SUPROCK TECHNOLOGIES

Turbine Generator Torsional Vibration Monitoring using the TDMS System – Recent Applications

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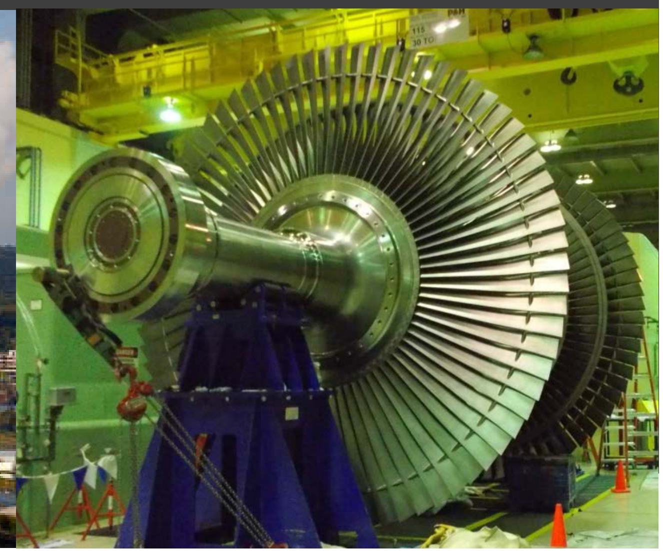


Outline

Introduction

Background tutorial / refresher

- Torsional vibration issue summary
- Design/acceptance criteria
- Importance of, and methods for, mode identification
- Methods of testing

TDMS System

- Description
- Recent nuclear installation experience
- Example data analysis
- Potential future applications / advancements

Suprock Technologies

- Developed Turbine Dynamics Monitoring System (TDMS) under EPRI Program 65 funded initiative
- Specialization in advanced sensor technology and machine monitoring

MPR Associates

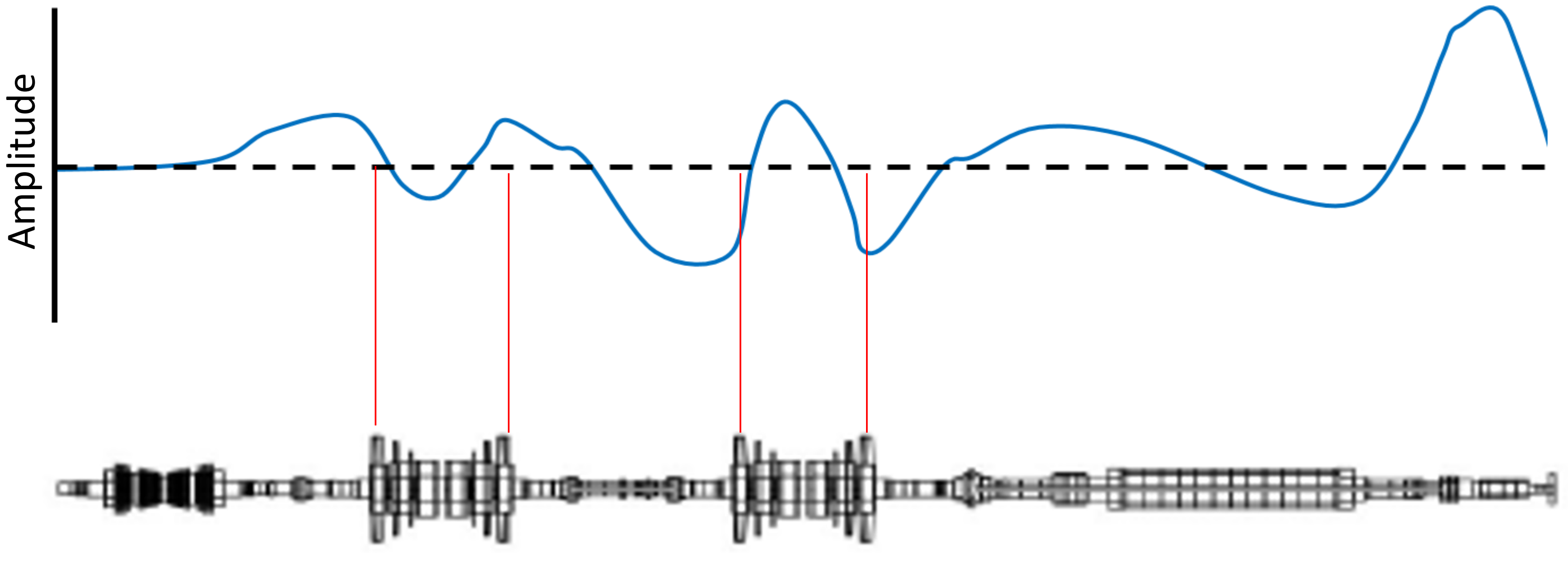
- Has supported the power generation industry since 1964
- Modeled, tested and/or analyzed >100 rotor trains with respect to torsional vibration issues

Teaming approach to execute torsional vibration tests and related analysis for power generation industry

Torsional Vibration Background – Issue Summary

- Typically 20-30 modes < 150 Hz
- Modes with generator participation are excitable via connection to the grid
- Excitation from negative sequence current torques at twice grid frequency always present
- Excitation via faults acts like an impulse torque with grid frequency and twice grid frequency content
- Damping is very low, mode specific and difficult to estimate with high accuracy
  - Typical values of damping ratios (% of critical damping) are in the in 0.02% to 0.1% range
- Excessive torsional vibration can lead to fatigue of rotor train components (e.g., last stage LP blades)

Example Mode Shape



Acceptance Criteria

- ISO Standard 22266 *recommended guidance* (paraphrased)
  - 1% margin from resonance (1.2 Hz around 120 Hz, 0.6 Hz around 60 Hz)
  - 2.5% allowance for grid frequency deviation (3 Hz / 1.5 Hz)
    - Grid specific – significantly lower grid frequency deviation allowance can be justified in the U.S.
  - 2.5% calculation uncertainty (3 Hz / 1.5 Hz)
- NEIL (nuclear) Loss Control Standard paragraph 2.2.4.3.2.10
  - +/- 2 Hz margin from 120 Hz as tested
  - +/- 5 Hz margin from 120 Hz as calculated
- General industry practice
  - +/- 2 Hz margin from 120 Hz as tested
  - +/- 1 Hz margin from 60 Hz

Importance of and Methods for Mode Identification

- Important to not only measure mode frequencies, but to assign those frequencies to the proper mode shape
  - Confirms if all modes of interest have been identified during testing
  - Allows for proper tuning of a model to actual mode frequencies
  - Critical to assessing impact of rotor train modifications (e.g., frequency tuning modifications or retrofits)
- Mode identification achieved by
  - Comparison of to model predicted frequencies
  - Strain vs. displacement relative magnitudes
  - Phase relationship between two different axial measurement locations

Modeling vs. Testing – do I need both?

- Modeling compliments testing, and vice versa
- Drivers for testing
  - Often difficult to achieve required margin by calculation as there are usually ~ 20 to 30 modes between 0 Hz and 150 Hz for most large rotor trains
  - Requirements always subject to change – calculation alone may not be acceptable in the future to insurers
  - Grid response and interaction outside of turbine-generator modeling scope.
- Drivers for modeling
  - Assists in mode identification
  - Provides a tool that can be used quickly if tuning modifications or analysis is needed

Common Torsional Testing Instrumentation Approaches

- Shaft mounted strain gages
- Shaft mounted accelerometers
- Non-contacting speed sensors
  - Magnetic (e.g., at turning gear)
  - Optical (e.g., laser system with “zebra” tape)
- Blade vibration monitoring systems (e.g. tip timing)

- **Shaft mounted sensors have higher signal to noise ratio than non-contacting sensors**
- **All sensors measure either motion or strain.**
  - **Why don’t we have both?**

EPRI developed TDMS

TDMS
TURBINE DYNAMICS MONITORING SYSTEM

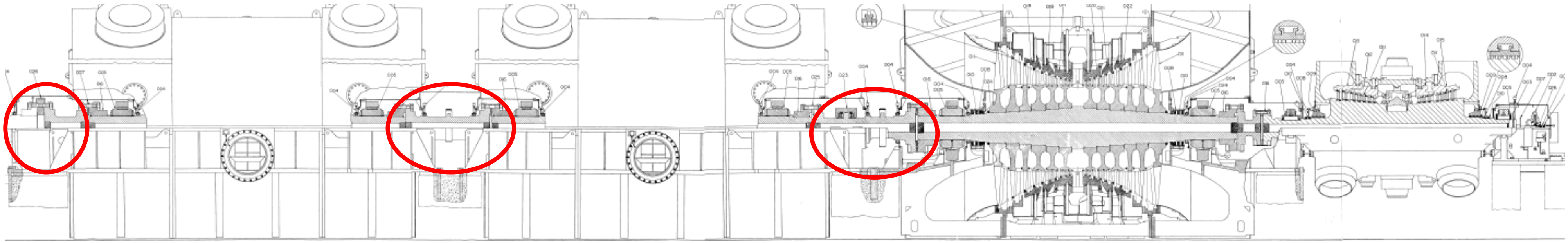
- TDMS- *Turbine Dynamics Monitoring System*
- Patent and commercial license through EPRI.

- **EPRI response to industry need for torsional testing.**
  - Simple engineering documentation.
  - Rapid response time to test requests (days, not months or years).
  - Multi-dynamics telemetry increases test confidence.
  - Capable of long term operation during extended startups and/or monitoring.

Benefit of multiple dynamics sensors

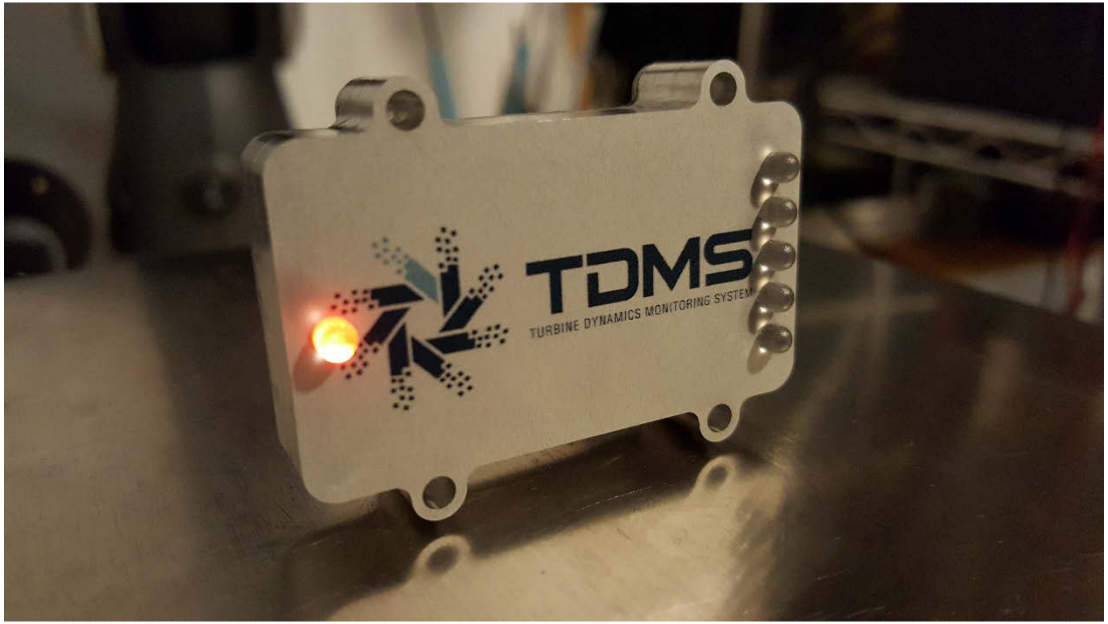
- Kinematic and elastic energy varies over the rotor train depending on the mode shape.
  - Given a mode, some locations lack strain energy, but have high motion.

- **Generally locations for telemetry are limited to inside bearing housings and at open shaft locations.**
  - Due to limited location options, it is important to cover all possible behavior of a mode- either elastic, kinematic, or combined.



TDMS Quad Telemetry

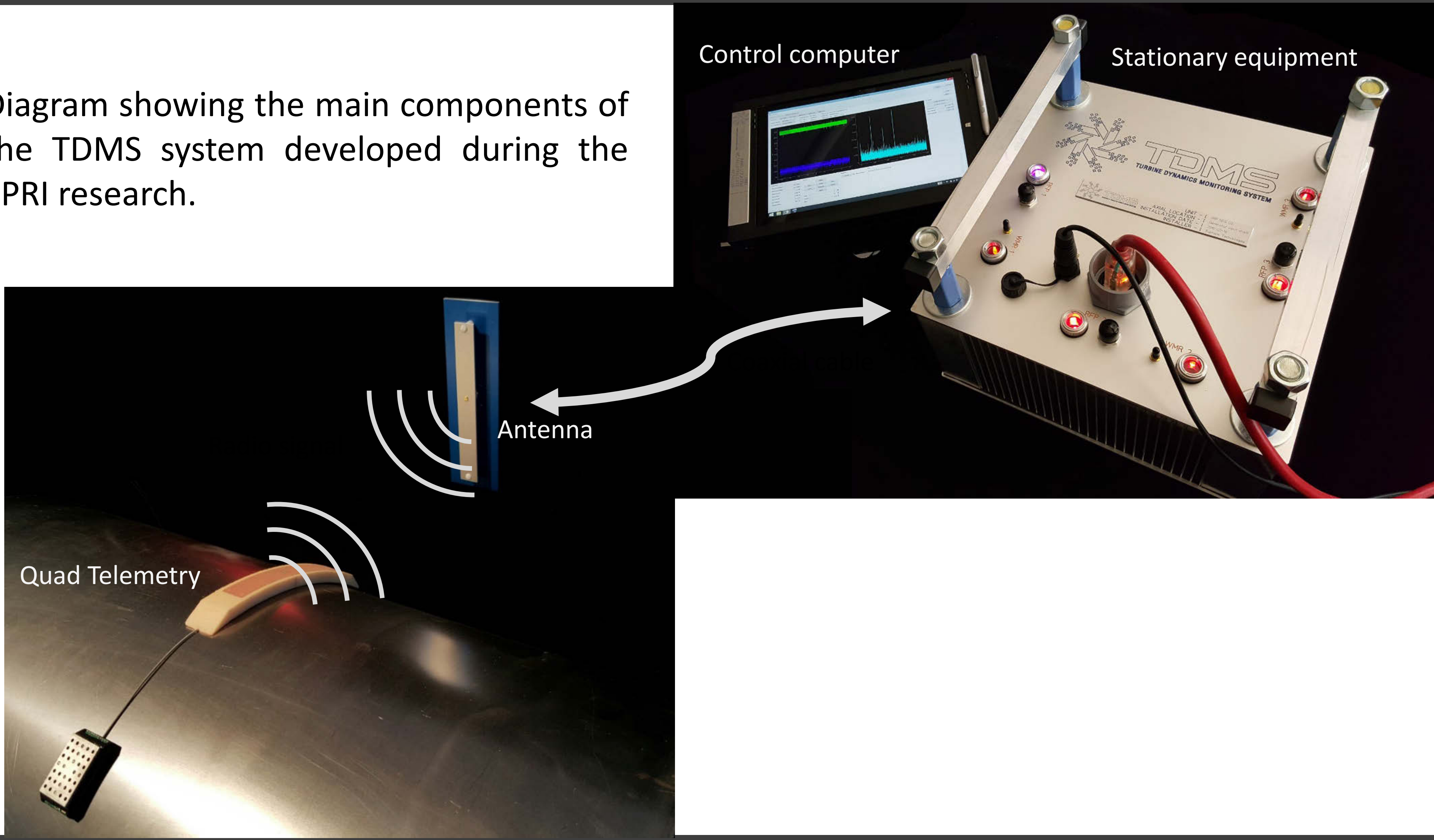
- **Quad telemetry**
  - Torsional strain
  - Tangential acceleration.
  - Lateral strain.
  - Radial acceleration.



- **Battery free wireless**
  - Extended data acquisition.
  - No battery replacement or risks of electrolyte contamination.
  - No inductive ring or high tolerance alignment.

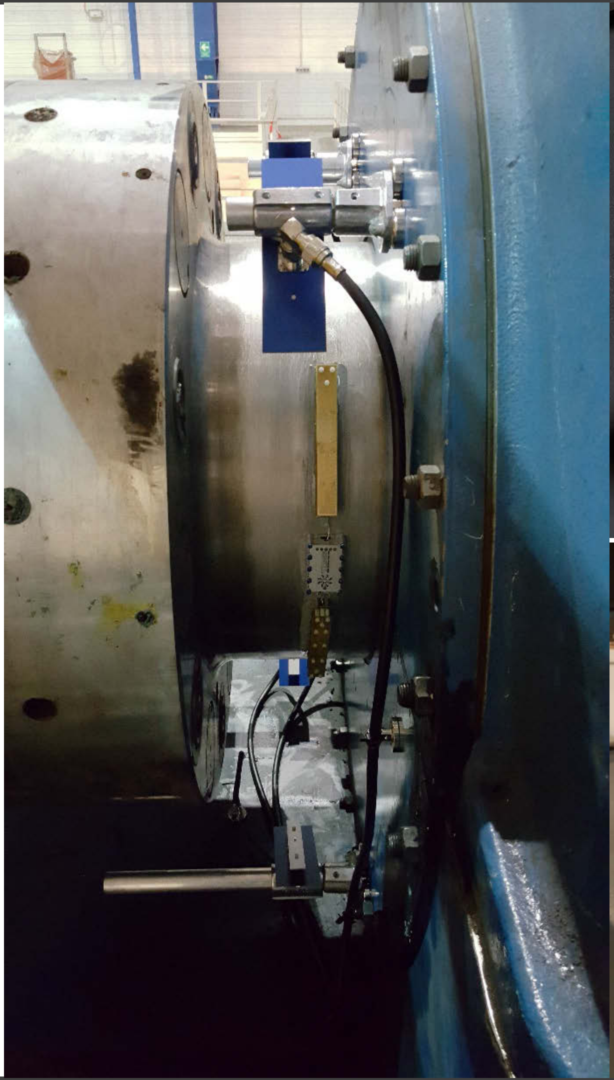
TDMS System Diagram

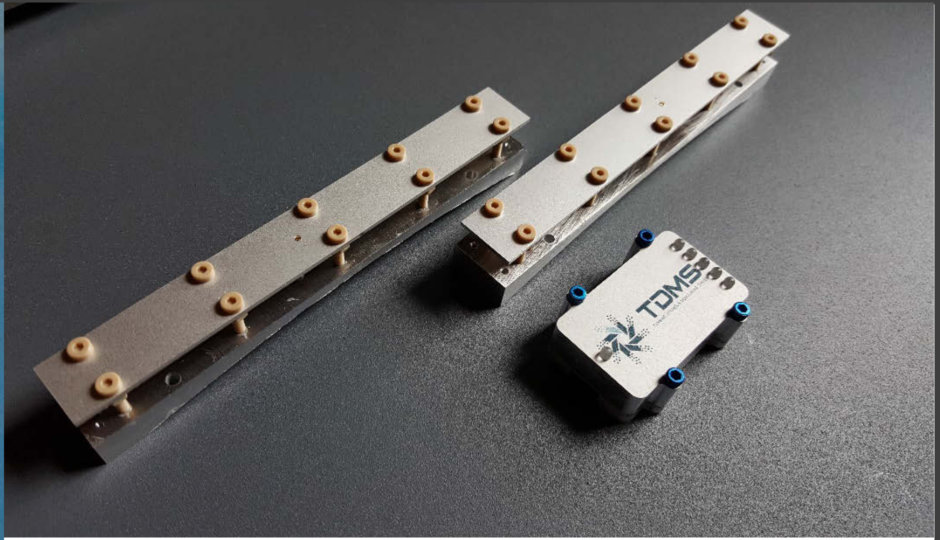
Diagram showing the main components of the TDMS system developed during the EPRI research.



TDMS Commercial System Components

- Quad Telemetry
  - Telemetry module.
  - Antennas.
- Stationary Telemetry
- Stationary antennas



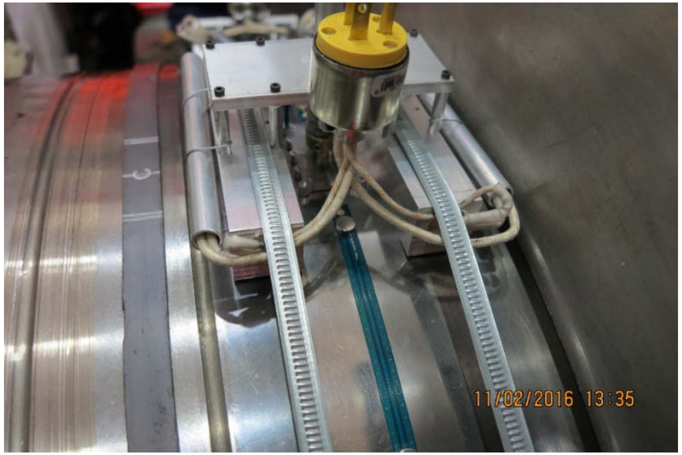


Installation Process

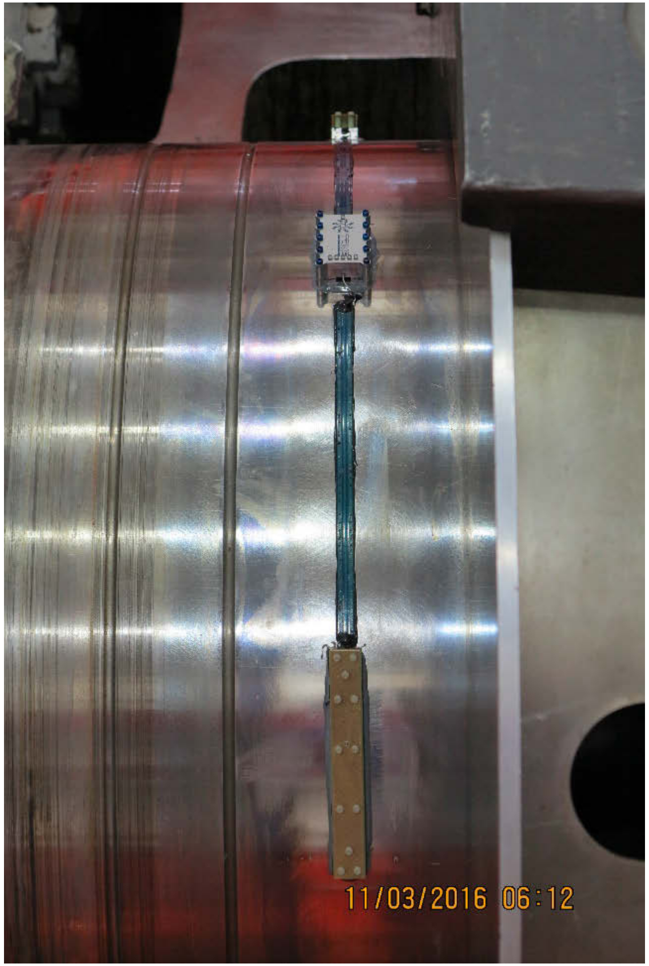
1. Prepare shaft surface

2. Bonding process

- Jigs are used
- Thermal set adhesive



3. Resulting installation

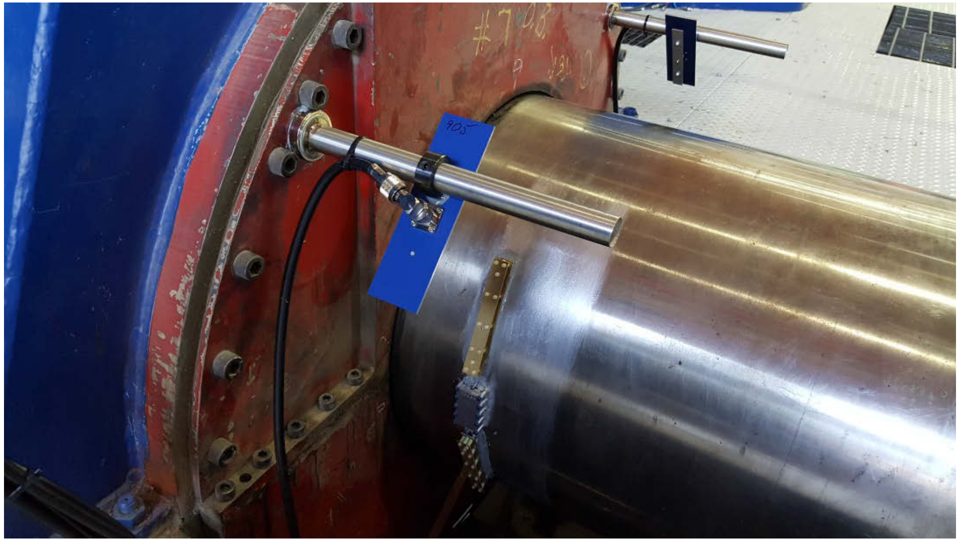


TDMS Application History

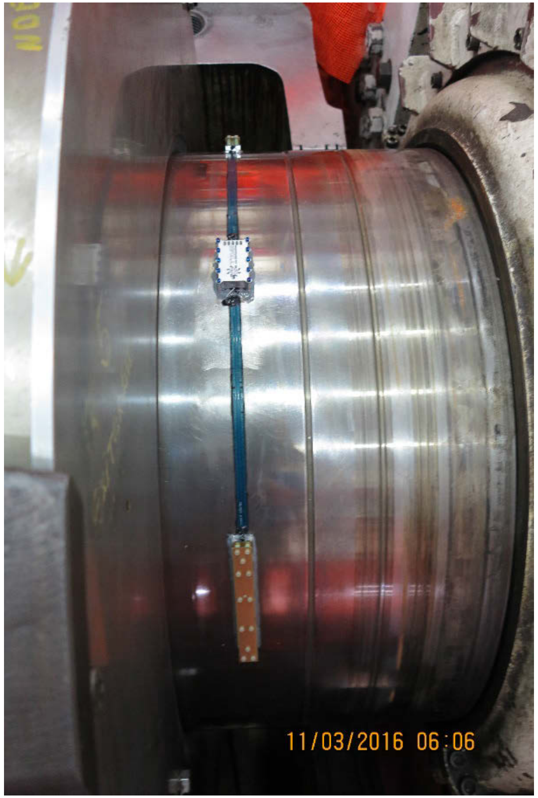
- *2015*
  - Early R&D telemetry was attached under a vacuum infused Kevlar band.
  - Single channel torsional strain.
- *2015 / 2016*
  - Project matured through 2 fossil plant installations on 3 units.
  - Quad Telemetry introduced. Four channel rotor dynamics.
  - TDMS made into modular components replacing Kevlar band.
- *Fall 2016/Spring 2017* First nuclear application.
- *Summer 2017* Second nuclear application.
  - **First commercial nuclear application.**
- *2017* Hydro applications in pumped storage vertical Francis turbine units and ongoing discussions for additional hydro.

Nuclear Installations

- The TDMS supports nuclear requirements.
  - Complete EC Package example from previous tests.
  - Minimal site time for installation tasks. Typically one 8hr shift.
  - Ability to respond to schedule changes.
  - Easily train/include site engineers on data acquisition.



Siemens BB style unit- LP Jackshaft location

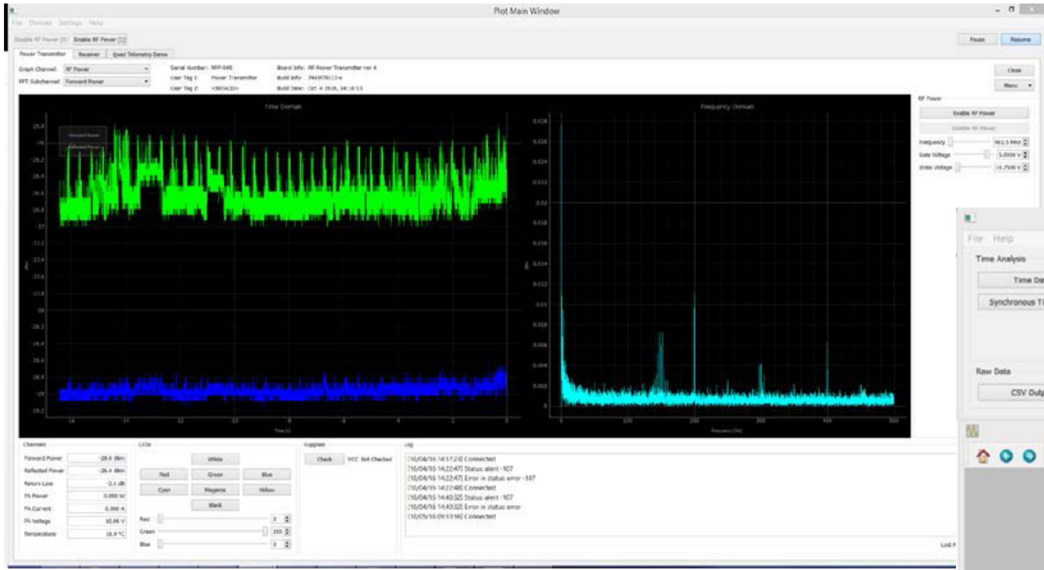


Alstom retrofit ABB unit- Generator Rotor

Data Analysis / Post-Processing

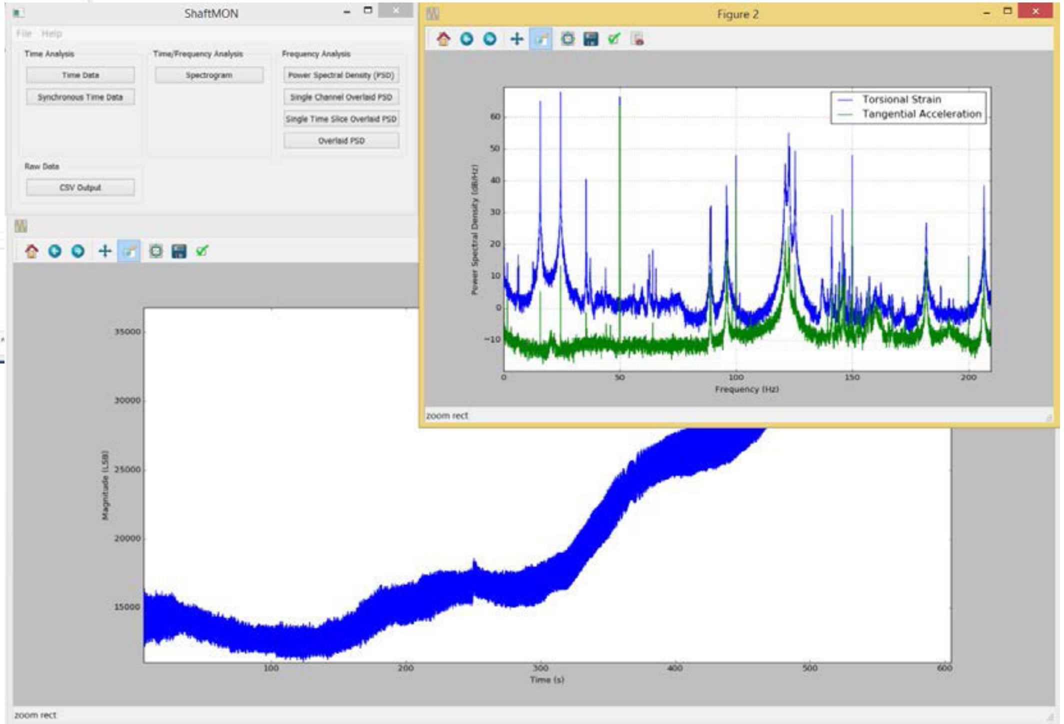
- EPRI sponsored software for the TDMS.
  - Suprock provides software to TDMS utilities at no cost.
  - Empowers utilities to continue to use equipment on-demand.
  - Allows engineers to post process data for reports, communication, and documentation.
- ShaftDAQ – Data acquisition for the TDMS system
  - User friendly control over the DAQ process.
  - Utility engineers can use
- ShaftMON – Data plotting and time/frequency analysis.
  - PSD plots of frequency
  - Overlays of different sensors/time windows
  - Spectrograms (frequency/magnitude vs. time)
  - Combination of plots

Software interfaces

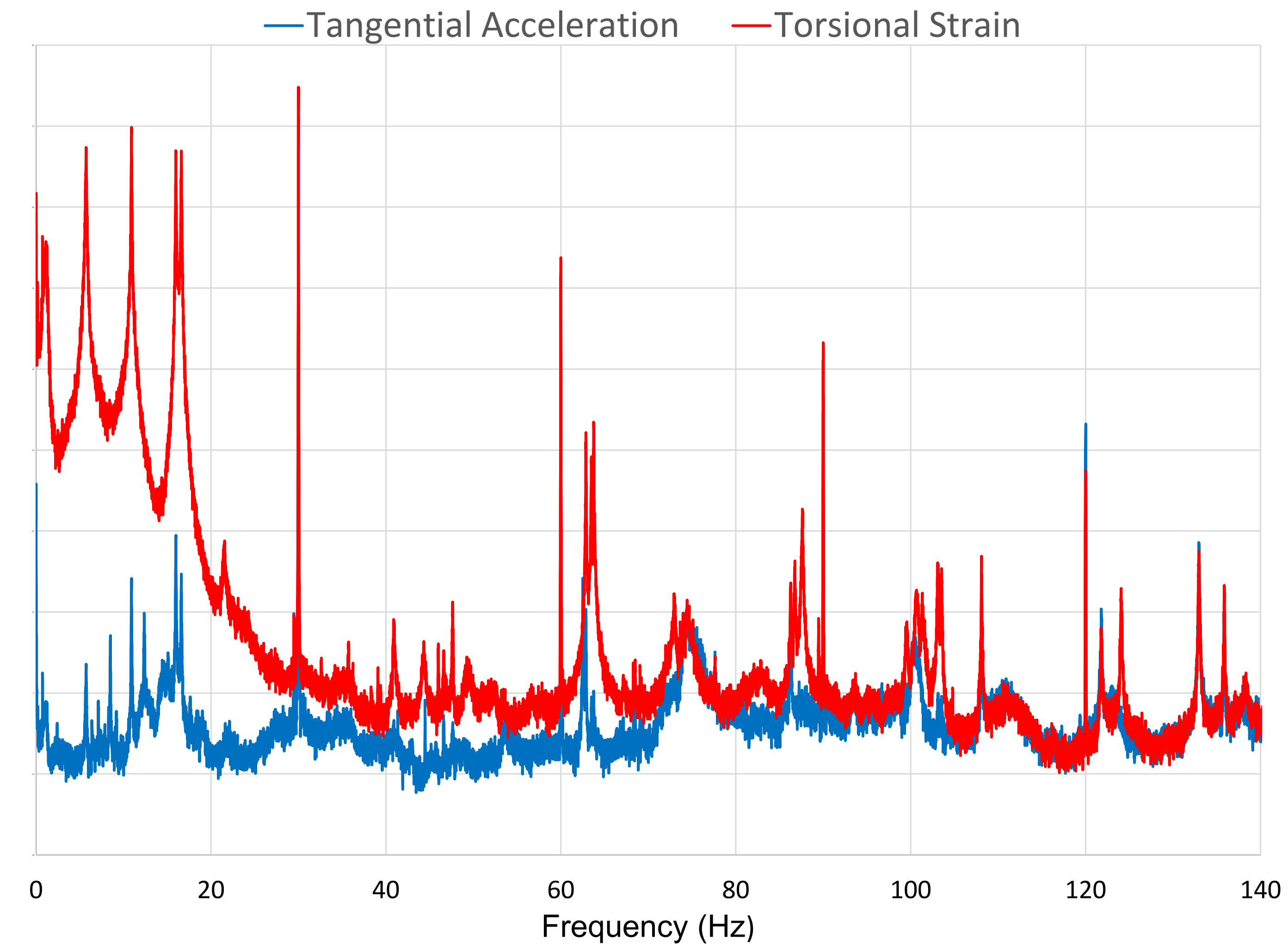


ShaftDAQ

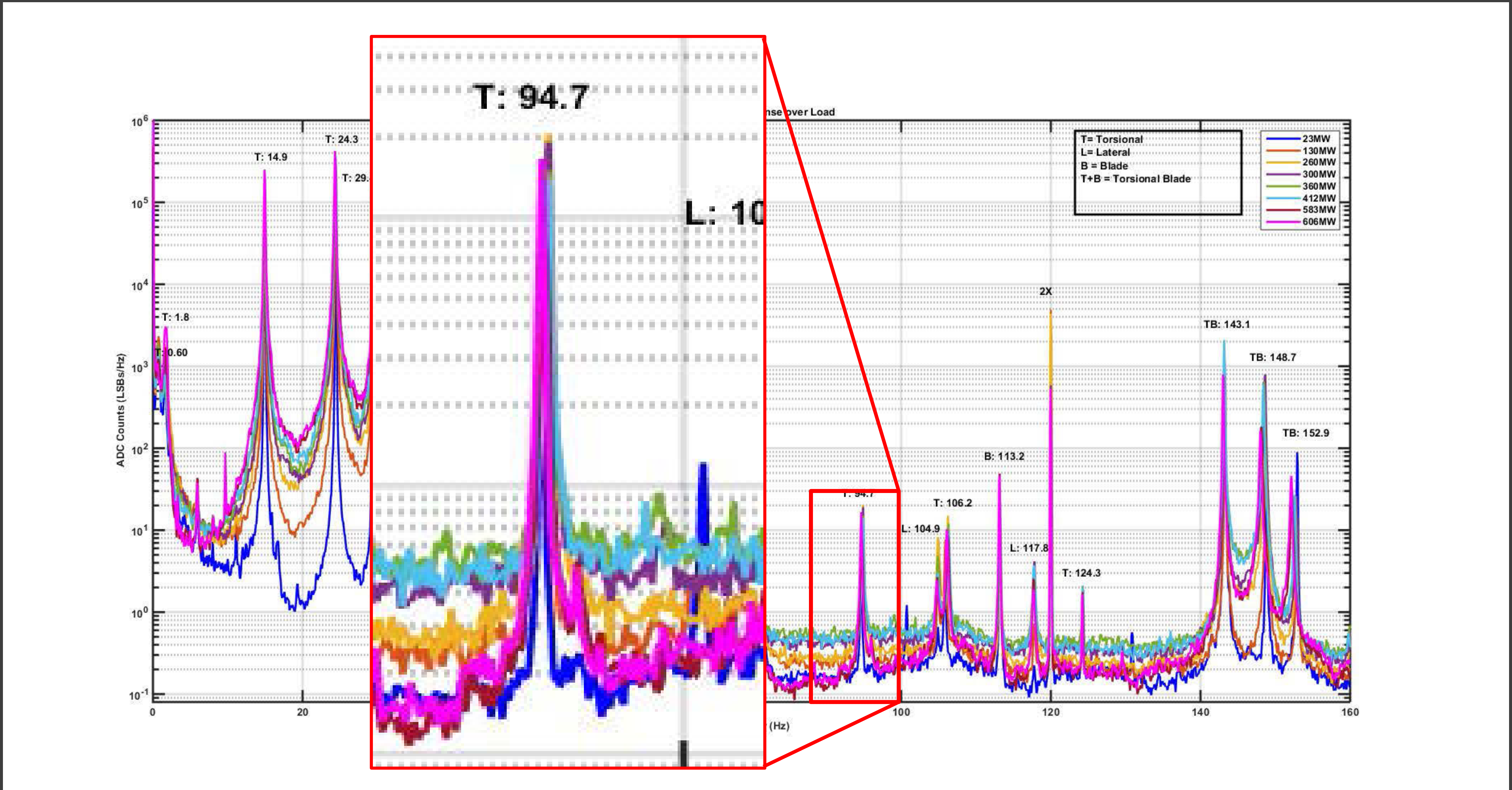
ShaftMON



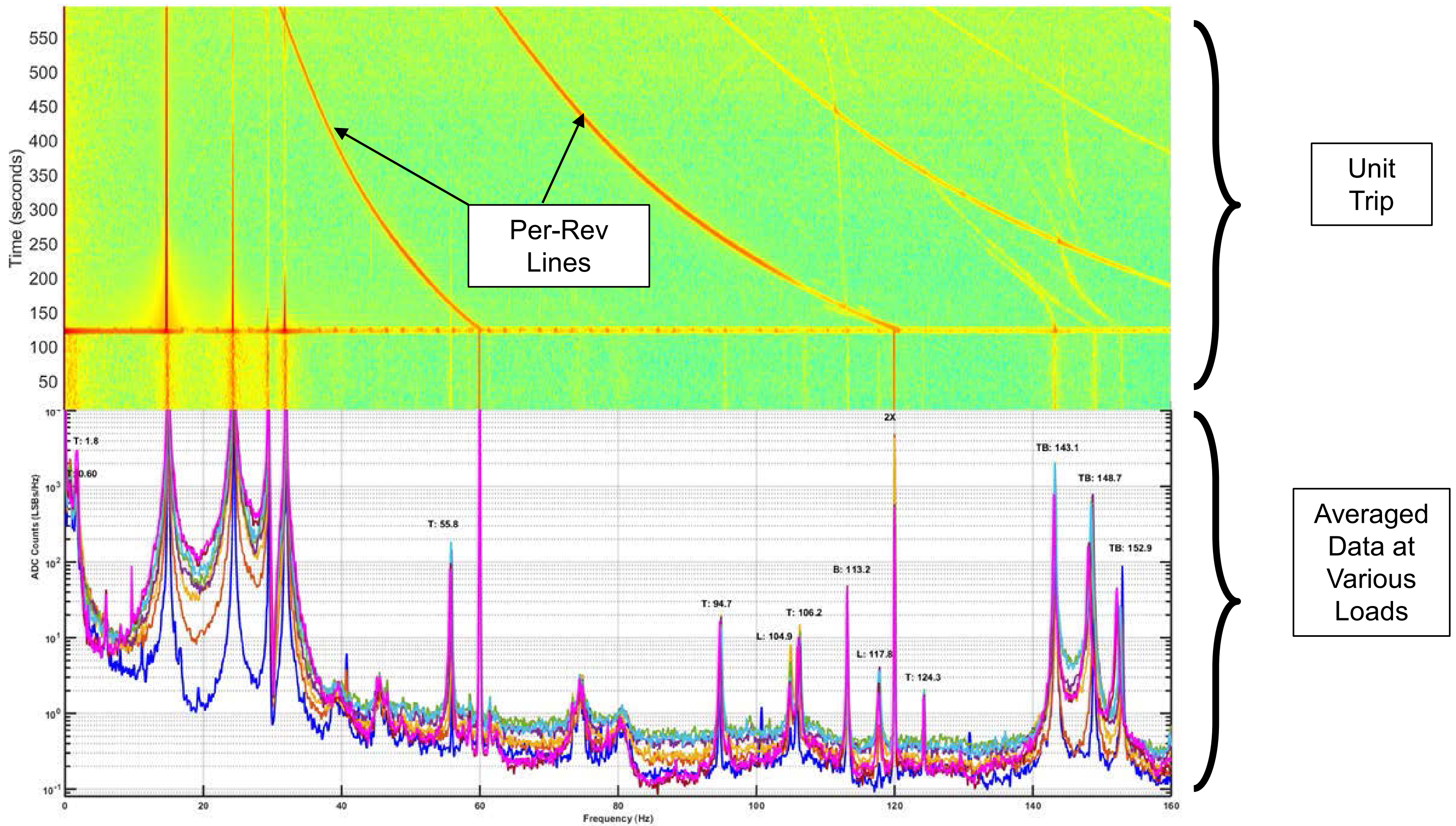
Example Spectral Plot from TDMS – 1800 RPM Nuclear Unit



Example Spectral Overlay – 3600 rpm Fossil Unit



Example Plot - Spectrogram During Unit Coastdown



Reporting

- Initial evaluation can be performed near real-time
  - Remote monitoring has been demonstrated over network connection.
  - Triggered automatic monitoring is being implemented.

- Formal report typically follows within 3 weeks (can be expedited if needed)
  - Typically includes a table of mode frequencies as measured.
  - Comparison to model predicted frequencies is done if a model exists for the rotor train.

Considerations for Pursuing Torsional Testing

- Is a torsional analysis available already (including level of confidence in the analysis)
- Pre-retrofit vs. Post-retrofit testing
  - Pre-retrofit test should be done early in (or before) retrofit design process begins
- Number of locations to instrument
- Lead time with TDMS
  - Equipment typically 3-6 weeks. Emergencies can be handled in days.
  - Installation package development (nuclear) – < 1 week
  - Equipment can be ready in parallel to EC package preparation.

Continued Evolution of the TDMS

- Existing system is proven and commercialized
- Working on applications tolerant of extreme temperatures
- Combustion turbines (simple and combined cycle)
- Long term monitoring including APR data intake
- Historian integration
- Installation simplification and standardization
  - Plans in process to train other installers, OEM, and utilities.

Questions?

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