Hydroturbine Monitoring using Advanced Telemetry

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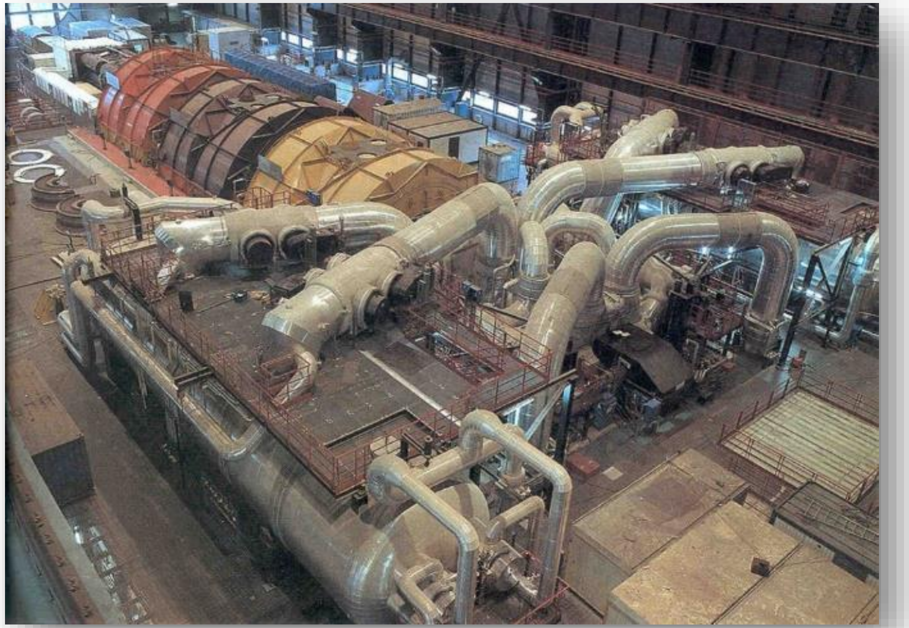
Presentation Outline

- EPRI has engaged a team of real world expertise in sensors to address a industry wide need in hydro monitoring.
- Better signals give practical value.
- Advanced sensors including wireless battery free telemetry.
- Software infrastructure.
- Real world results.



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Data and real value perspective

- **Why is this EPRI project of value to utilities?**

- State of the art sensors give a deeper perspective on data dynamic range and sensitivity.

- There is value in monitoring signals that were not previously considered practical.

- Parts of the turbine-generator system can be measured that were previously unmonitored.

- Key concepts:
  - *Sensor dynamic range =* ***Early detection.***
  - *Frequency bandwidth =* ***Comprehensive dynamic data from fewer sensors.***
  - *Multi-sensor fusion =* ***Cause/effect and actionable engineering information.***

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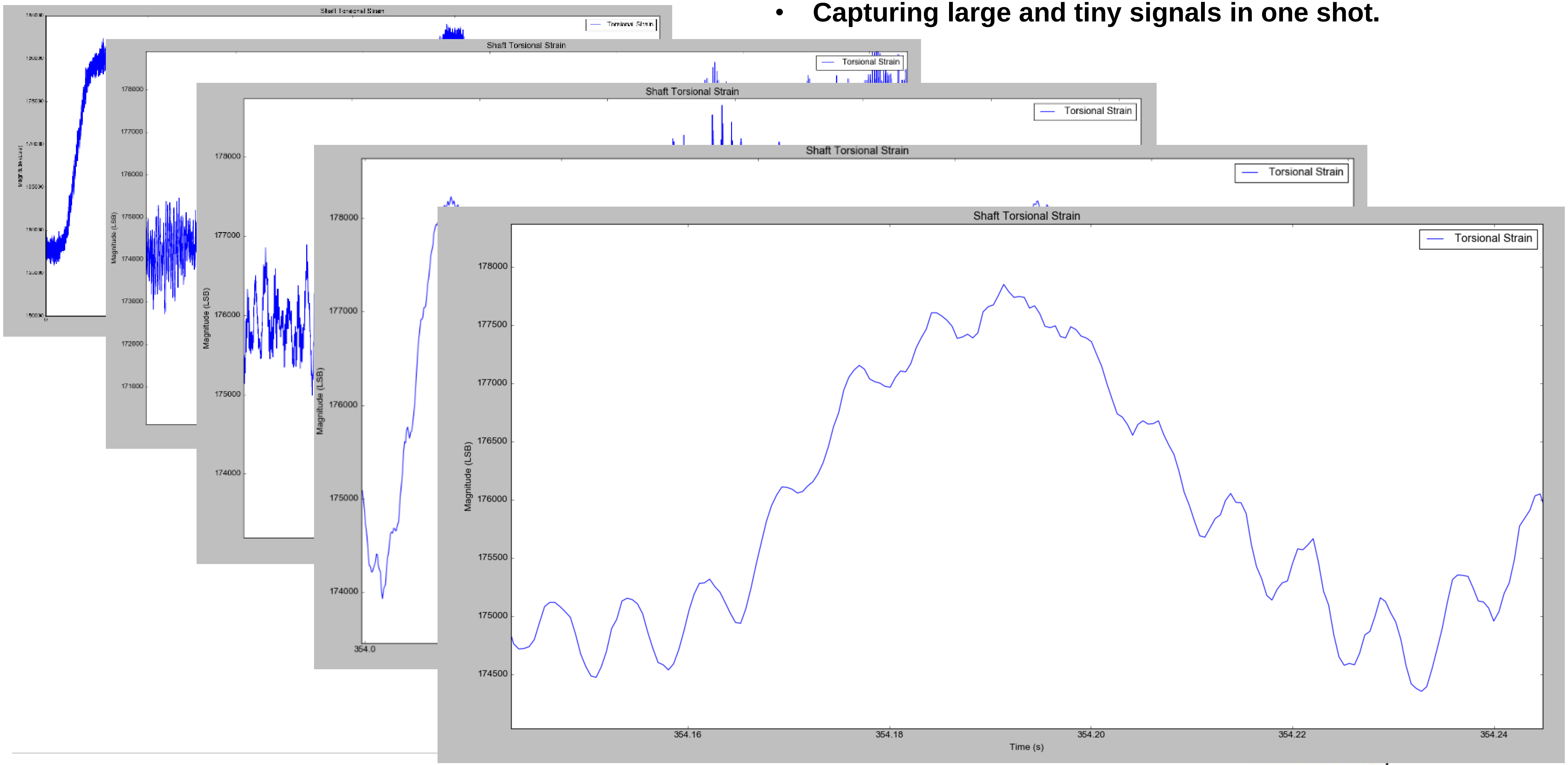
Dynamic range. Effective no-compromise signals.

- **Capturing large and tiny signals in one shot.**



What Dynamic Range actually means to humans

- **Google maps is a data structure with a large dynamic range…**

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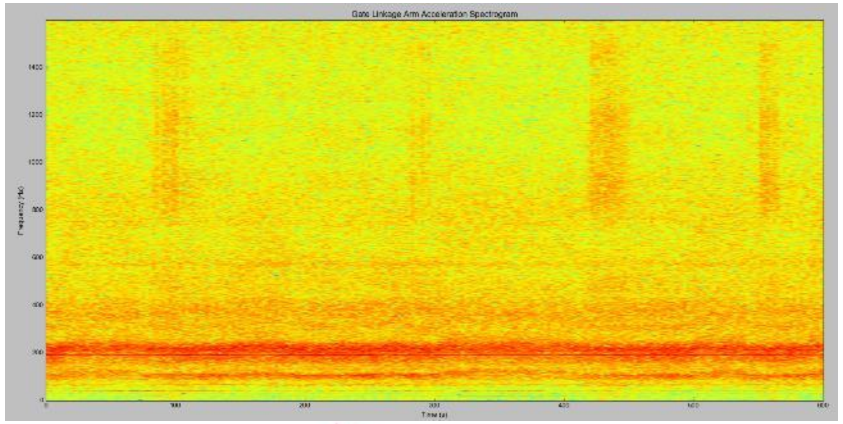
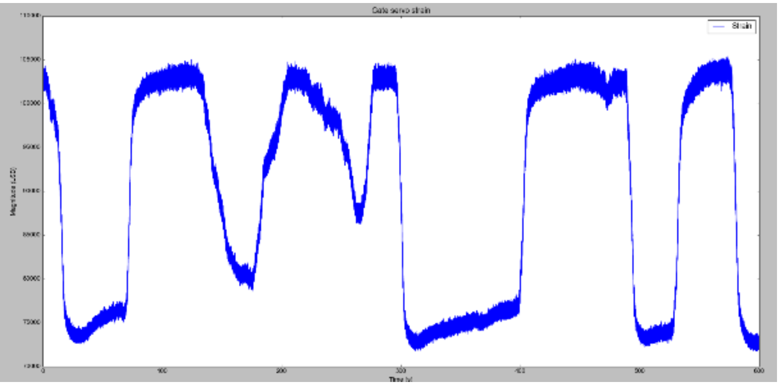
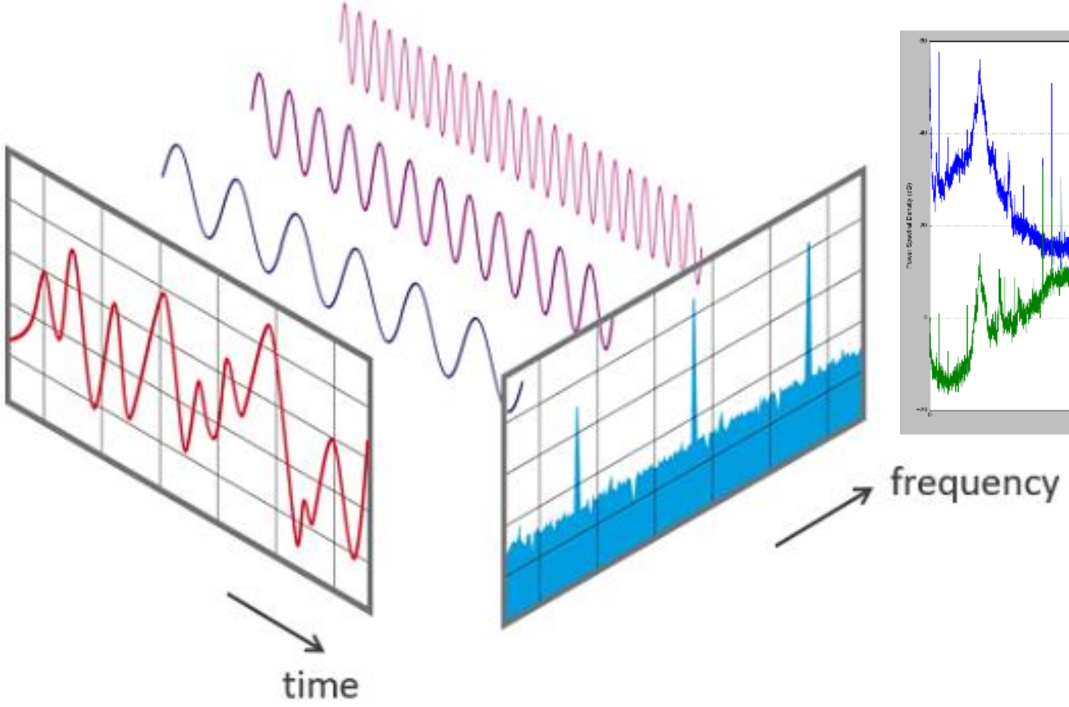
Data analytical facets

Time-frequency (spectrogram)

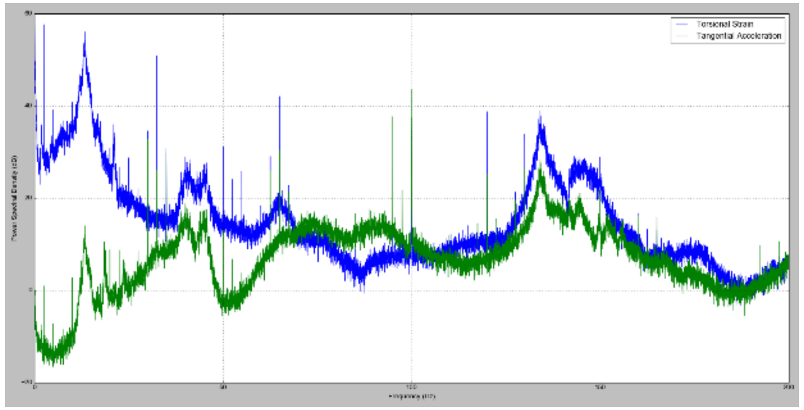


Time domain





Frequency domain



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Extracting information

- Time domain analysis is good for:
  - Wave shape and understanding motion behavior.
  - Assessing continuity (e.g. jumps in position, looseness, intermittent events).

- Time-frequency is good for:
  - Identifying when a vibrational behavior changes.
  - Pinpointing what vibration modes (frequencies) of a machine are associated with an event.

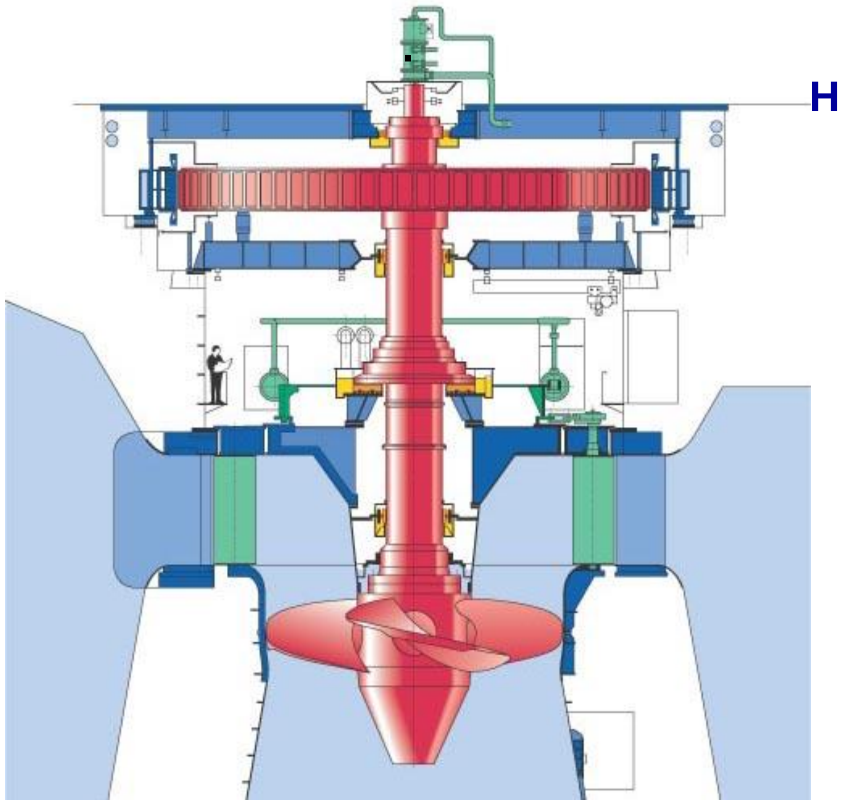
- Frequency domain analysis is good for:
  - Understanding how a machine responds to forced inputs.
  - Evaluating if the machine is in a safe operating condition (e.g. P65 steam turbine results to measure if forcing functions are away from resonant frequencies).

The EPRI monitoring plan

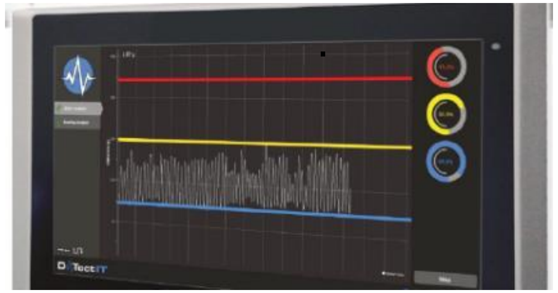
- EPRI applied better data sources…
- Turning huge data into operational value requires a bridge.

Create manageable information from advanced sources WITHOUT disrupting existing infrastructure.

Advanced sensors on the power unit.



High speed analytics local at the power unit.



Data results & alarms sent to legacy systems in-place.

Sensor technologies for primary asset monitoring

- TDMS (Turbine Dynamics Monitoring System)

- State of the art stationary sensors including:
  - Field mountable strain sensors.
  - Wireless battery free (long term wireless) monitoring.
  - Tri-axis accelerometers.
  - Surface wave vibration sensors.

On-rotor telemetry; TDMS overview

- Torsional strain
- Tangential acceleration
- Lateral (bending) strain
- Radial acceleration

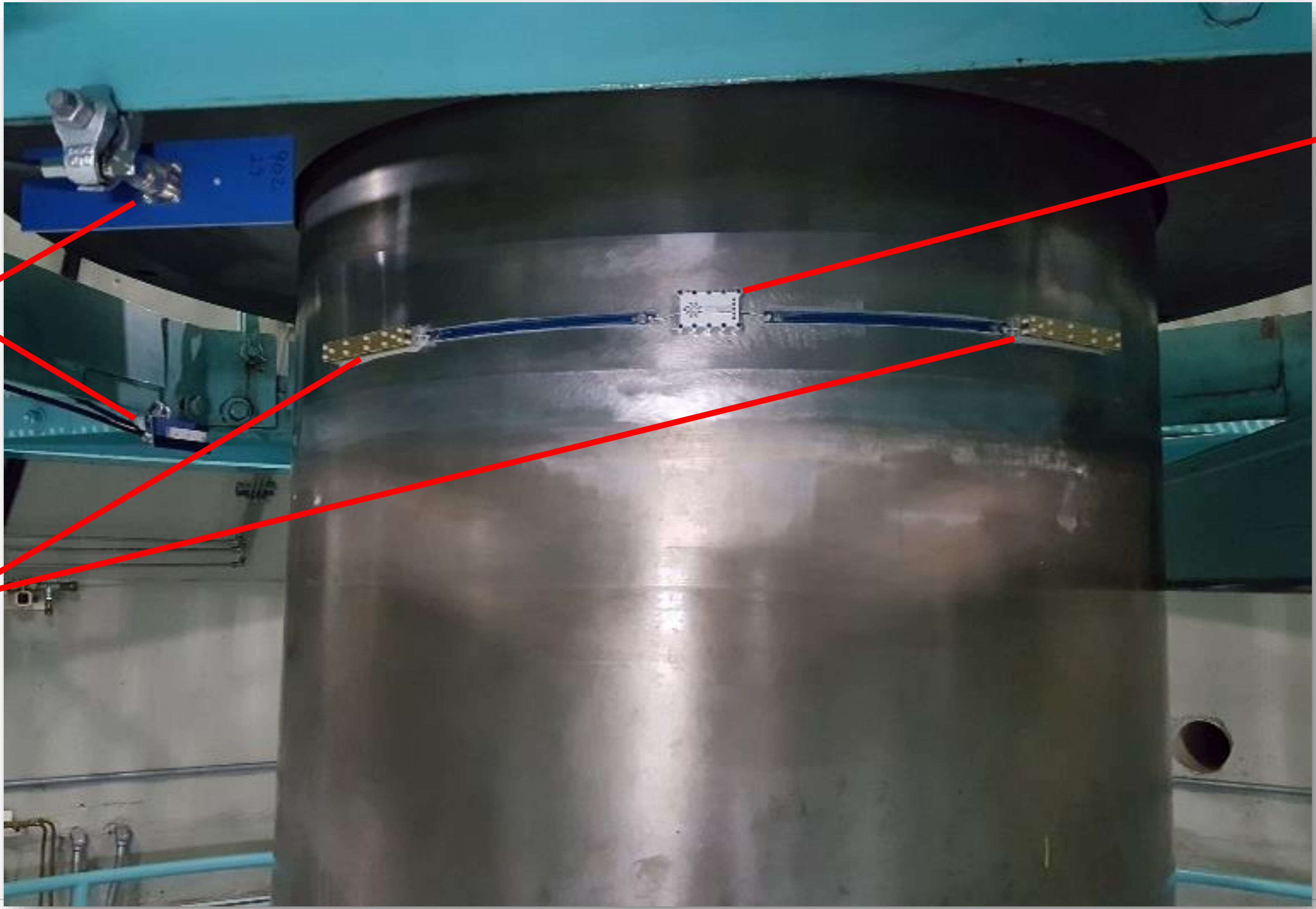
TDMS
TURBINE DYNAMICS MONITORING SYSTEM

- Wireless battery free
- No welding, drilling, or straps
- User friendly DAQ software
- Simple post processing

Hydro rotor mounting of TDMS

Stationary antennas

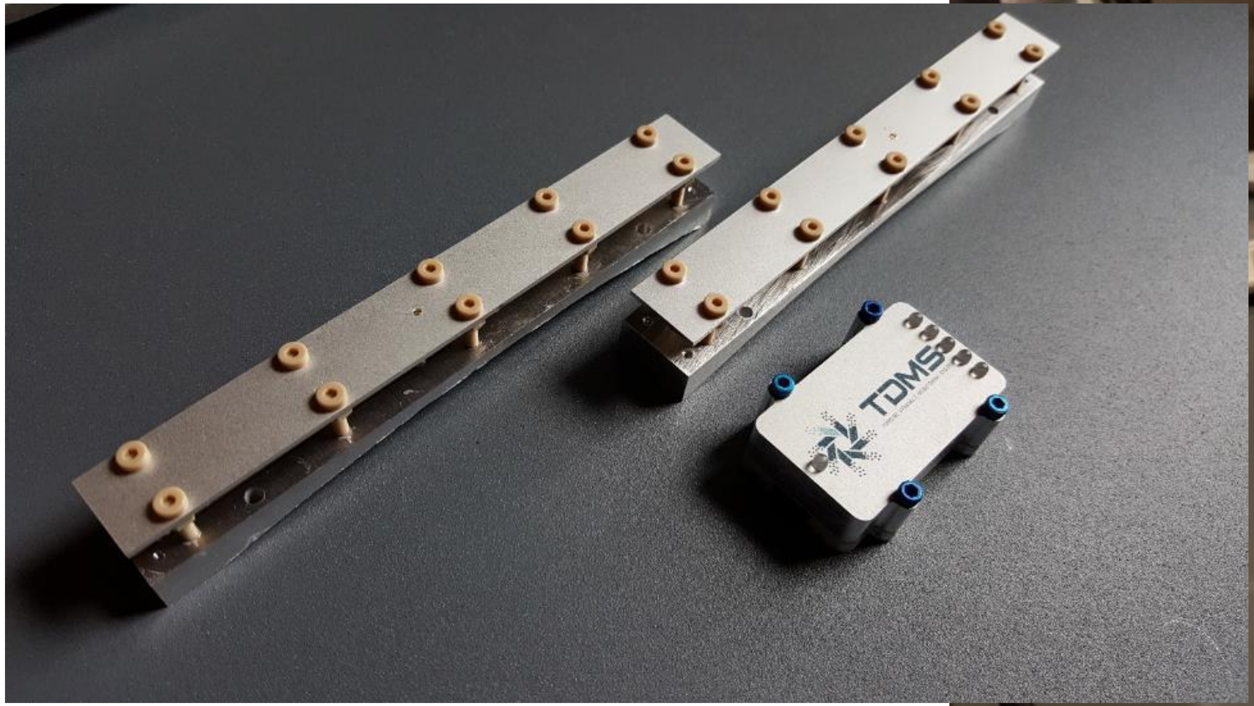
Rotating antennas

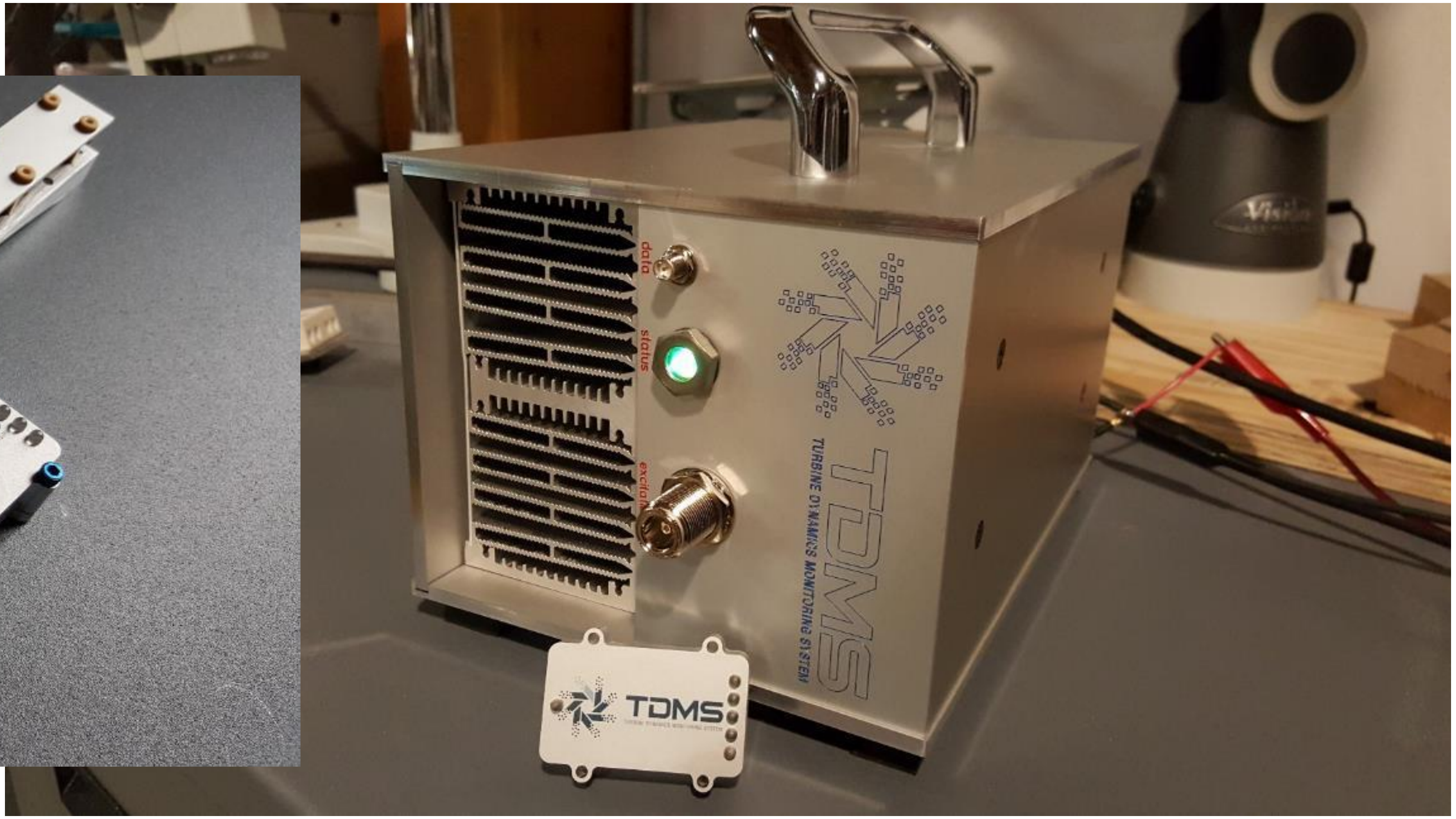


TDMS telemetry

Hydro rotor mounting of TDMS

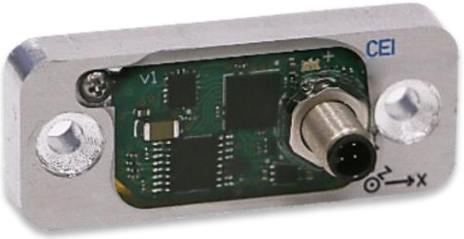
TDMS Components



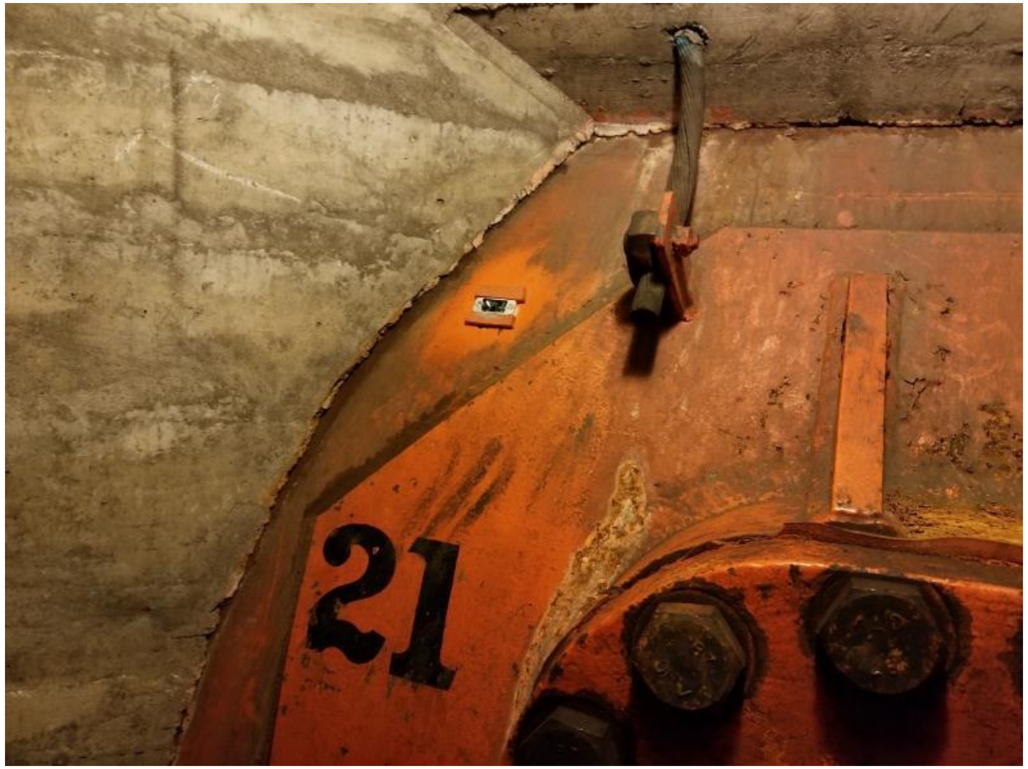


Stationary strain sensors

- Gate drive servo strain
- Scroll case strain
- Anywhere…

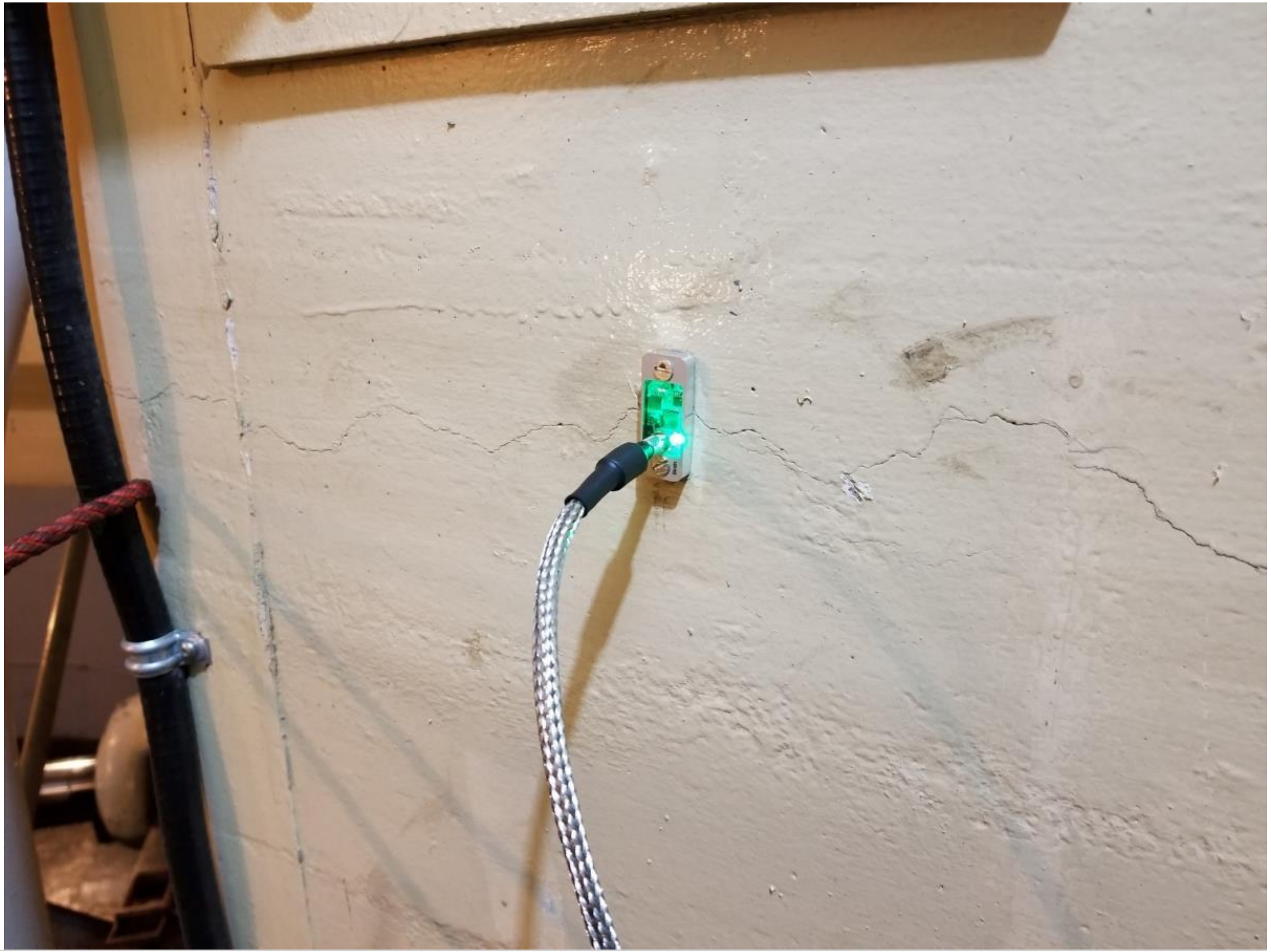


- Fully digital.
- No setup, soldering, etc.
- Rapid deployment.



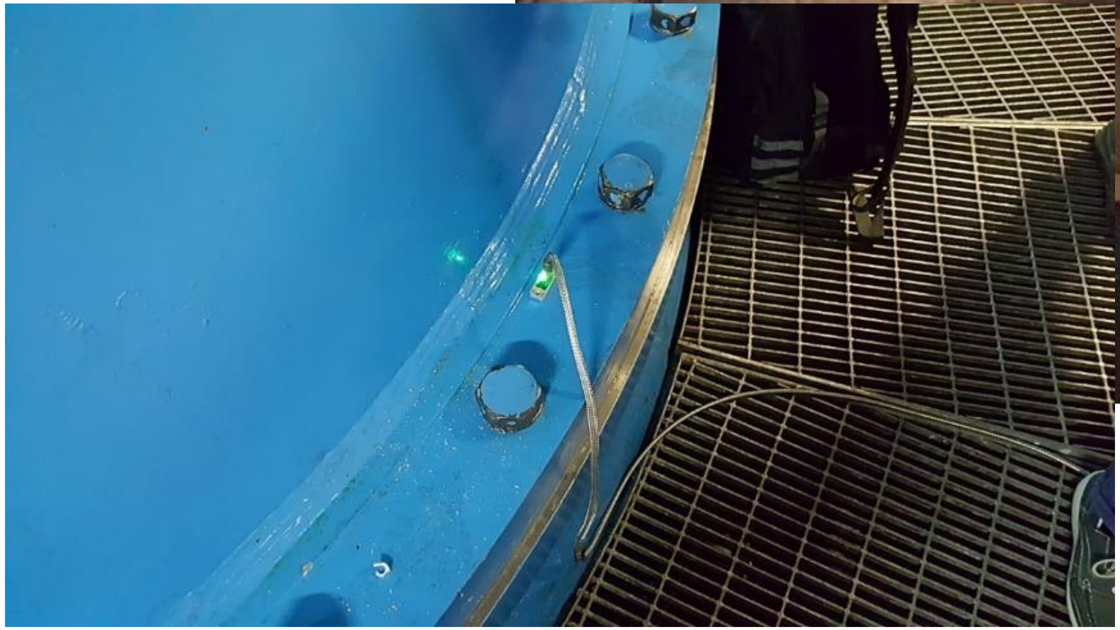
Stationary strain sensors

- Foundation measurement.
- Relevant for vibration.
- Data discussed later…



Stationary accelerometers

- Gate linkage measurements.
- Cavitation and gate vibration.



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Wireless asset monitoring for auxiliary equipment

- Plant-side monitoring in support of the primary turbine-generator asset.
- Emerging concept to deploy wireless monitoring for turbine-generator plant peripheral equipment like hydraulic pumps, fans, etc.
- Tri-axis acceleration up to 25.6ksps, Strain, etc.




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“Any program is only as good as it is useful”- Linus Torvalds.

- The infrastructure being developed in hardware is supported by software that does not limit adoption or configuration.
  – Completely free to EPRI members and developers.
  – Suprock offers open communication libraries.
  – Source code with **no license dependencies (not tied to Labview, Matlab, or any other third party software).**
  – Runs on Windows, Linux.
  – Data streaming and plotting software are available.

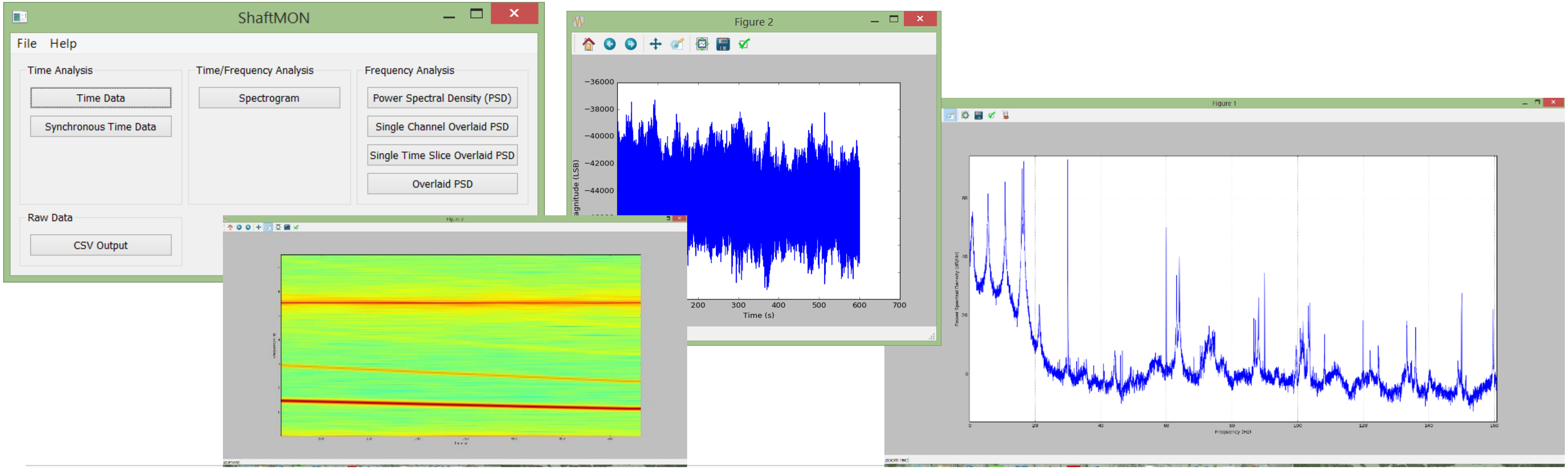
- A mature infrastructure exists to gather the data.

- Not limited to Suprock or EPRI… Can also acquire signals from legacy sensors.
  – Voltage, 4-20mA, etc.

EPRI-Suprock data acquisition interface

Data Post Processing Tools

- Produces various common plots useful for communicating turbine performance.
  - PSD plots of frequency
  - Spectrograms
  - Time data
  - Overlaid spectral data (various sensors or various time windows)



Next: Real applications and research results.

- Pause for questions about hardware, software, data infrastructure.

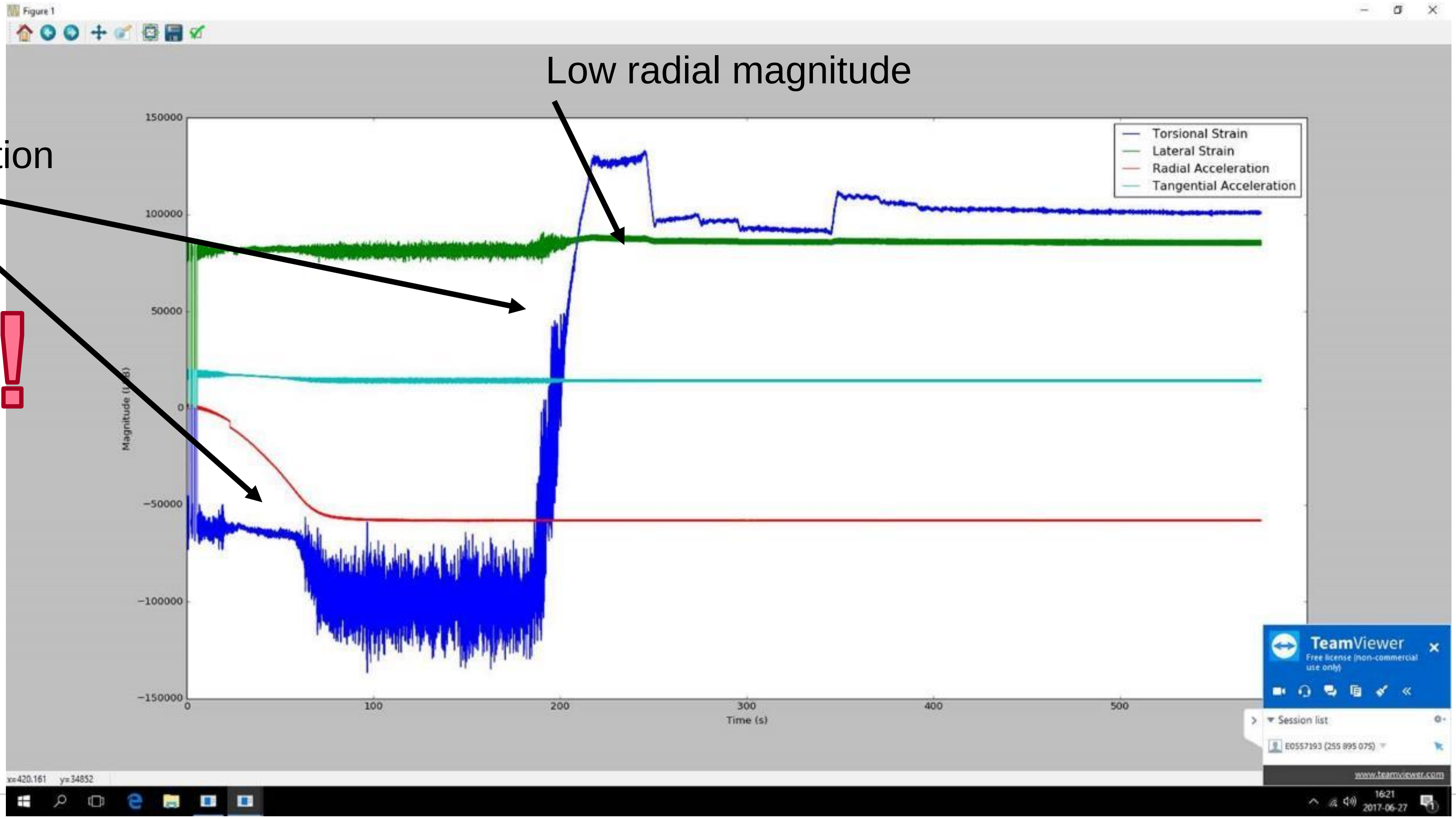
275MW/300RPM hydroelectric Francis turbine-generator

- Torsional vibration from bearing failure and turbine rope cavitation.
- The gates were opening too fast during speed ascension at no load.
- Oscillation is unstable and persists until torsional loading re-estabilishes stability.

~2M ft*lb

torsional oscillation

Yikes!



Notice how radial acceleration does not disclose the magnitude of the torsional vibration.

Likewise radial probes are blind to this major vibration.

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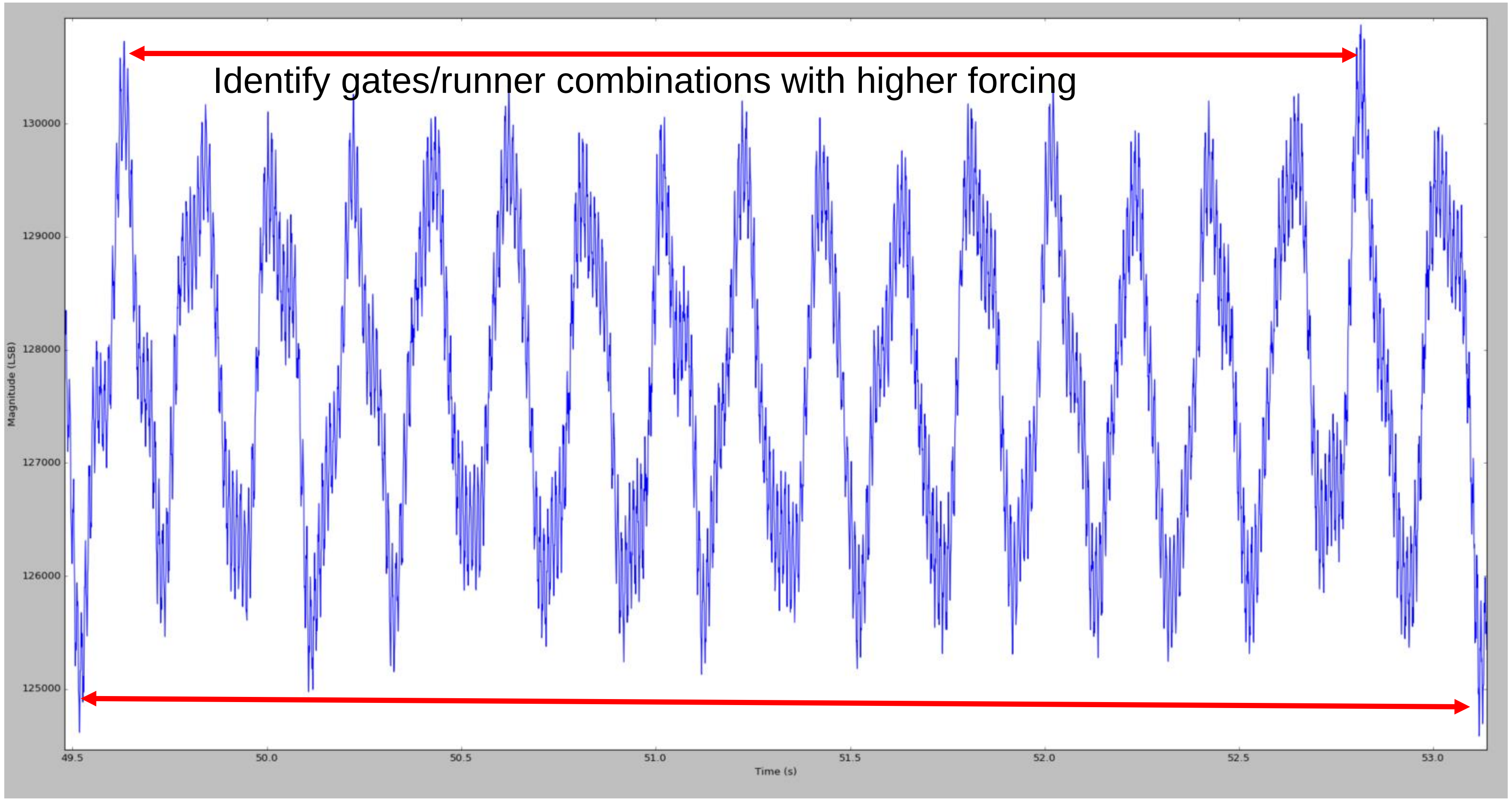
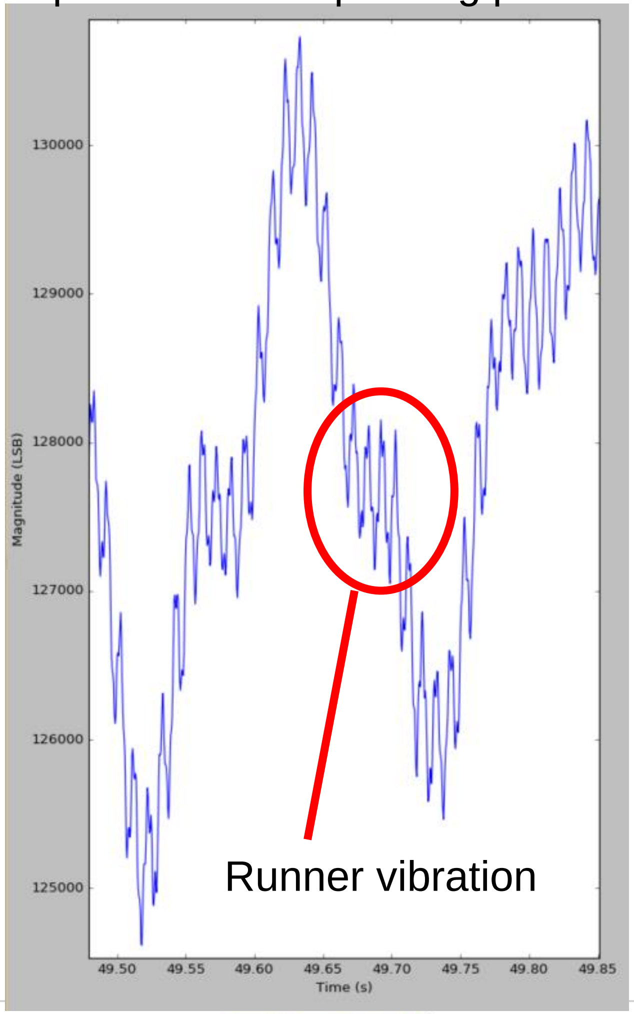
Resolution of telemetry allows deep inspection

- Inspect periodic features with high resolution, like gate/runner passing magnitudes.
- Each waveform tells a story about the motion of the rotor.



Inspect individual passing periods



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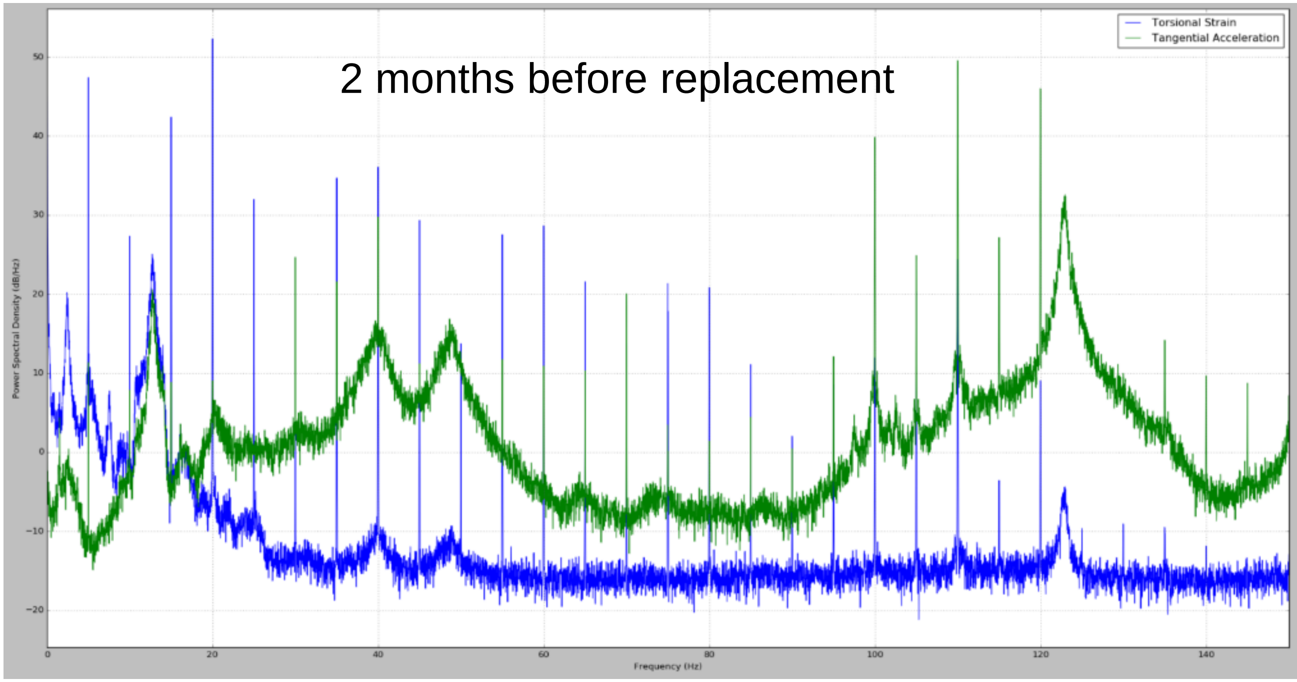
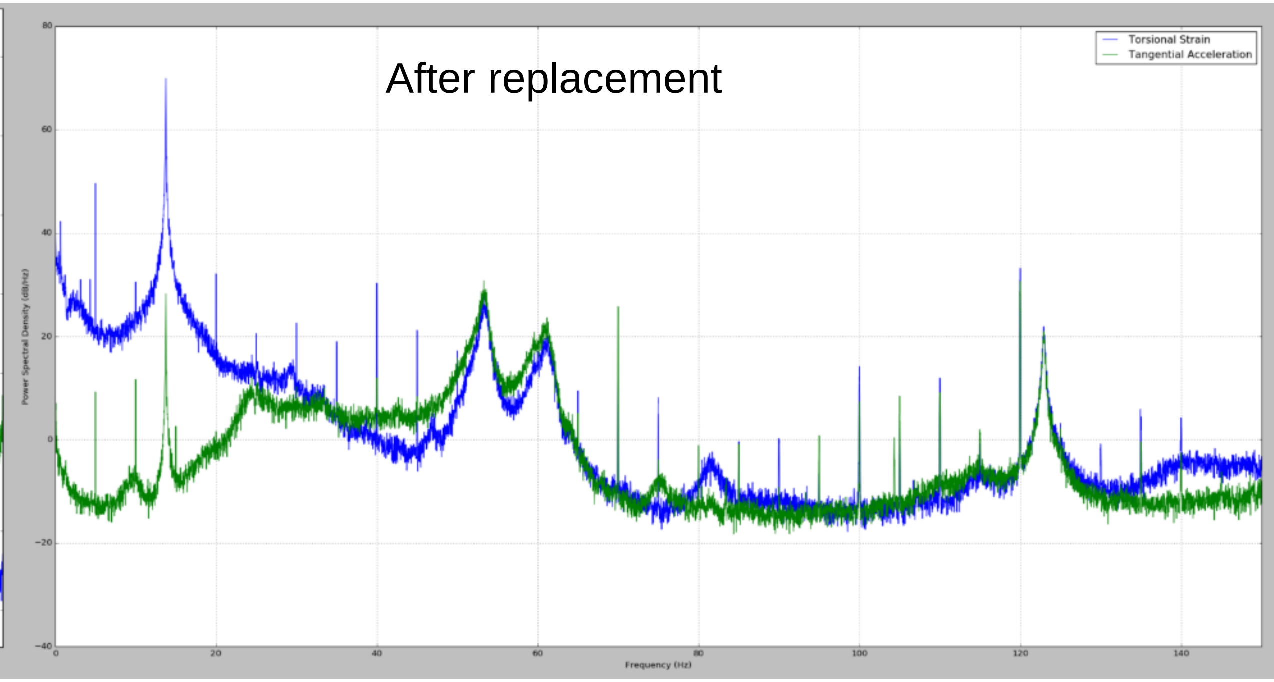
Detecting bearing shoe failure in rotor dynamics

- Utility did not notice significant trend in APR from stationary probes until complete failure of a bearing set screw.
- Major differences in machine dynamics identify an issue with bearing orbit.





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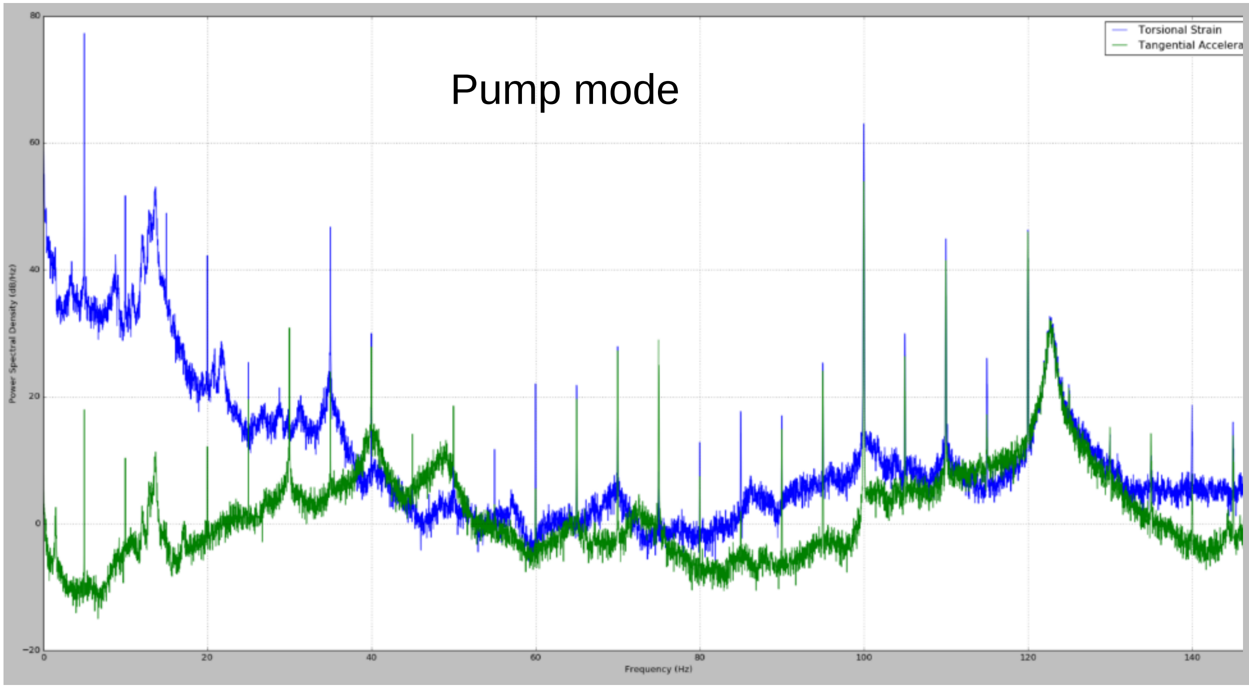
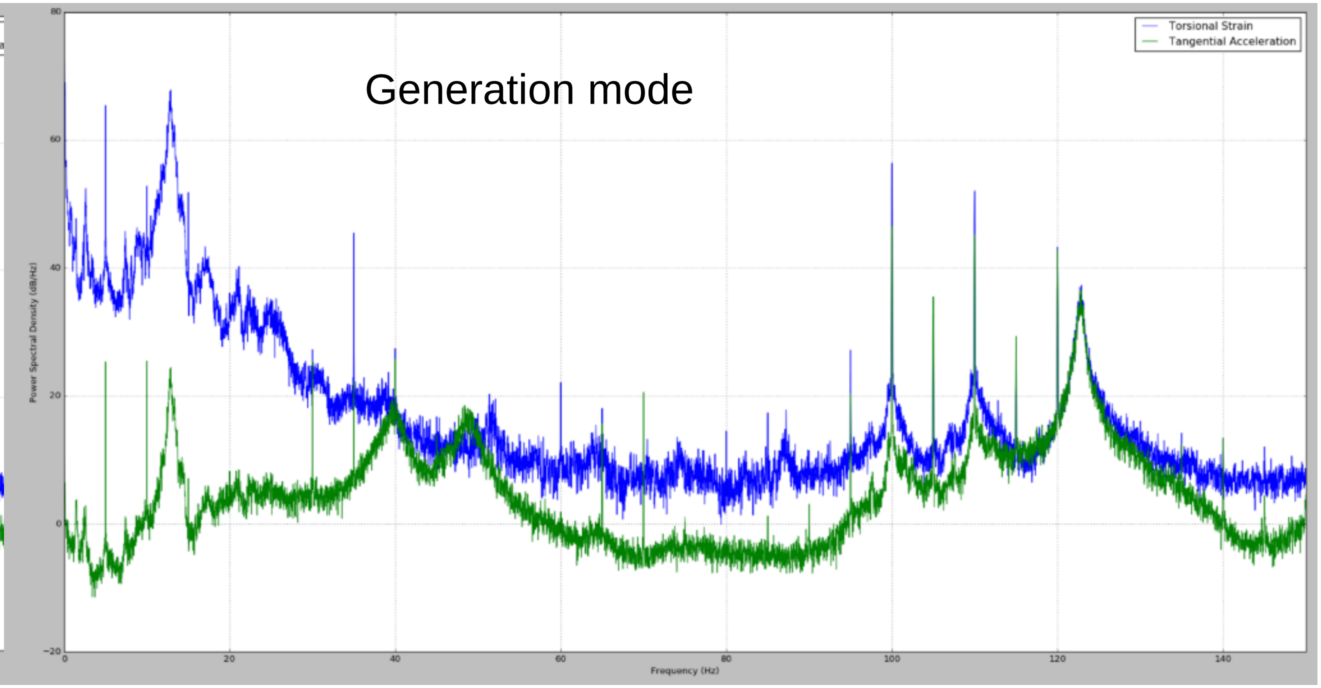
Comparing pump and generation modes in pumped storage

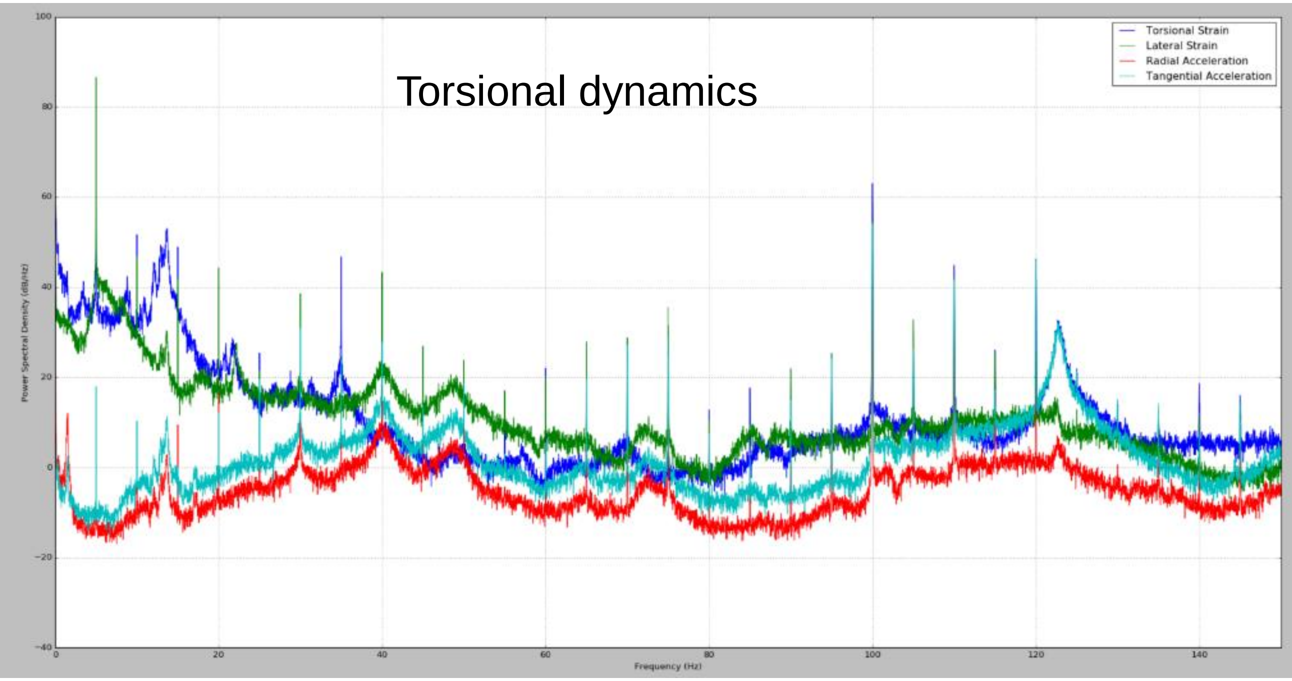
- Behavior differences in driven/vs reactive turbine use.
- Differences due to gate control.
- Gate passing frequency magnitude very different.
- Forced response excites different modes of the unit.
- **Same unit has two different monitoring signatures depending on mode.**

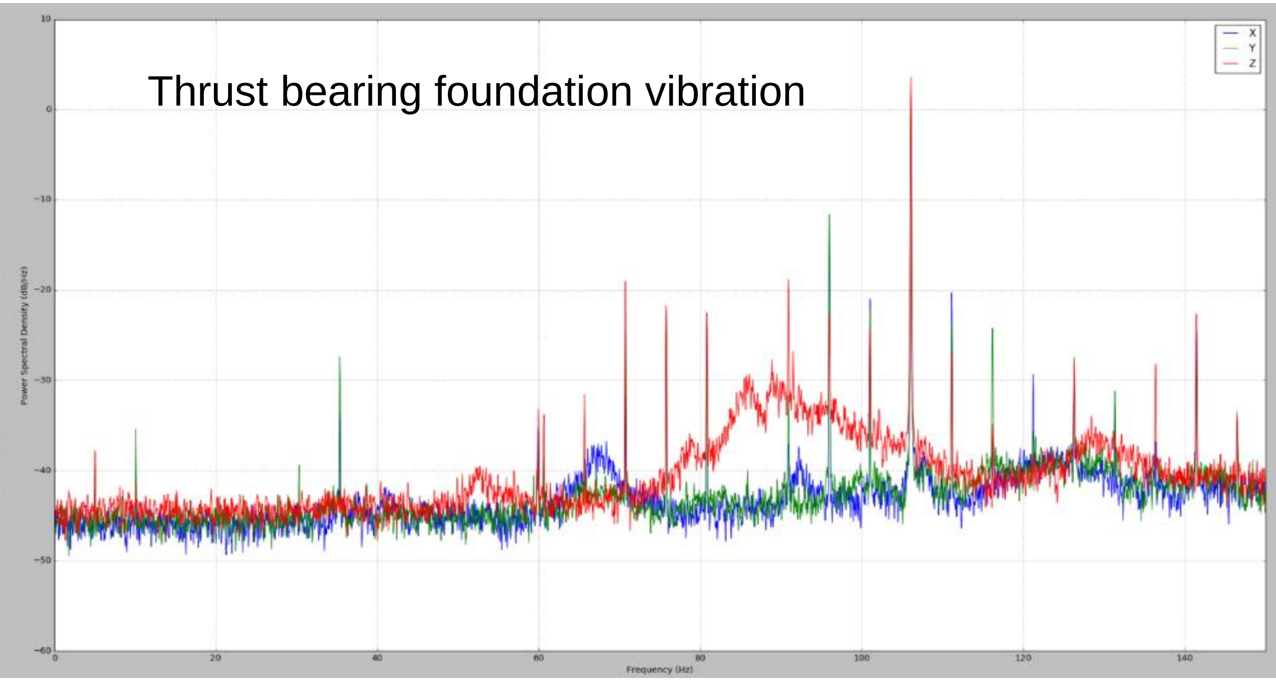




Bearing vibration vs rotor vibration

- Very different sets of information!
- Stationary vibration does not capture torsional behavior.
- Event driven monitoring or pattern recognition should have both sources to predict different types of failures.





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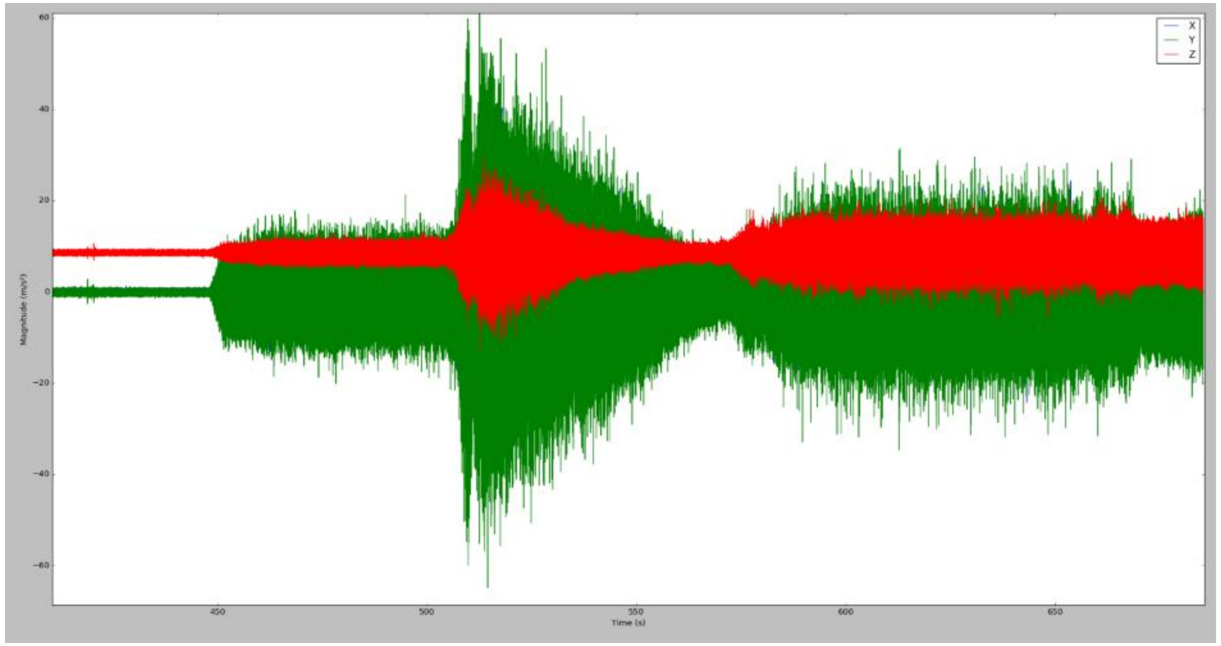
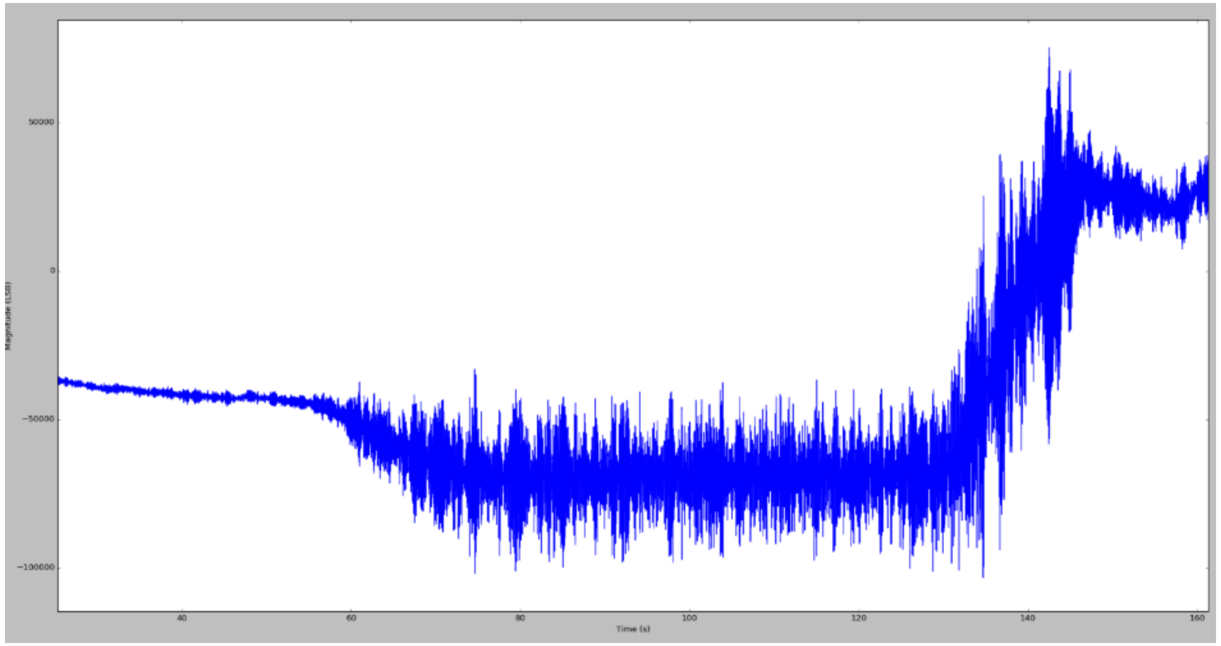
Gate vibration vs torsional vibration

- Next steps include transmissibility between individual gate motion and torsional dynamics.
- Instrumentation of gate drive linkage components with strain gages (especially in ring controlled gates where motion is not independent)





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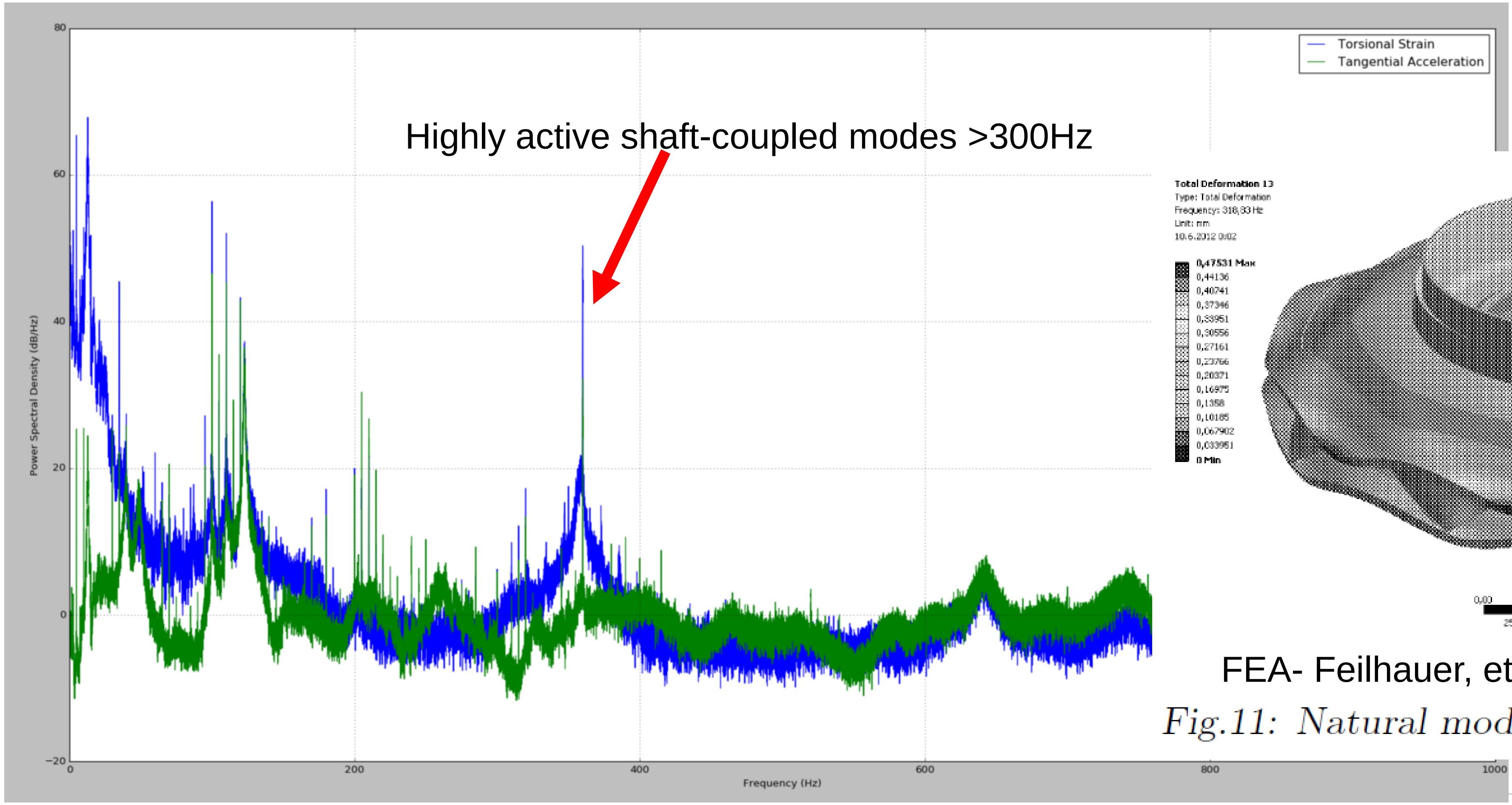
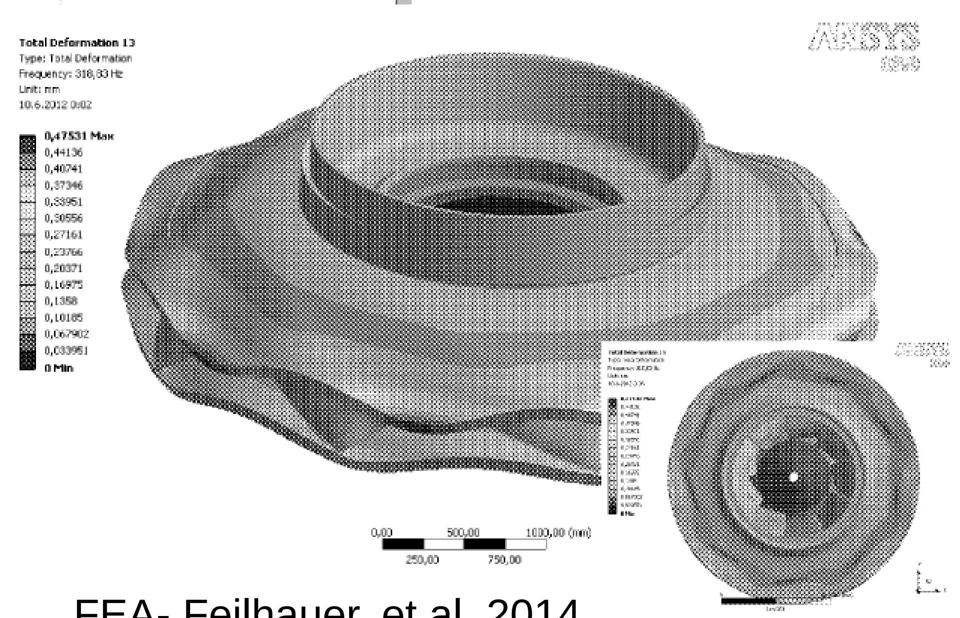
High frequency turbine vibration detection from the shaft location

- Cavitation or higher order modes of the turbine vibration.
- Turbine modes, etc.
- Similar to blade vibration detection in steam turbine-generators.





FEA- Feilhauer, et al. 2014

Fig.11: Natural mode shape $- f_{13} = 318.833$ *Hz*

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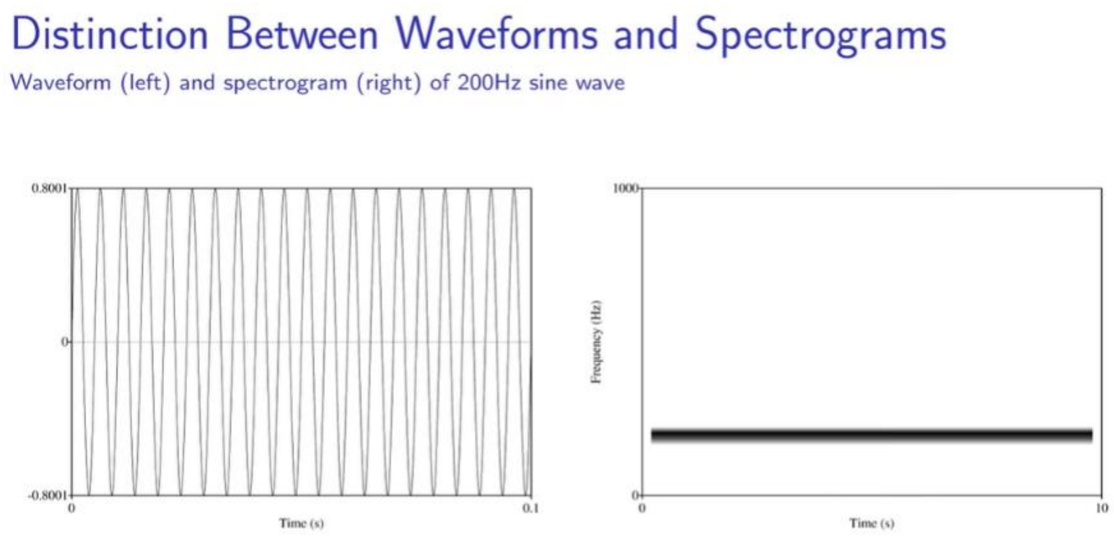
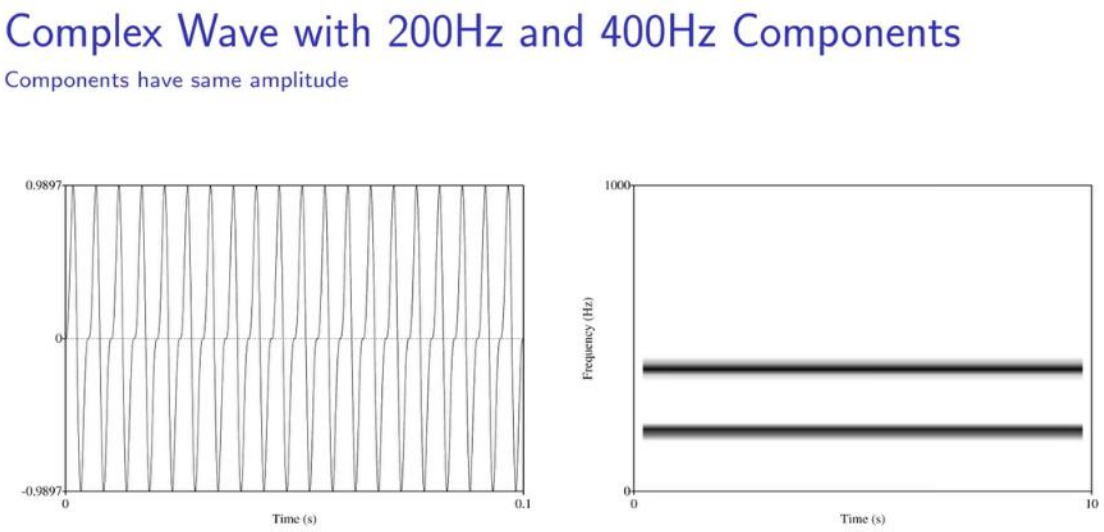
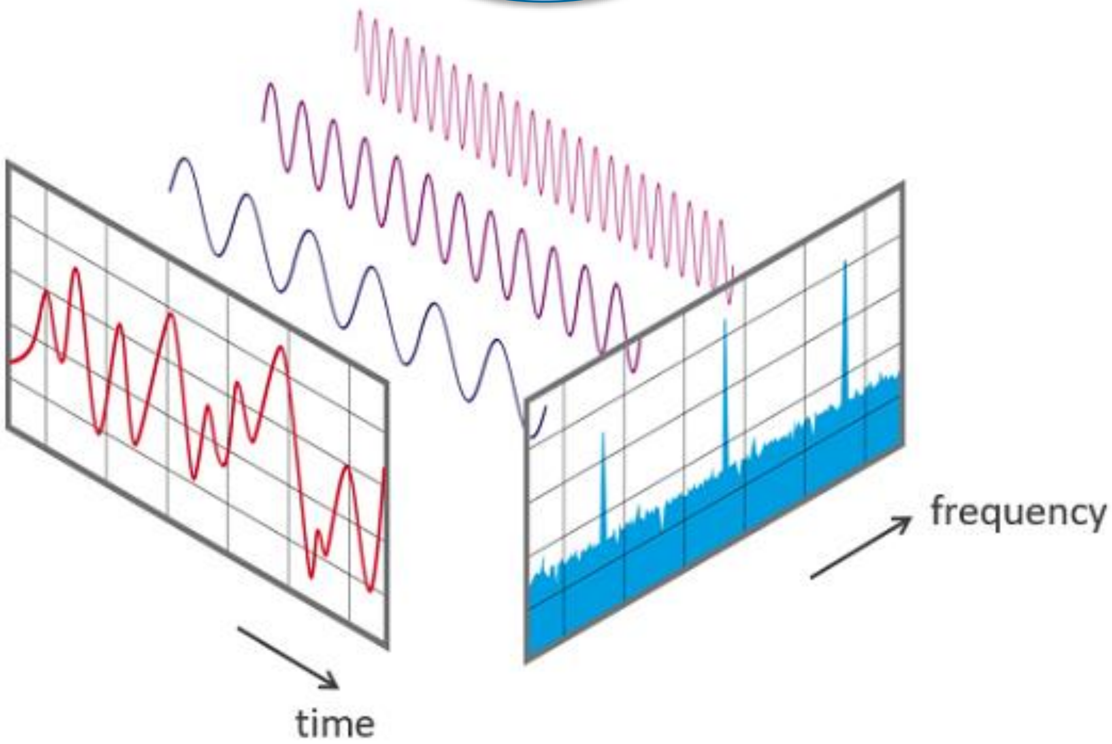
Brief introduction to time-frequency "Spectrograms"





Operational deflection is not just a static parameter at different MW values. Operational deflection happens across a wide bandwidth of frequency.



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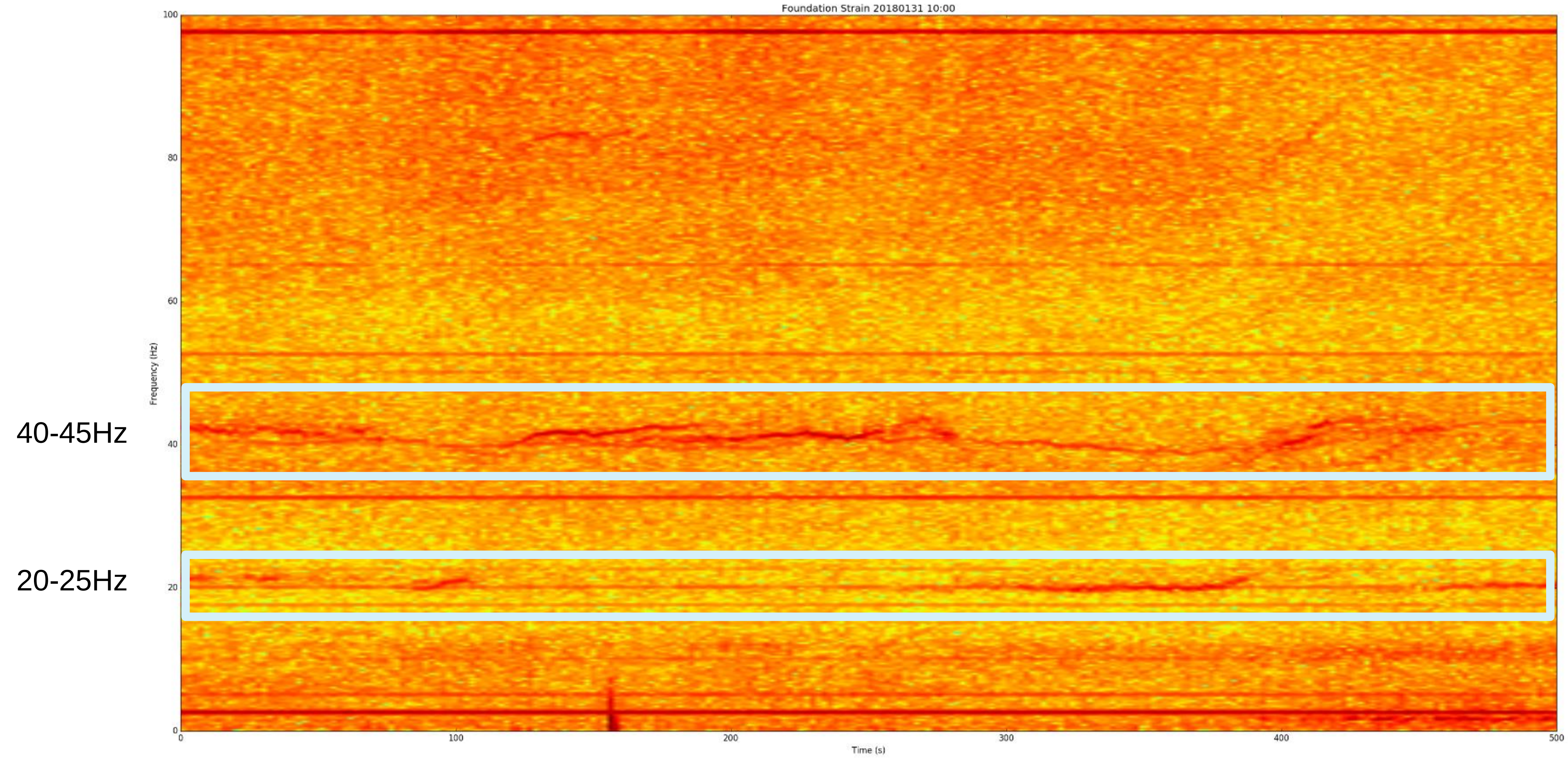
Identifying non-linear frequencies related to foundation cracks.



Completing the monitoring vision

- Connecting to SCADA, DCS, APR, etc.

- Implementing analysis of frequency, magnitude, and alarm limits based on these new sources of data.

- Leveraging proven fast data analytical packages.

- Avoid burdens to legacy plant systems.
  - Provide information results at a rate and form that is acceptable to plant systems in-place.
  - **“Painless” approach works with plant systems as-is without upheaval of existing controls or historian systems.**

Reporting of data reduction

- Massive amounts of data are turned into valuable information.
- High speed data can be preserved during events of note. (before & after a fault)
- Example data reduction summarizing measurement point:

Spindle Analysis Results		
Parameter Type	Result	Description
Bearing Result	Satisfactory Fault Stage 1	Good condition
Vibration Result	Other Vibration Alert	Needs immediate attention

Spindle Analysis Parameters	
Parameter Type	Value
Acceleration RMS	0.217984 g's
Highpass Acceleration RMS	0.003098 g's
Velocity RMS	0.149795 ips
Sampling Frequency	62500.000000 hz
TWF Peak	1.590326 g's
Crest Factor	7.295616

This is the type of result information a plant system can receive without issues about the data rate or complex analytics.

Utility directed sensors (unit specific monitoring)

- Rim & ledge movement/crack sensors.
- Bus bar temperature and current sensors
- Generator lamination temperature sensing.
- Etc…

Takeaways

- EPRI is leading the way by engaging experts and creating a team to solve real world hydro monitoring challenges.
- The infrastructure that EPRI is developing is applying proven technologies.
  - No “pie in the sky” or theoretical approaches.
- A wide selection of sensor technologies have enabled utilities to outline a plan for specific asset monitoring using high value sensors.
  - Not limited to a pre-defined package of sensors.
  - Can be adapted to unit specific monitoring needs.
  - Value oriented approach with no fluff. Monitor what is important for the circumstance.
- Extract value from the data without added overhead.
  - Automate monitoring of sensor data and feed results & alarms to existing plant systems

Together…Shaping the Future of Electricity