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

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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

Electric Generator
- Rated Power: 25000 kW
- 4-poles synchronous
- Rated Voltage: 13.8kV-60Hz

Gearbox
- Parallel Offset-Double Helical
- Input speed: 6100 rpm
- Output speed: 1800 rpm
- Quill shaft on LSS

PGT25+ Gas Turbine
- 100% speed: 6100 rpm
- Max power: 33000 kW

Dry Flexible Diaphragm Coupling
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
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.
Checks & Tests performed

- Soft Foot check acting on Gearbox & Generator anchorage bolts
- Machines alignment check
- Flange Planarity Measurement

Negligible dial gauge variations when tightening/untightening bolts: **OK**

Alignment records depended on Generator/Gear flanges relative clocking: Alignment not repeatable

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

Theorical axis of rotation

0° axis rotation

180° axis rotation

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

- Generator DE
- Generator NDE

- Alarm Level
- Trip Level

- Chart showing phase lag and amplitude under different speeds for Generator DE and Generator NDE.
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
The flange deviation was corrected on the field, by the grinding process performed on the generator flange face.

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.
Rotor-dynamics after re-machining

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.

Bode plot of Generator vibration probes
Rotor-dynamics after re-machining

Bode plot of Gearbox vibration probes
Keypoints and basic troubleshooting

- High radial vibration
- Since low speed
- 1X REV component
- Semi-rigid connection

Machine Alignment check

Flanges planarity check

Flange re-machining

According to tolerances?

Not a geometric issue

Repeatable?

Y

Alignment according to spec?

N

Validation test

Alignment Correction

N

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

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