpendicularity deviations; hence, perpendicularity control on flanges not required by the process

- However, pre-defined shaft production sequence was not followed (actual sequence was based on machine tool availability)

Robust process without final control

BUT

Actual manufacturing sequence not according to process

Possible improvement:

- Systematic dimensional and geometric checks on orthogonality and perpendicularity of flanges

- Strictly follow process and tooling sequence