DEVELOPMENT AND IMPLEMENTATION OF VFD ACTIVE DAMPING TO SMOOTH TORSIONAL VIBRATIONS ON A GEARED TRAIN

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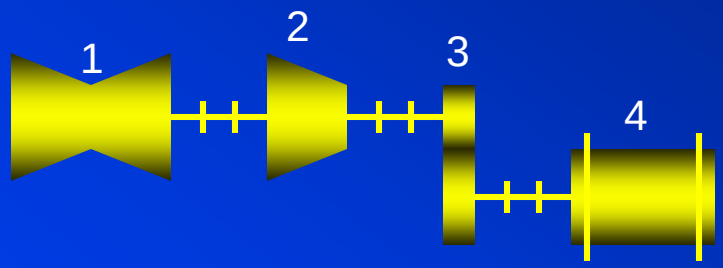
imagination at work

37th Turbomachinery Symposium

Talk Overview

- ✓ Problem Description
- ✓ Vibration Characteristics
- ✓ Analytical Efforts to Diagnose Problem
- ✓ VFD Control Algorithm Modifications
- ✓ Prediction vs. Test Effectiveness
- ✓ Concluding Remarks

Overview

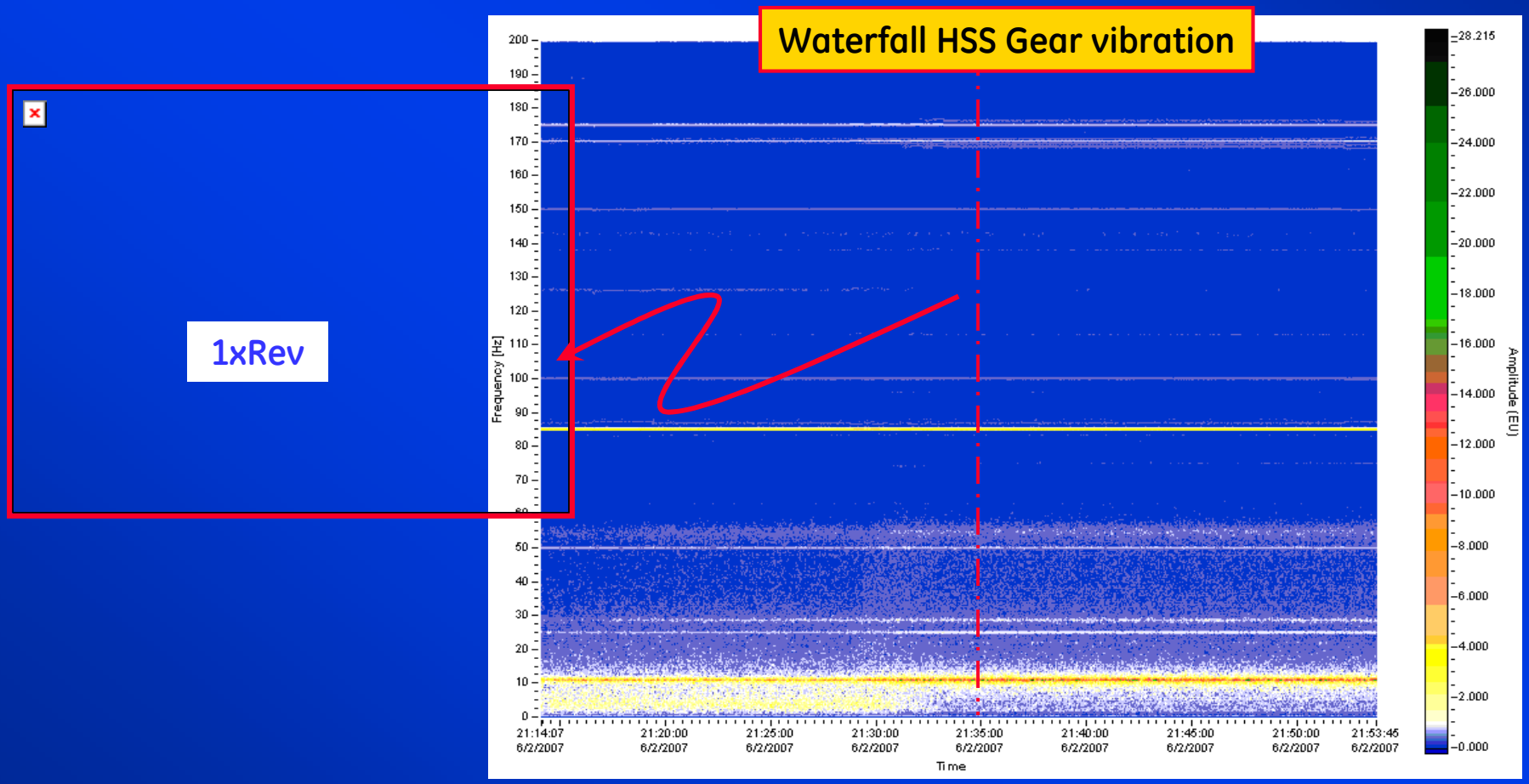


- **NLG Train consisting of:**
  - Frame 6B Gas Turbine Driver (1)
  - Centrifugal Compressor (2)
  - Gear (3)
  - Variable Frequency Driver (VFD) Helper/Starter Motor (4)

- **During full load testing (at GE Massa Plant)**
  - Normal vibration with gas turbine drive only
  - Appearance of subsynchronous gear vibrations with VFD & Gas Turbine drive
  - Operation limited to 60% of rated power due to vibration levels on gear

Gear Vibrations w/ VFD Engaged

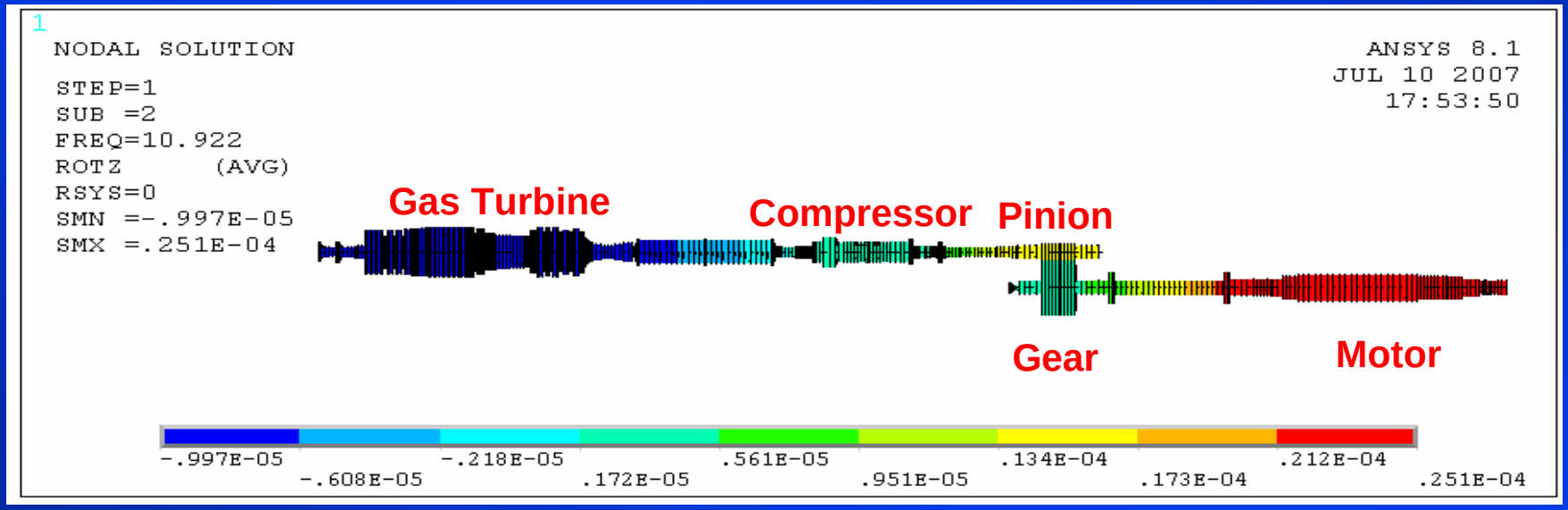
- High Subsynchronous pinion radial vibration @ 11 Hz



GB subsynchronous vibration grew increasing VFD power

Problem Diagnosis

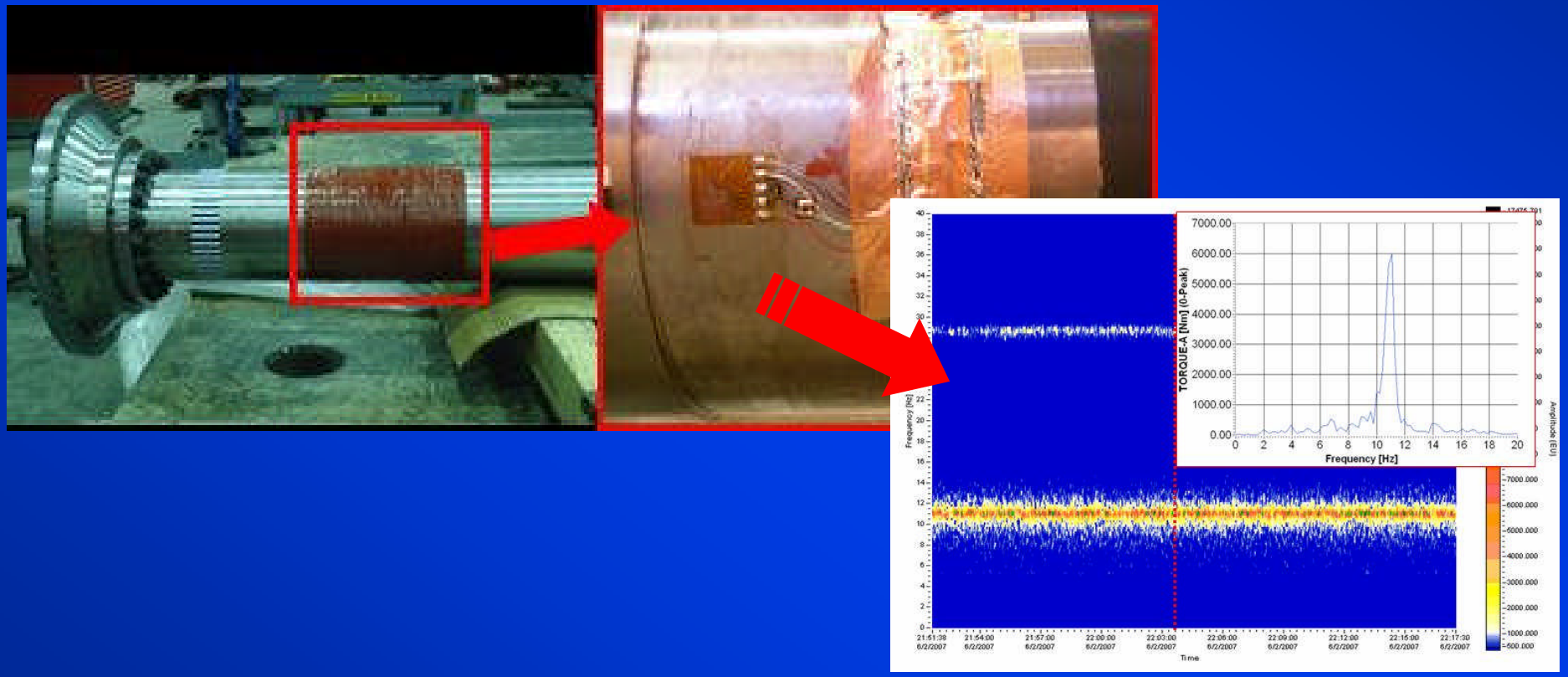
- Subsynchronous vibration on pinion determined to be associated with 1st torsional natural frequency (TNF)
- Torsional analysis of train revealed 1st TNF at 11 Hz with motion associated with LS coupling



- FEM analysis was performed to characterize the dynamic behavior of the Full train
  - result exclude any possible interaction of torsional-lateral resonance.

Train Analysis

- Low Speed (LS) coupling instrumented to record torsional behavior of train



Torsional shaft stress measured was more then expected

Torsional Issue

- Employed real time monitoring of both mechanical and electrical data:
  - VFD output variables (currents / voltages, THD, Power, and Power Factor….).
  - Mechanical torque of the train (Static Torque, Dynamic Torque, Torque THD, Torque Ripple).

LNG train configuration analyzed and main variables post processed

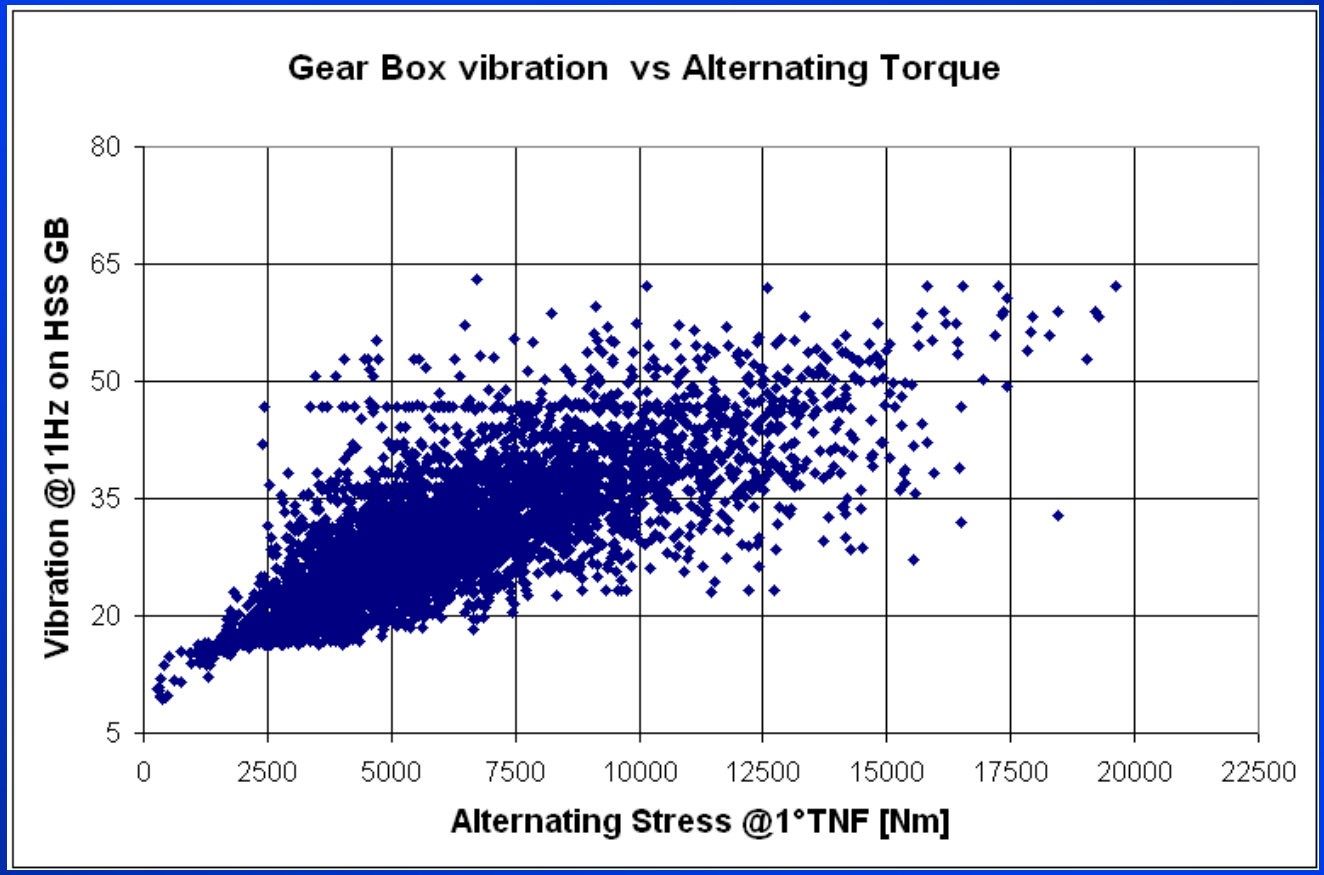
Measured shaft torque

Motor voltages and currents measurement

Motor airgap torque calculation

Pulsating Torque vs. Radial Vibration

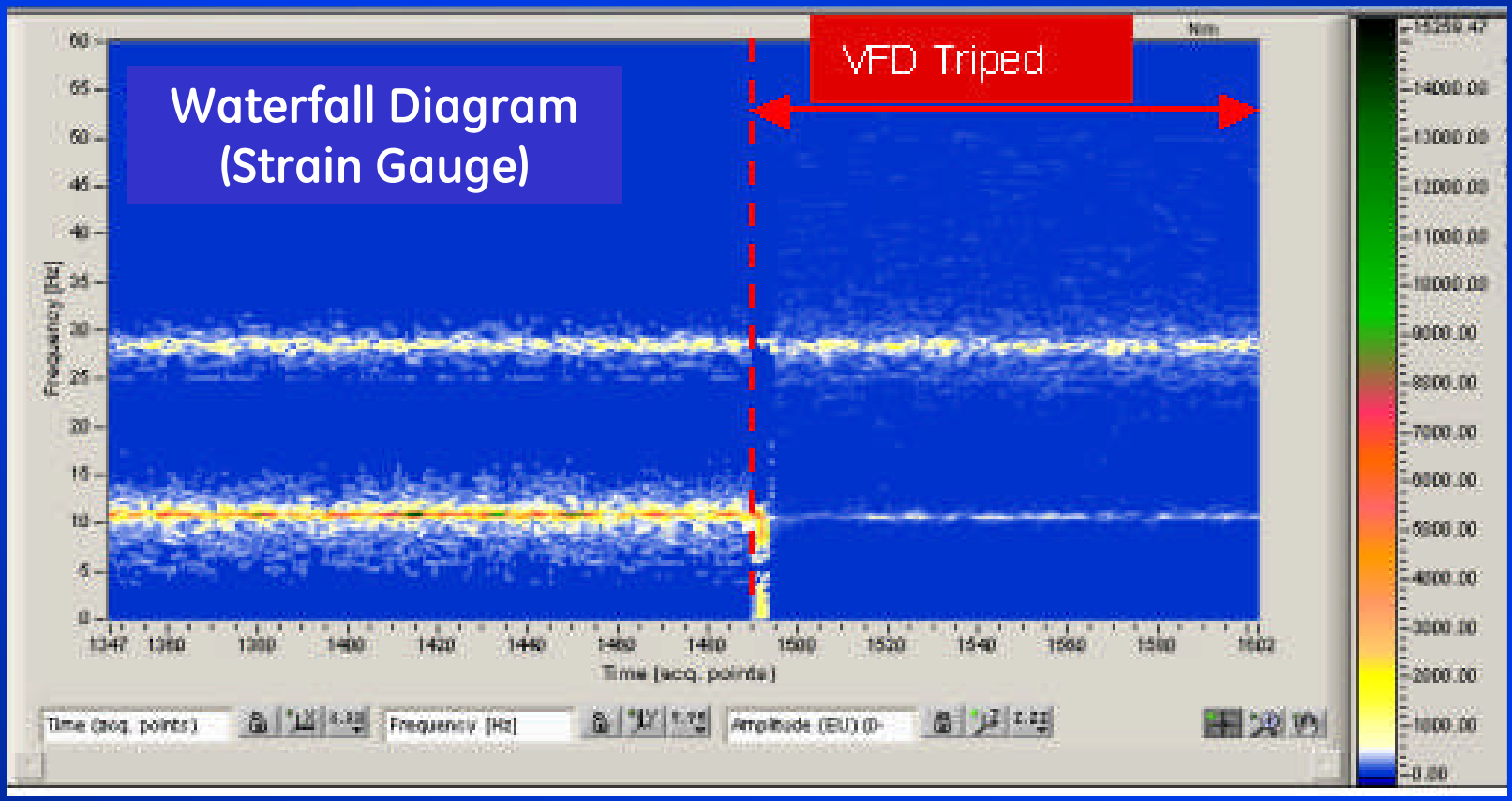
- All acquired data were compared in order to identify any possible relationship



Strict correlation between alternating torque and GB radial vibration

Influence of VFD Motor

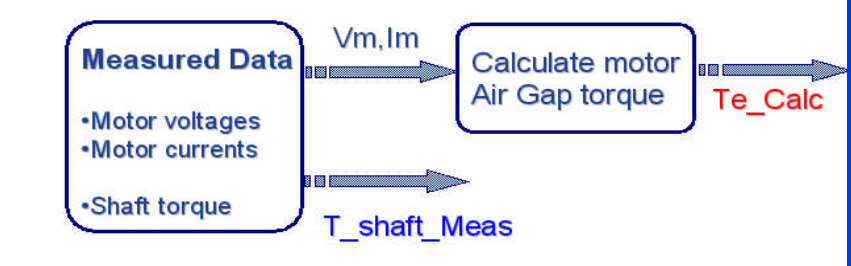
- VFD de-energized to examine impact on torsional pulsations

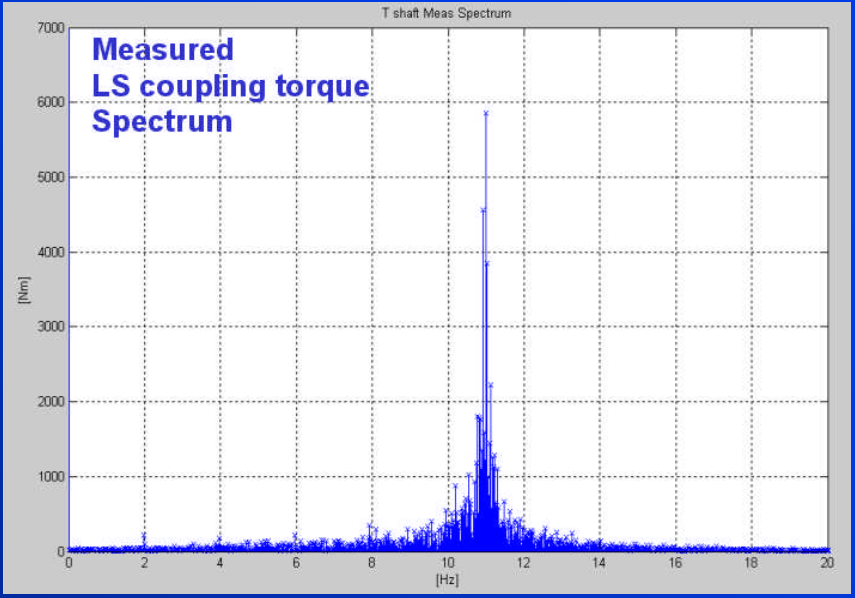


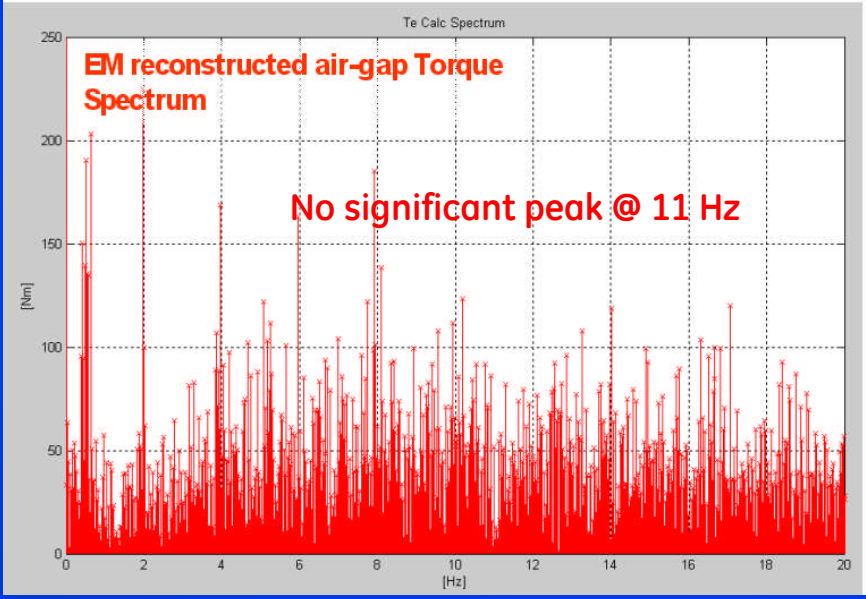
When the VFD was tripped the alternating torque disappeared completely

Motor Air Gap Torque Calculation

- Use measured electrical variables to calculate Air Gap Torque





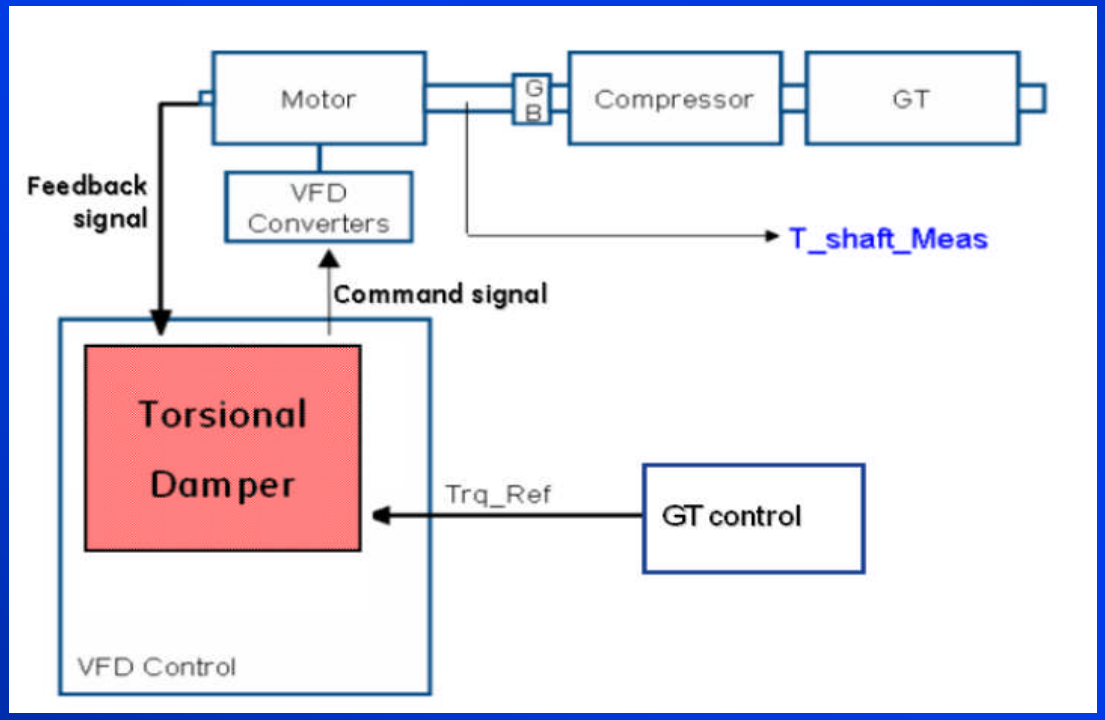


LS Coupling torque measurements clearly show 11 Hz (1°TNF) component.

Calculated motor Air Gap torque does not show 11 Hz

Torsional Damper Function

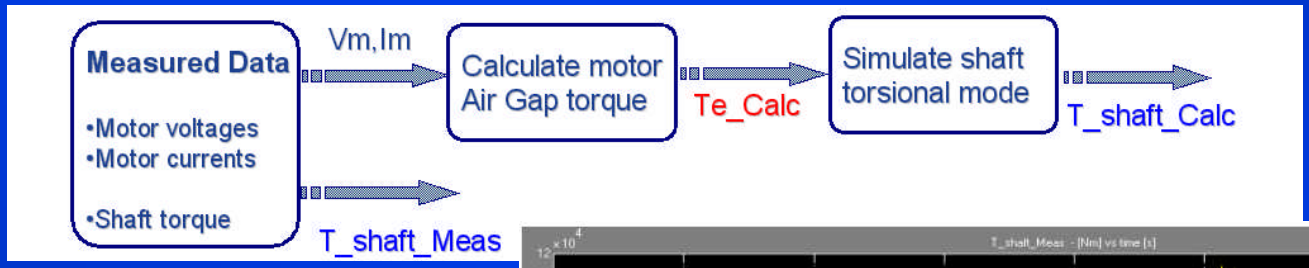
- Implemented "novel" concept of active damping function to VFD controller
  - Further reduce the motor pulsating torque only in the 11Hz components range.
  - Software function (no additional hardware)

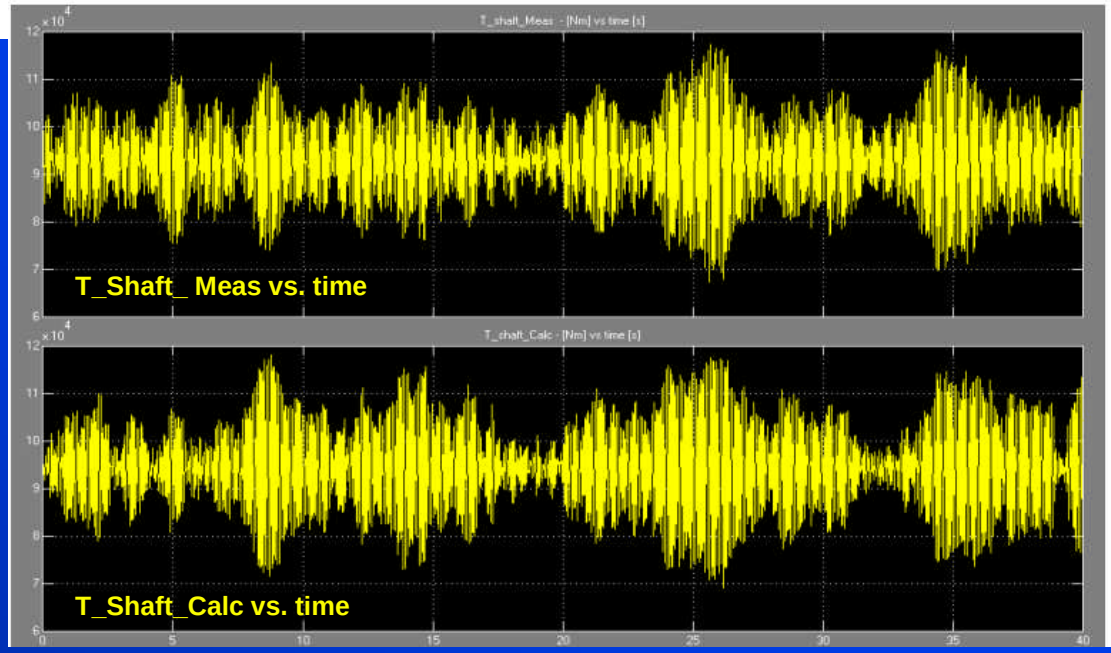


Torsional Damper Algorithm has been implemented in VFD control

Simulation Model

- Based on the detailed train mechanical data a simplified Simulink torsional mode model has been developed.



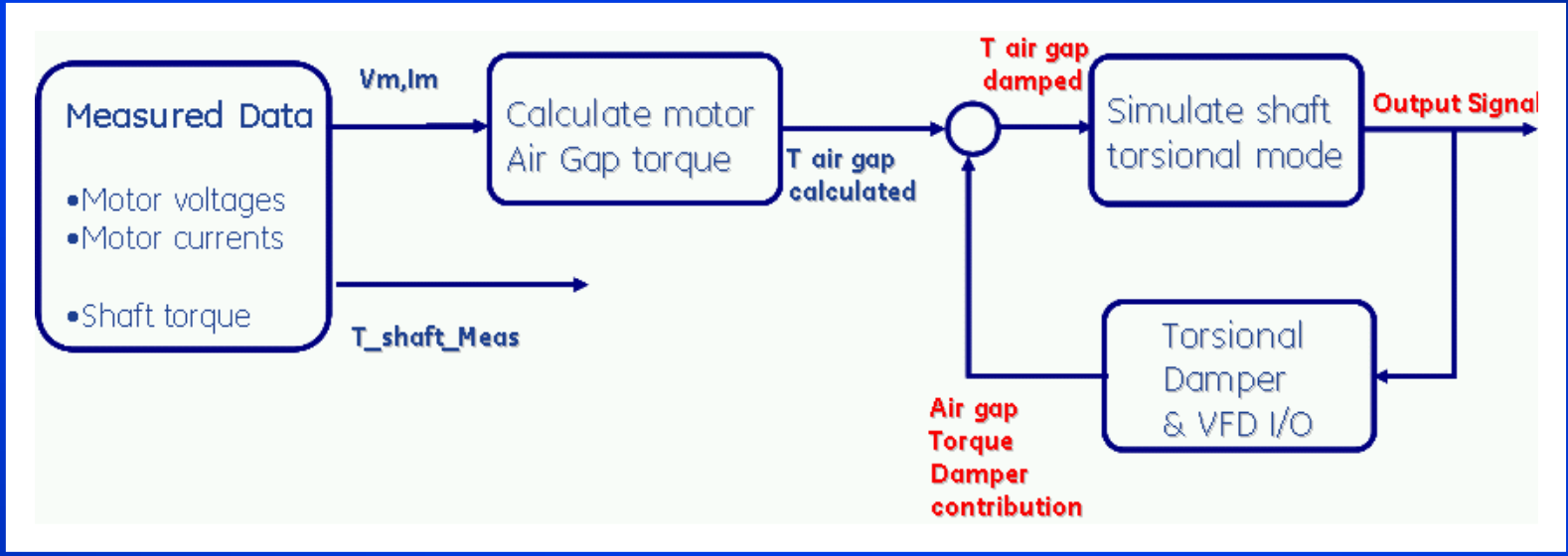


Shaft Torque Measured

Shaft Torque Simulated based on Measured Electrical Variables

The Simplified Simulation Model has been validated based on test results

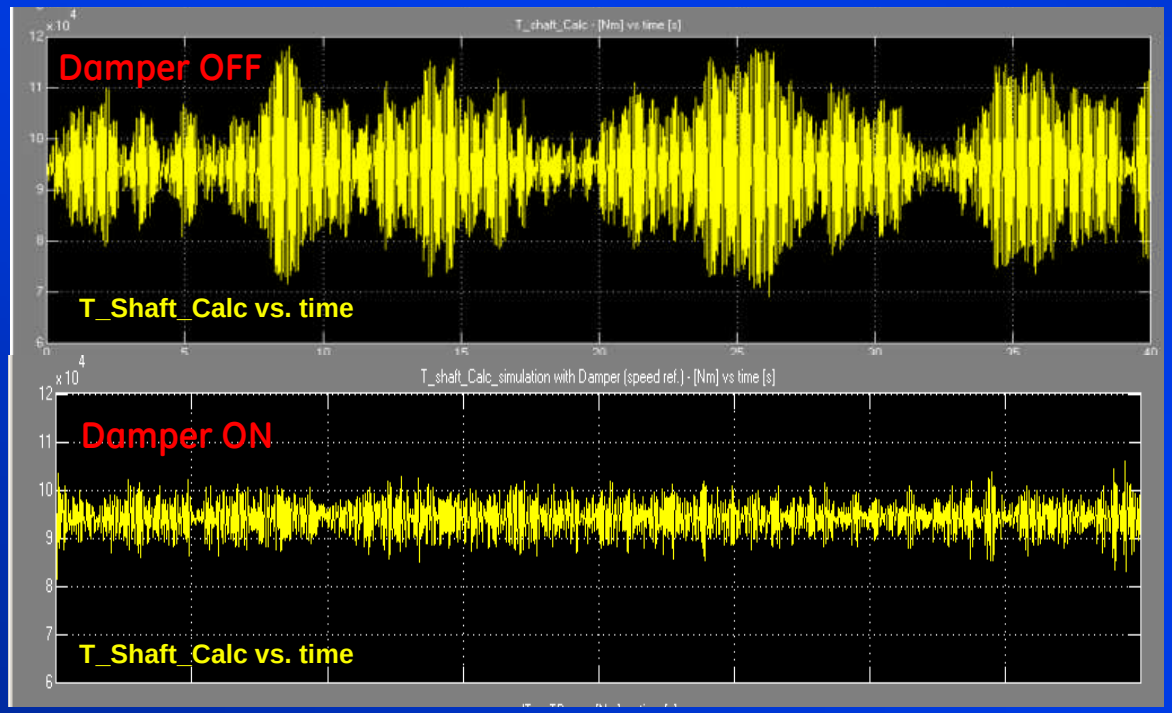
Approach to Active Damping Simulation and Validation



- ✓ Simulation: Add damper to show effect
  - ✓ Compare shaft torque estimated with damper to measured shaft torque without damper
    - ✓ Compare shaft torque measured with damper to measured shaft torque without damper

Predicted Effectiveness of VFD Damper

- Simulation of Torsional Damper Function - Time domain
  damper added to model and expected shaft torque recalculated



Shaft Torque Simulated without damper

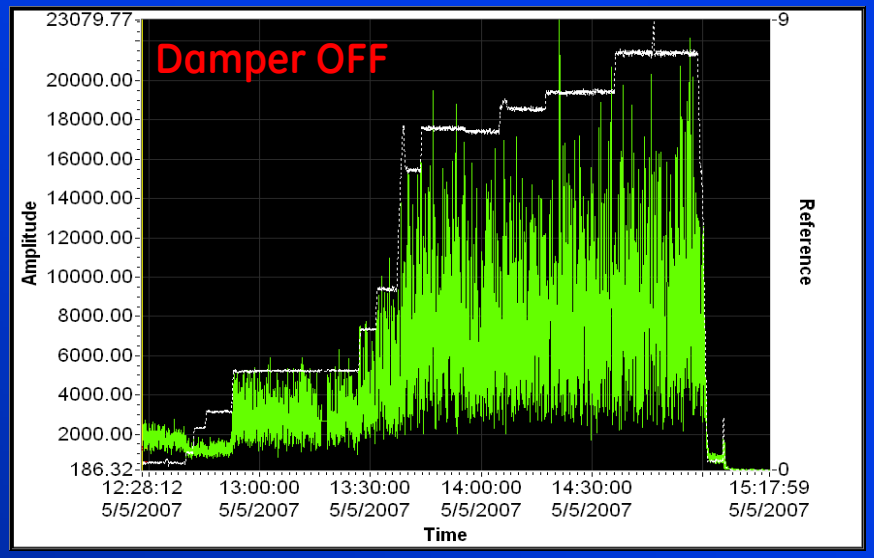
Expected Shaft Torque with damper (simulated) >3:1 overall reduction

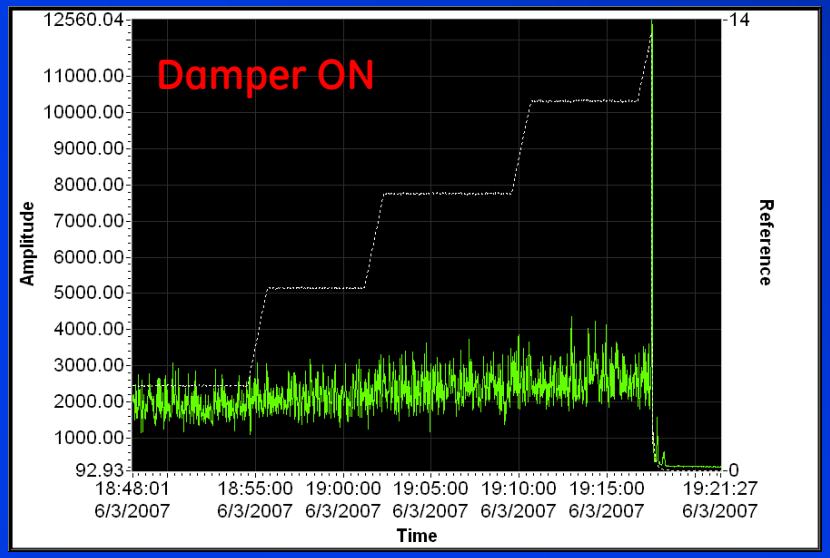
Damper effect Simulation Results - Time Domain (EM Load = 100% Tn = 100'000Nm)

Expected overall LS coupling torque strongly reduced with damper

Measured Damper Benefits - Testing

- String Test results - Time domain
  Torsional Damper software function implemented in VFD control platform





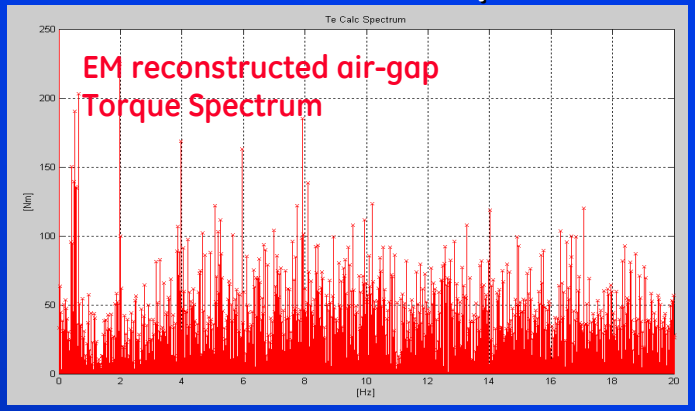
Alternating measured LS coupling torque [Nm] at different EM power [MW] vs. time

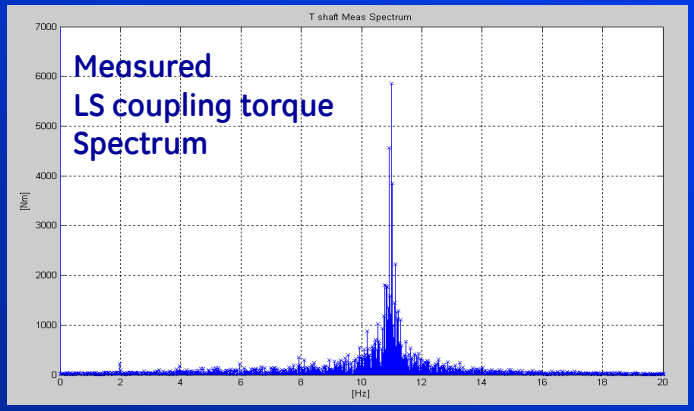
Damper control engaged clearly demonstrates effective reduction of torsional oscillations

Measured Damper Benefits - Testing

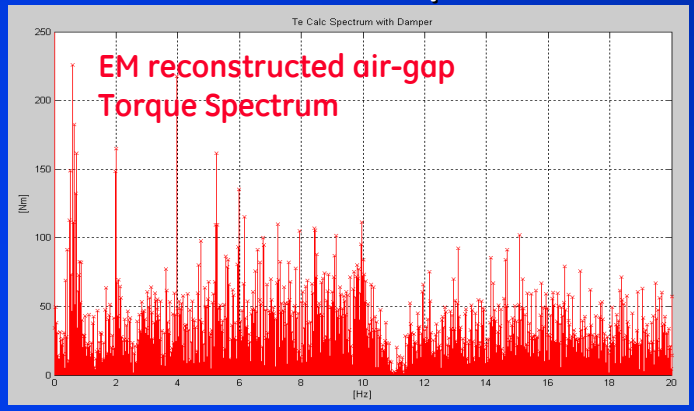
- String Test results - Frequency domain

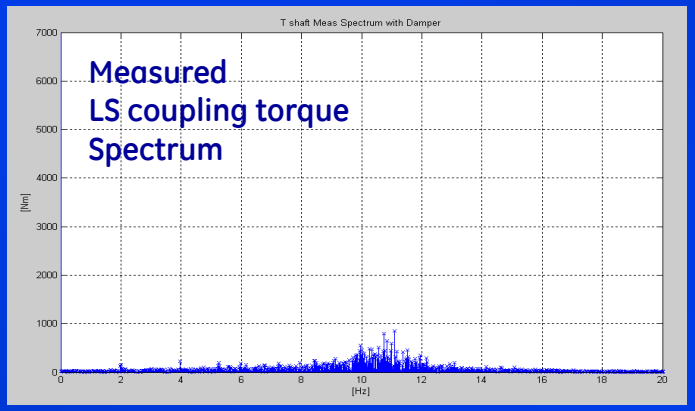
Measurement Without Damper





Measurement With Damper





Shaft stress strongly reduced @ 1° TNF with damper

Concluding Remarks

- ✓ NLG Train equipped with a VFD experienced a torsionally induced vibration problem
- ✓ Excitation of torsional mode can be a critical aspect for O&G application trains…that can result in high vibration on gearboxes
- ✓ To minimize torsional response of the train at 1st torsional mode an Active Damping software function was implemented in the VFD control.
- ✓ The Active Damping Function was successfully tested with strong match between Estimated and Measured Results
- ✓ Significant reduction in torque oscillations and torsional stresses ensuring infinite life of train components and shafting