December 31, 2018

[redacted]

Subject: Data report on [redacted] plant main TG torsional frequency response.

Dear [redacted]:

Please find attached Suprock Technologies' data report and comment on the torsional test data collected from [redacted] plant. The torsional frequency response data has been processed by Suprock Technologies staff with technical review by MPR Associates.

In summary, no torsional frequencies are observed within unacceptable proximity to grid forcing frequencies. Grid amplitude modulation is observed in the data which creates sidebands on 30Hz (1800RPM). Several events were captured that were of note to operations including the precursor to the governor valve LVDT failure.

- No torsional modes were detected within the exclusion zone around the grid frequency of 60 Hz. The closest torsional natural frequencies are 56.774Hz and 68.246Hz.
- No torsional modes were detected within the exclusion zone around the double grid frequency of 120 Hz. The closest torsional natural frequencies are 116.976Hz and 123.992Hz.

Sincerely,

Christopher Suprock, PhD

Enclosures: [redacted] main turbine-generator torsional vibration measurement

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Torsional Vibration Testing – [redacted] Nuclear Generating Plant

1 PURPOSE

This report is a summary of the as-recorded torsional frequency response of [redacted] plant main TG. The report presents the data and brief comment on the torsional response of the TG. No torsional modes were detected within the avoidance band around 120Hz and 60Hz.

2 BACKGROUND

[redacted] Nuclear Generating Plant is a Combustion Engineering designed Pressurized Water Reactor (PWR) plant which began commercial operation in [redacted] and is licensed to operate until [redacted] The plant's maximum dependable capacity is 811 MWe. The turbine generator is a Westinghouse 1800 RPM generator with Siemens turbines. The high pressure turbine has been upgraded and the low pressure turbines were obtained from [redacted]. Modeling of the turbine generator rotor train has indicated a possible resonance frequency near 120 Hz. Suprock Technologies does not have access to the OEM torsional model for this TG.

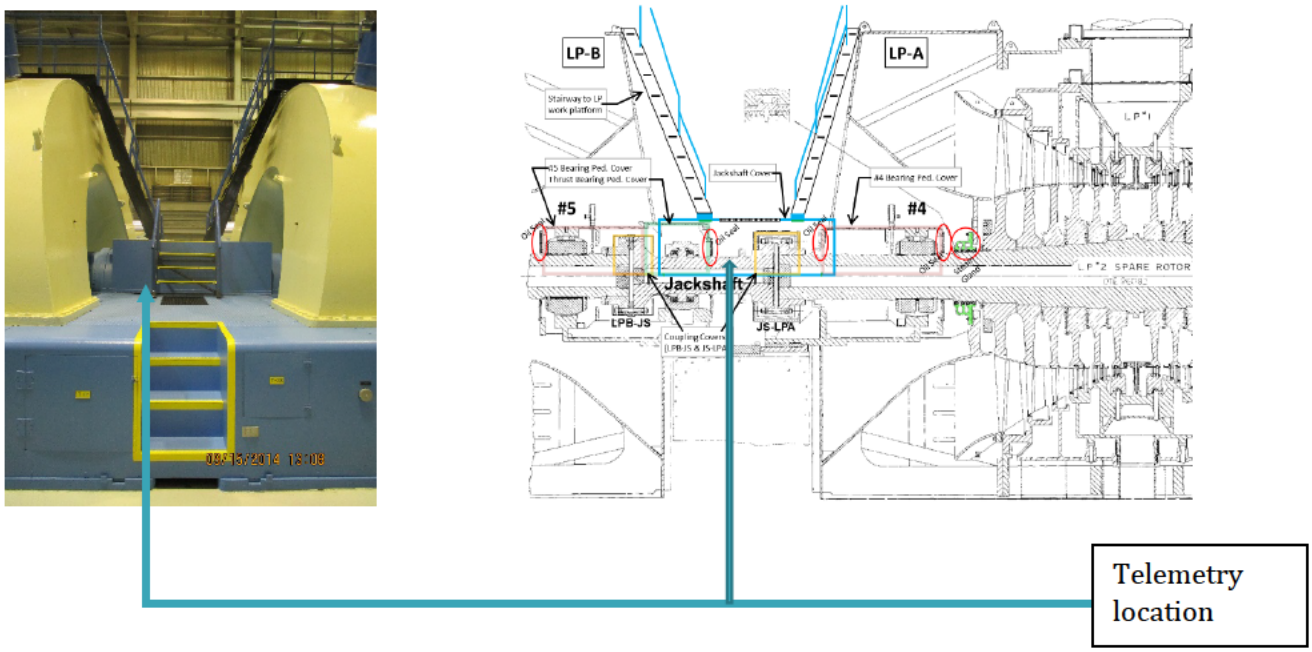
The location for the torsional test telemetry is on the jackshaft between the Low Pressure A and Low Pressure B turbines. A protective cover is located over this area during unit operation and has served as a location for mounting the TDMS stationary antennas. This location also provides a safety barrier to the rotating components of the system. The cables from the power unit to the stationary antennas exit below the turbine jackshaft area and did not require modifications to the existing structure.

2.1 REMOTE DAQ MILESTONE

The test was set up to be run locally by Suprock or [redacted] staff, or remotely through the [redacted] open vendor network. The latter was quite successful in accommodating changes to the outage schedule through Christmas. During the data acquisition, Suprock technical staff were on call locally but did not need to enter the plant. This is a milestone for Nuclear data acquisition of torsional test data. Suprock appreciates [redacted] willingness to accommodate the unplanned outage schedule changes with remote data acquisition process.

This avoided excess expense outside the scope of the project and was a cost savings to [redacted] should be recognized for permitting this cost savings which would have amounted to $19-22k over the approved fixed-price contract.

2.2 LOCATION OF THE TDMS EQUIPMENT



The TDMS equipment was located between LP A and LP B on a jackshaft location. This was an ideal location for the sensing of LP torsional activity.

3 DATA ACQUISITION

Data acquisition was conducted from 0RPM through the startup sequence of the main turbine followed by power ascension. A hold point at 1770RPM was recorded to verify that no natural frequencies were recorded at the forced frequency points of 120Hz and 60Hz. The data from the first hold point is as follows in figures 1 and 2. There are no turbine-generator torsional frequencies detected at the location of grid forced frequencies.

Subsequent measurements are made passively (no prescribed hold points) and follow synchronization and power ascension of the TG.

3.1 1770 RPM HOLD POINT

The plots 1-3 show the 1x-4x frequencies during the hold point 29.50Hz to 118.0Hz respectively. This test procedure has measured that no natural frequencies are masked by the presence of strong grid forced frequency during the synchronized operation of the unit.

At this hold point, torsional modes can be seen outside of the avoidance band criteria and it appears that the TG is free from concerning torsional modes.

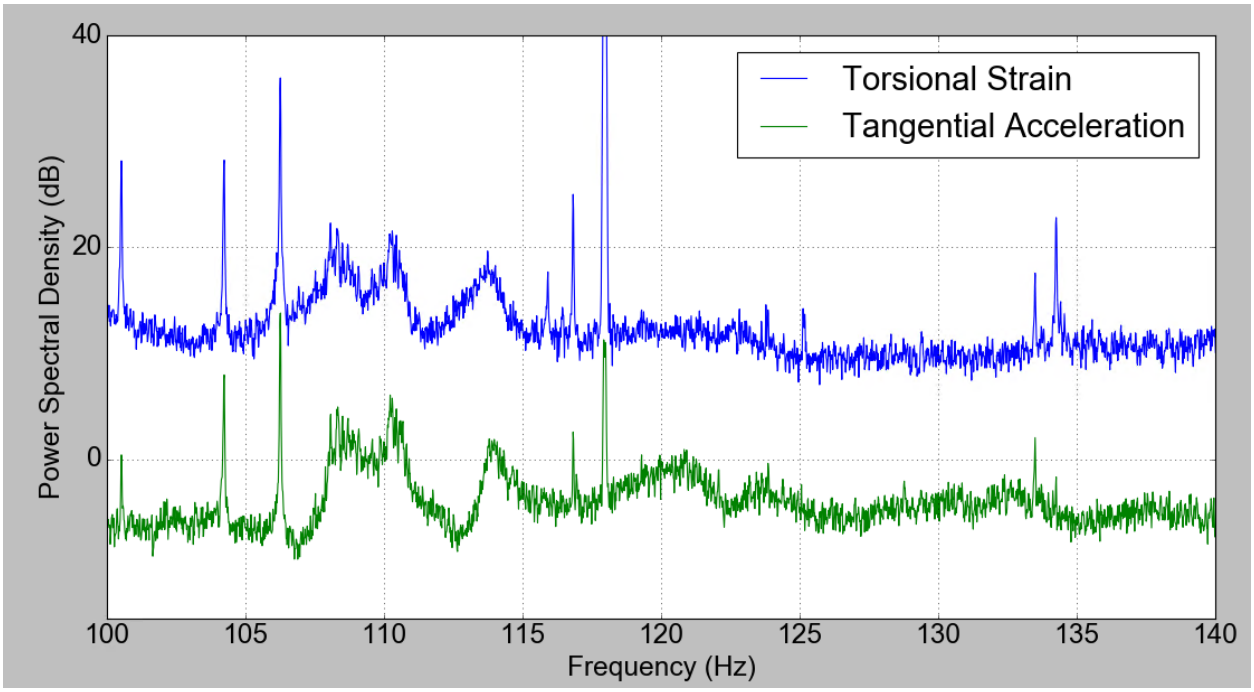


Figure 1 1770RPM hold point data - In proximity to 120Hz

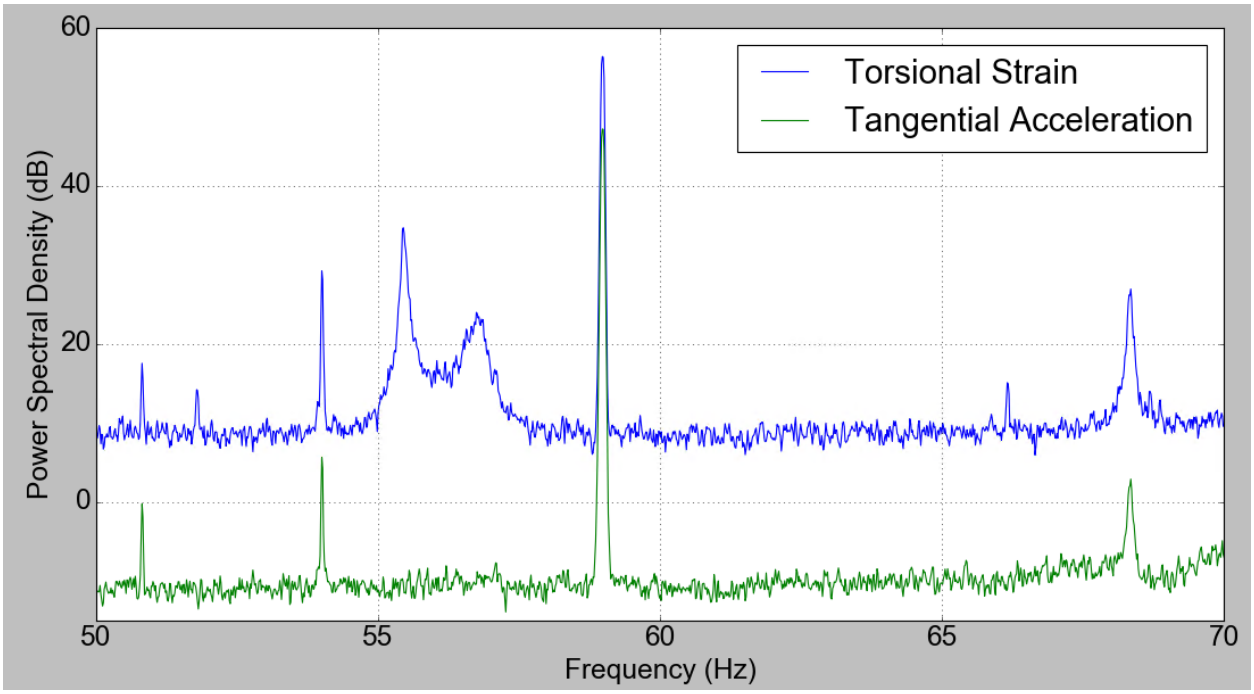


Figure 2 1770RPM hold point - In proximity to 60hz

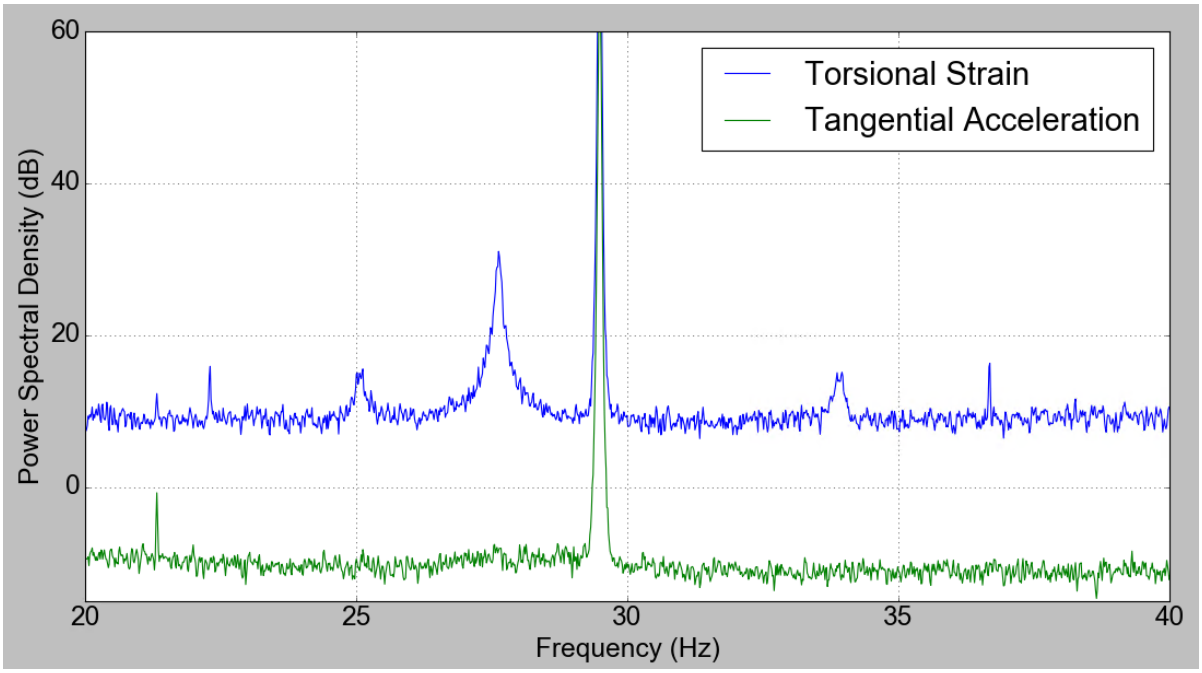


Figure 3 1770RPM hold point - in proximity to 30Hz

3.2 GRID SYNCHRONIZATION

At grid breaker closure a relatively significant impulse response was measured. The synchronization at breaker close was not ideal. It is recommended that the plant investigates the phasor and synchronization operations. The impulse response shows damping takes approximately 25 seconds to reach typical amplitude. The torsional impulse indicates that strain on the TG during this time is excessive and this may have an impact on cumulative damage to the TG rotor train components. Modes primarily participant in this impulse response are subsynchronous modes below 15Hz.

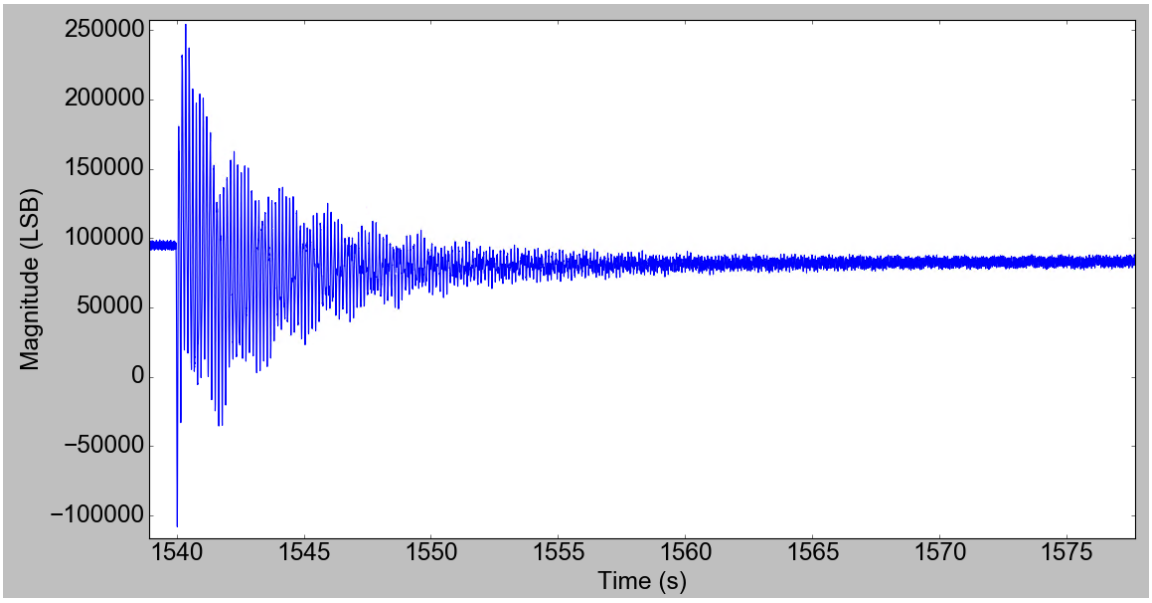


Figure 4 Torsional impulse response at breaker close.

4 POWER ASCENSION MEASUREMENTS

4.1 100MW

Two torsional frequencies are detected at 117.298Hz and 124.315Hz. As the unit continues to heat soak, these frequencies will drop lower.

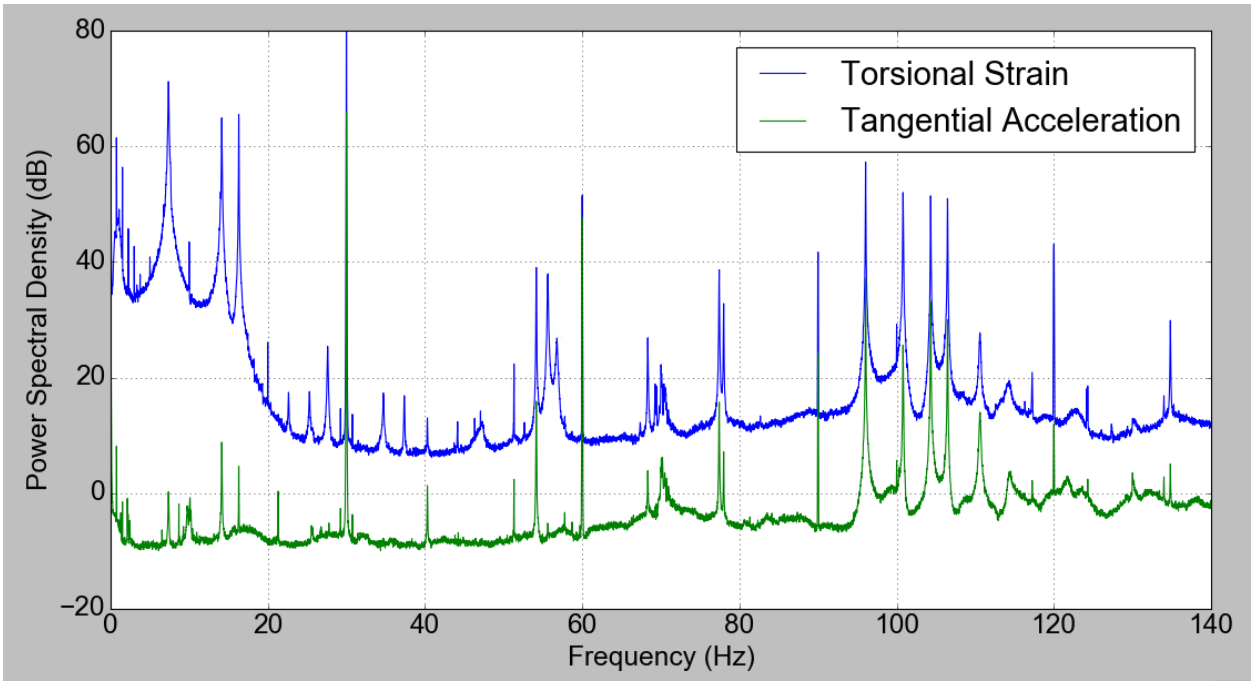


Figure 5 Full torsional spectrum at 100MW

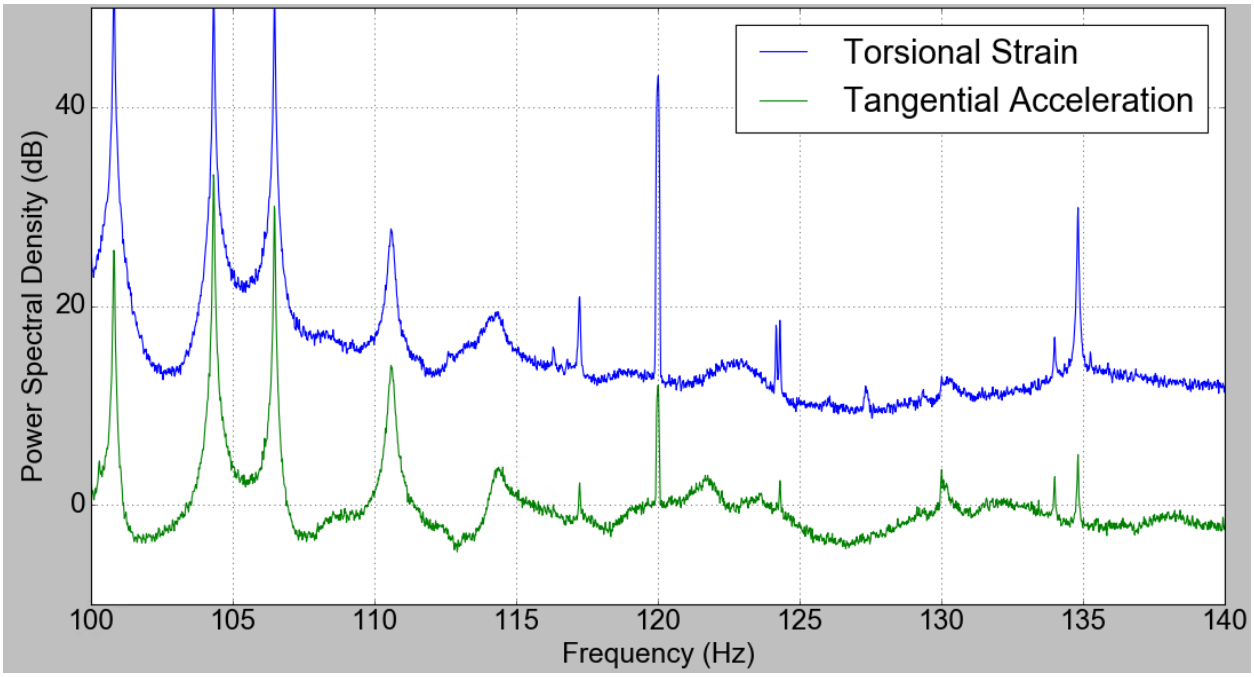


Figure 6 120Hz torsional spectrum at 100MW

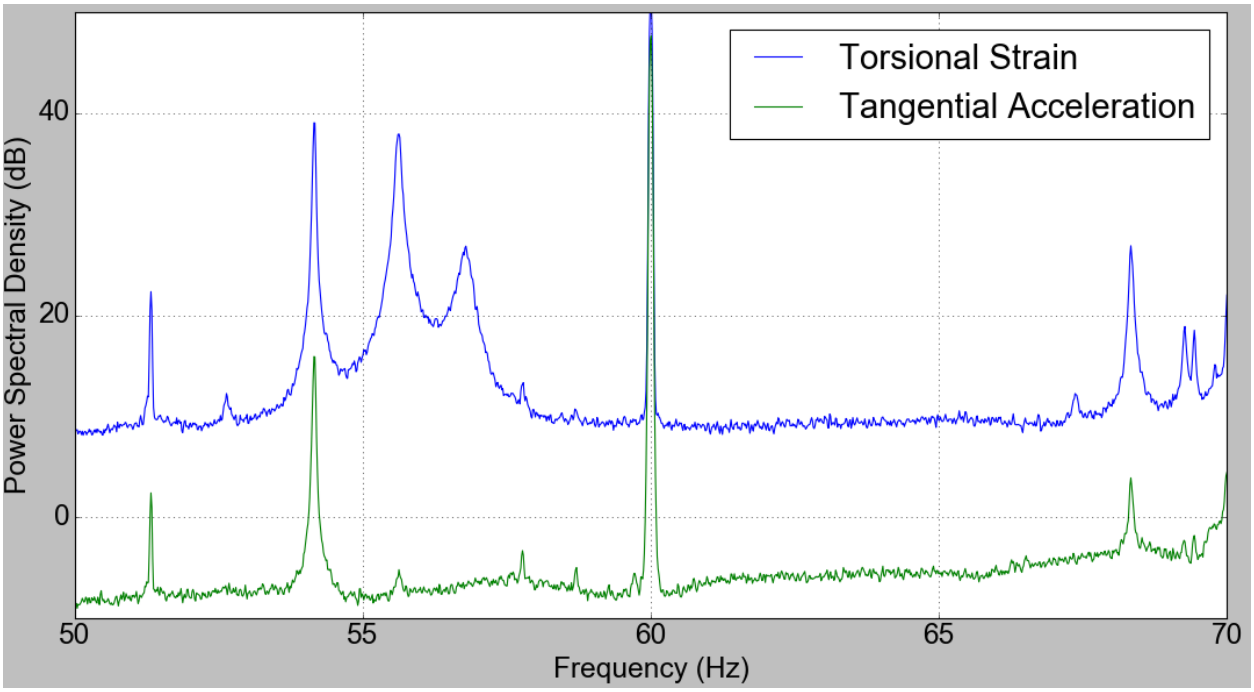


Figure 7 60Hz torsional spectrum at 100MW

4.2 550 MW

Two torsional frequencies are detected near 120Hz at 117.002Hz and 124.065Hz. The unit is heat soaked and the HP section is up to temperature. There are no significant changes between this load and higher power.

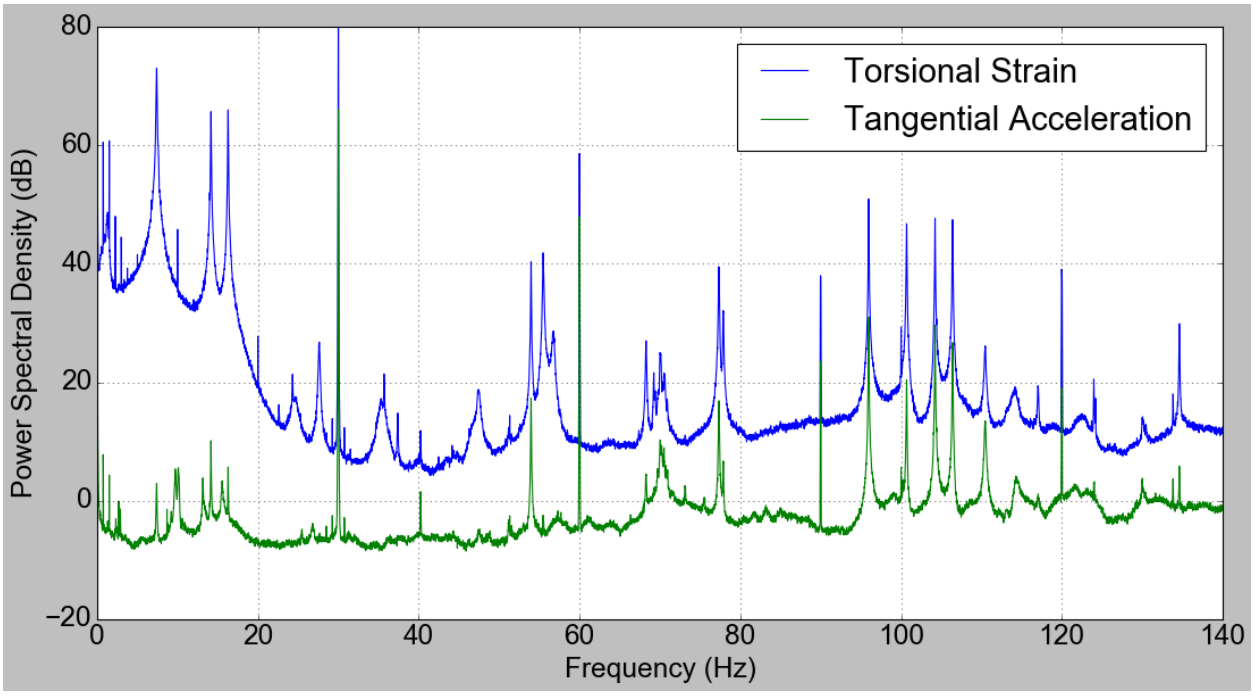


Figure 8 Full torsional spectrum at 550MW

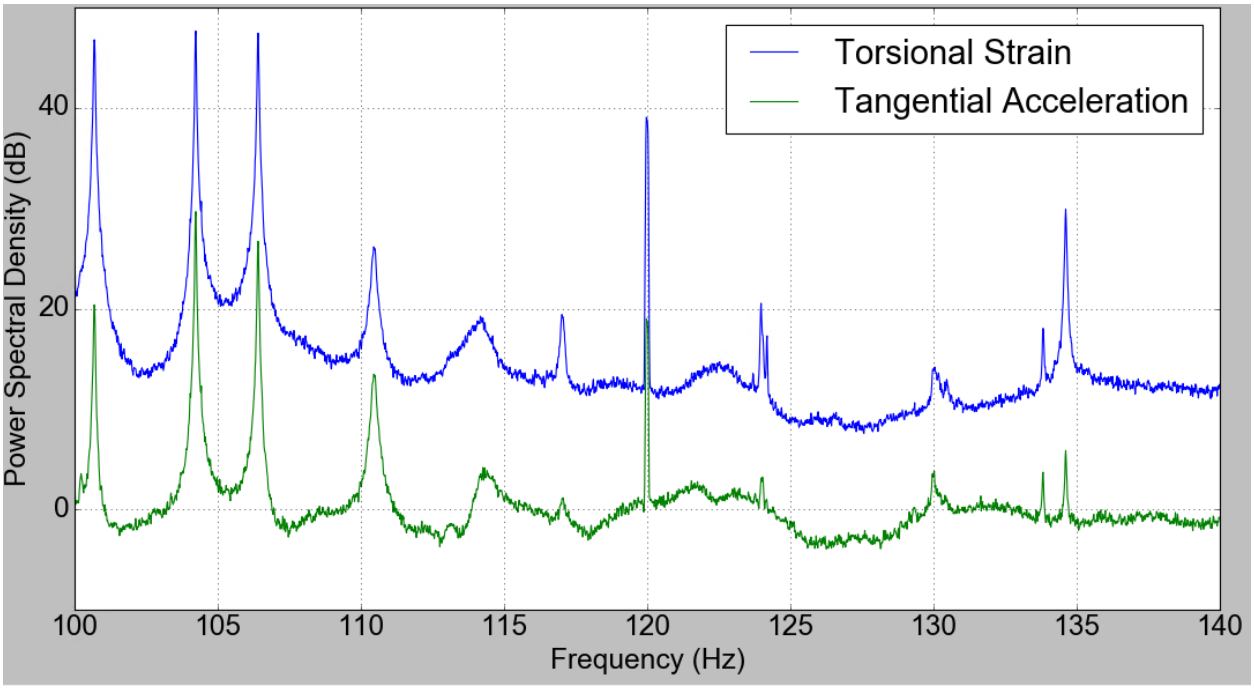


Figure 9 120Hz torsional spectrum at 550MW

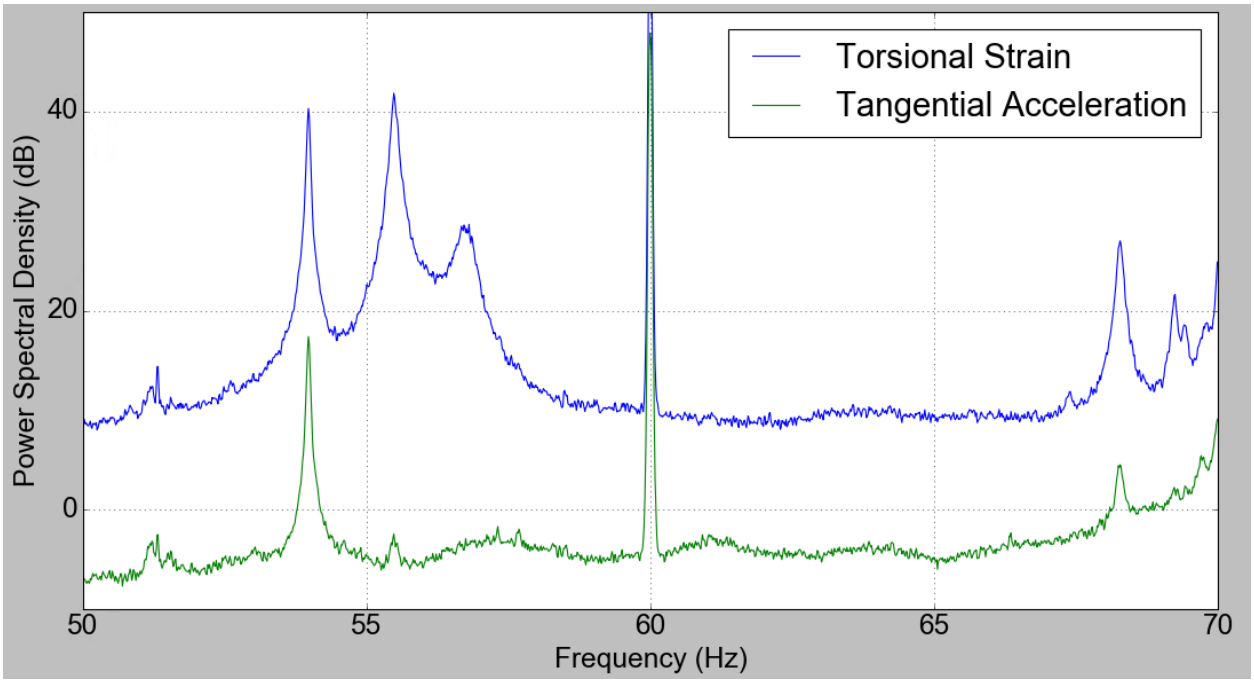


Figure 10 60Hz torsional spectrum at 550MW

4.3 760MW

As expected there is not a significant change between the 550MW and 760MW torsional natural frequencies near 120Hz. The closest torsional natural frequencies are 116.976Hz and 123.992Hz.

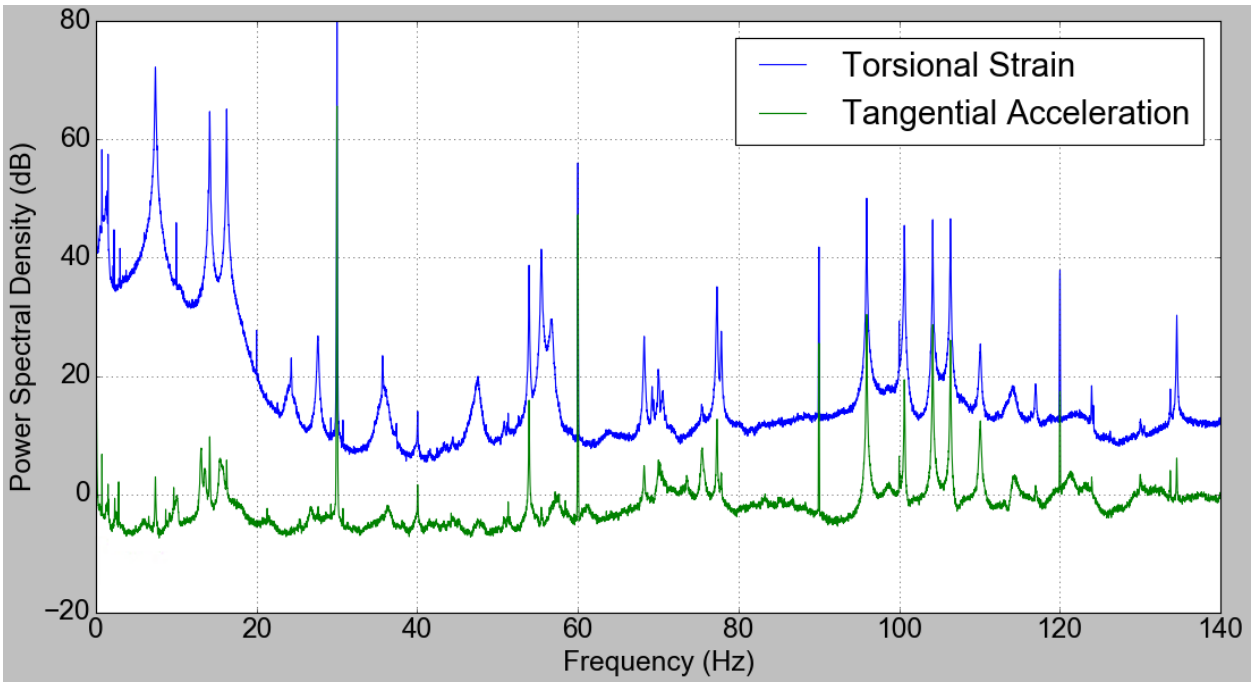


Figure 11 Full torsional spectrum at 760MW

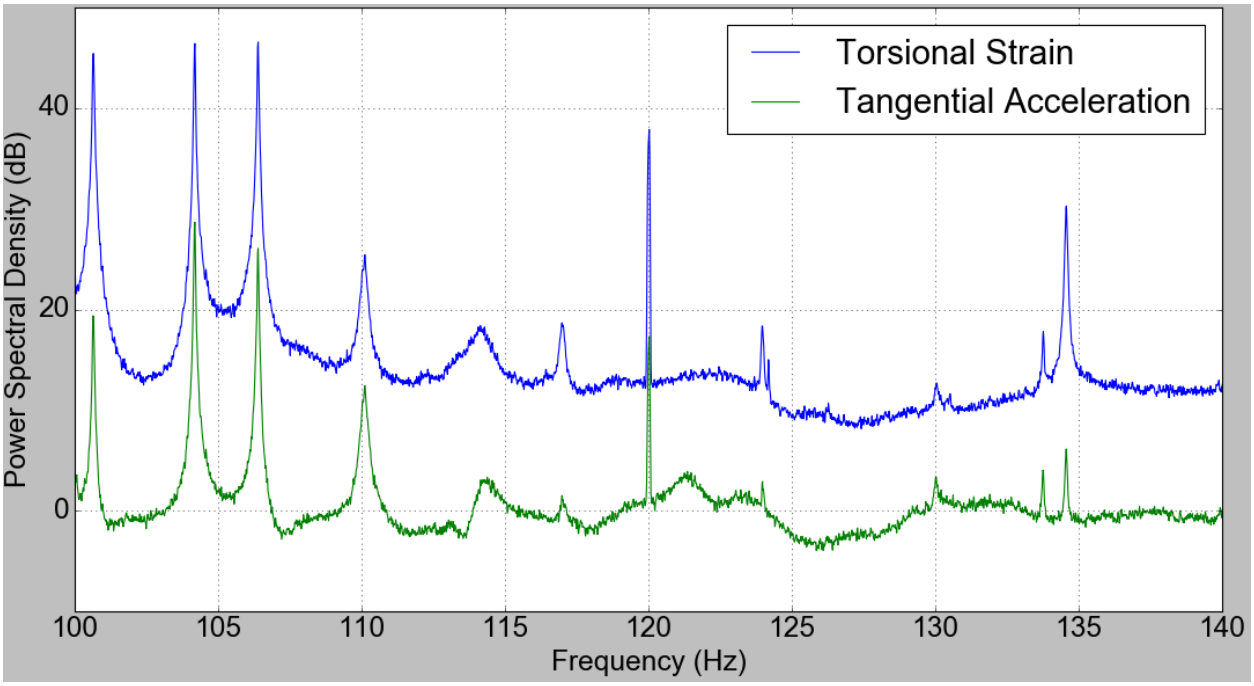


Figure 12 120Hz torsional spectrum at 760MW

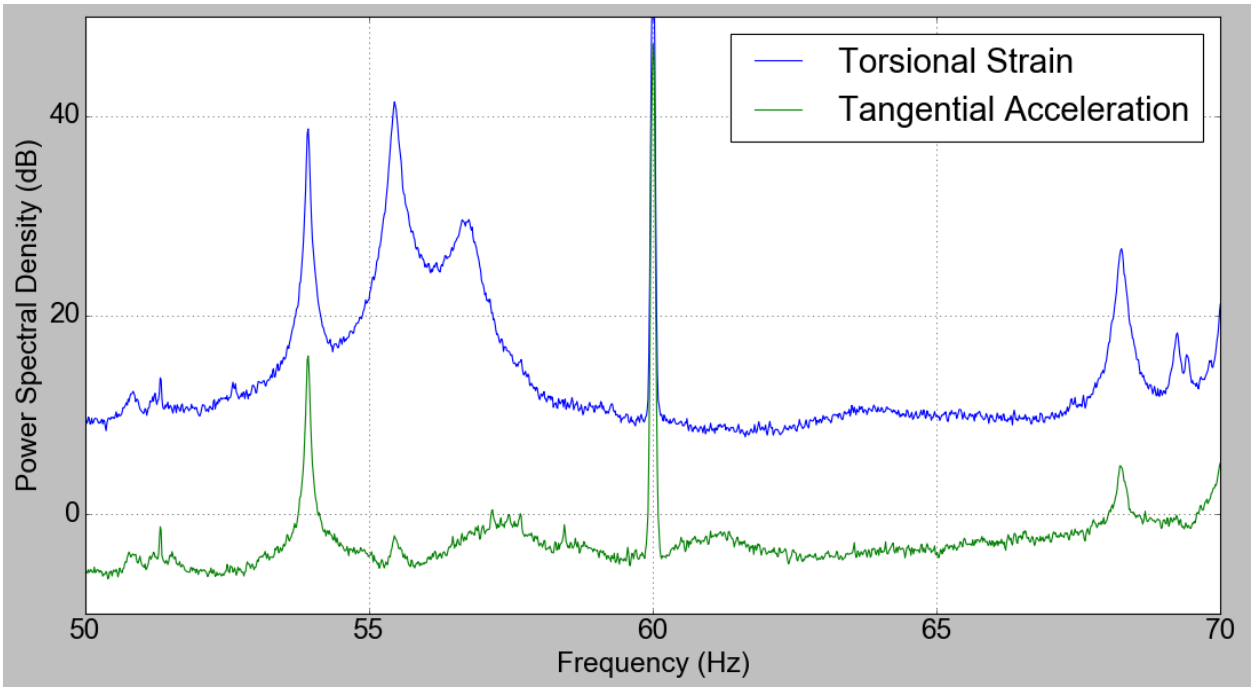


Figure 13 60Hz torsional spectrum at 760MW

5 MAJOR TRIP EVENT

An LVDT failed on one of the turbine governor valves. The TDMS detected torsional oscillations prior to the TG trip from load which indicated a turbine load problem. The TG trip produced strains at the telemetry site in excess of 1/3 material yield. The dynamic range of the TDMS sensor was able to capture this event. The telemetry survived the peak torque and continued to operate.

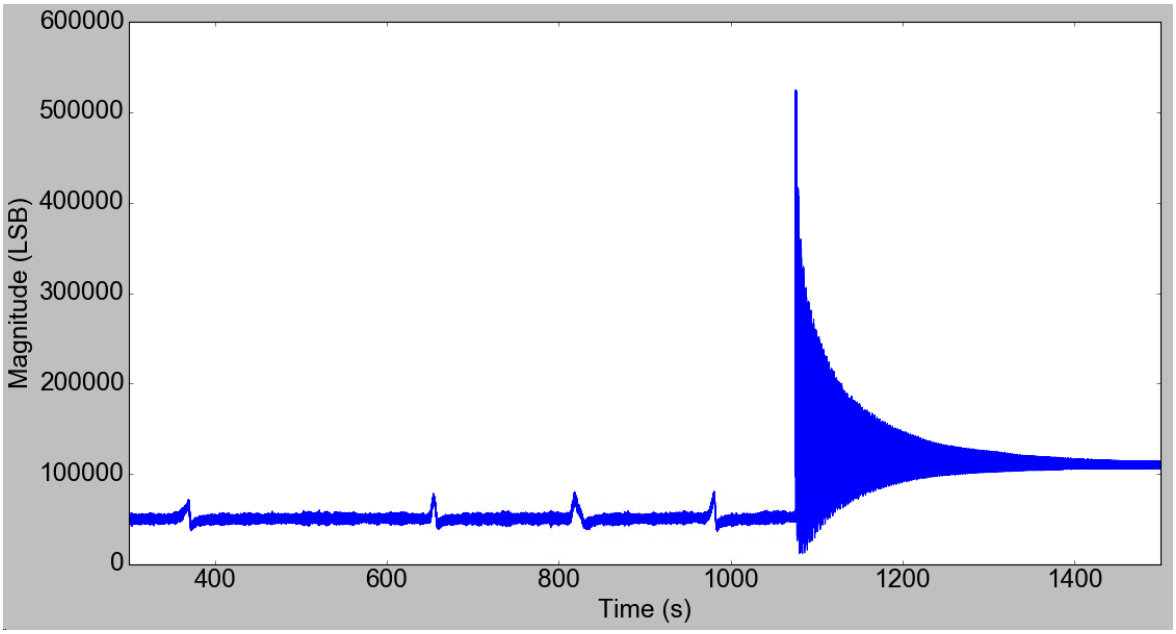


Figure 14 Trip from load following torsional disturbances related to valve control failure.

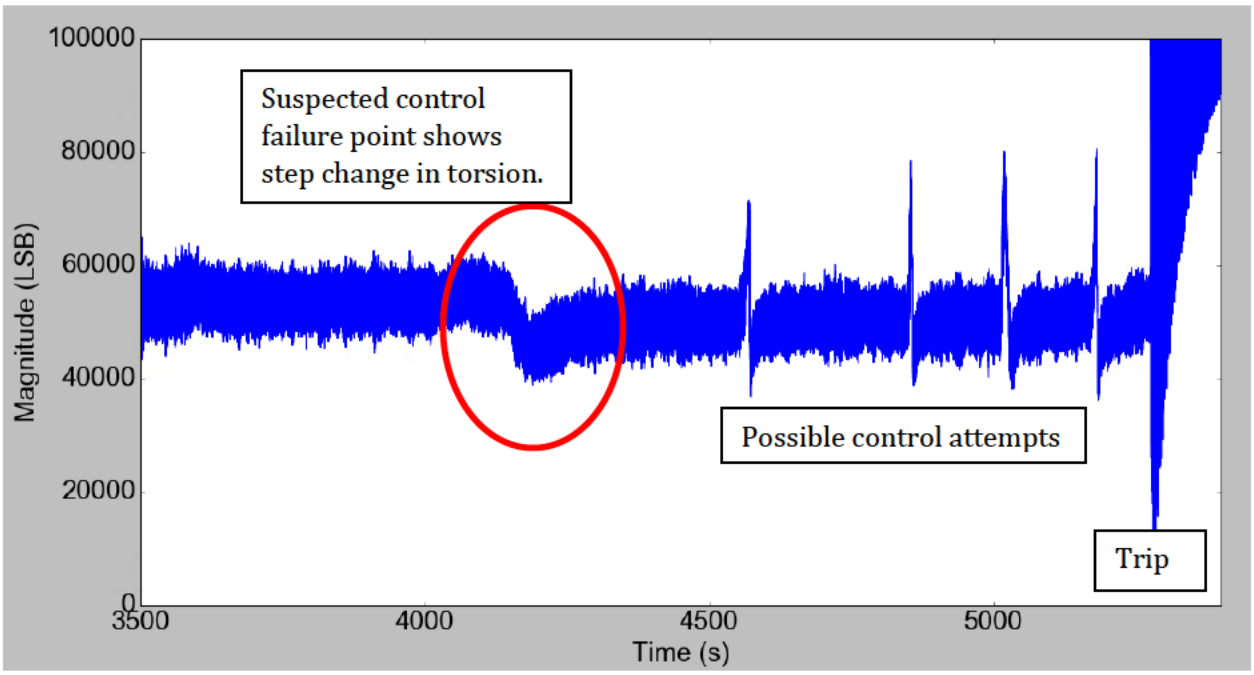


Figure 15 Torsional strain showing torque increase and 4x subsequent load control attempts prior to trip of the TG.

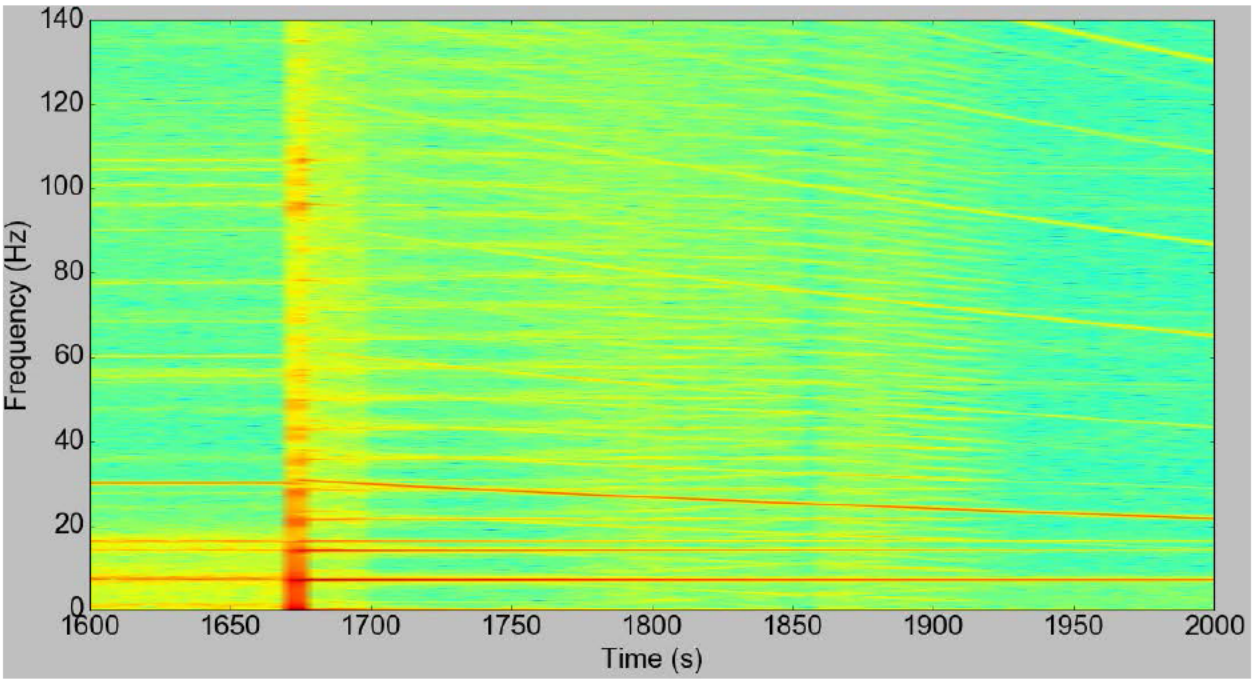


Figure 16 Trip and torsional ring-down of the TG.

6 CONCLUSION

The required torsional test was completed successfully and validated across a range of TG loads. The torsional natural frequencies are acceptable and have margin away from the forced frequencies of 60Hz and 120Hz. The TDMS recorded several events of interest during the torsional test including detecting the governor valve LVDT failure as it occurred by detecting a change in the TG torque followed by unsuccessful control attempts.