Stripped down report example – ODS Section for summary purposes only.

Also includes a Shaft Position (DC) ODS – Please ask with questions about this test or if you would like to use it. Credit to Tony DeMatteo – 4X Diagnostics.

Background

The purpose of the testing was to diagnose the source of high vibration affecting wire connections below the generator on the current transformers (CTs) and Neutral Enclosure.

Consists of a high pressure turbine, two low pressure turbines, a generator and a single bearing stub shaft that replaced the original exciter. XXXXXX Turbine Generator shaft rotational speed is 3600 cpm (60 Hertz).

Two Proximity Probes mounted 45 degrees from vertical are mounted on each of the nine bearings. The probes along with a keyphasor are connected to a Bently 3500 rack and to Bently System 1.

Operational Deflection Shape Study (ODS) – A Frequency based Operational Deflection Shape analysis (ODS) was completed on XXXXXX on XXXXXX operating normally at 333 MW.

The ODS test consisted of 2428 ODS Frequency Response Functions measured on rotating shafts, bearing housings, turbine and generator housings, sole plates, isolated and non-isolated floors and concrete foundations from the basement to the machine deck.

All measured points were referenced to a fixed single axis 100 mv/g accelerometer placed in the "Z" direction (vertical) on Bearing 7 – the Generator inboard turbine bearing. The reference sensor signal was double integrated to displacement.

Response vibration on machine housings, sole plates concrete floors and columns was measured sequentially at all test points using a CTC model AC115, 100 mv/g triaxial accelerometer. Response vibration directions were X, Y and Z where X was aligned horizontally (north/south), Y was parallel to the rotating shafts (east/west) and Z was vertical.

Response vibration on rotating shafts was measured from the Bently 3500 rack X/Y probe BNC outputs.

Figure 7 shows the undeformed structure drawing used for the ODS test.

Figure 8 names the bearings and couplings.

Figure 9 identifies the components mounted to the bottom of the generator housing.

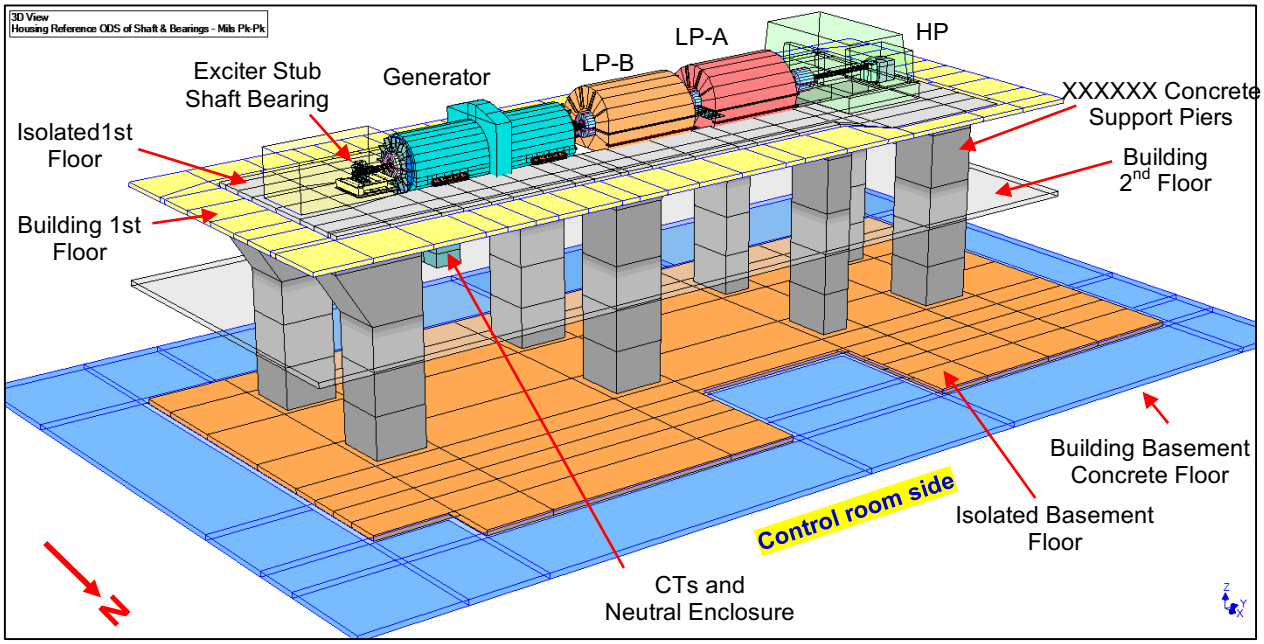


Figure 7
XXXXXX TG, ODS Undeformed Structure Drawing
(Complete Structure)

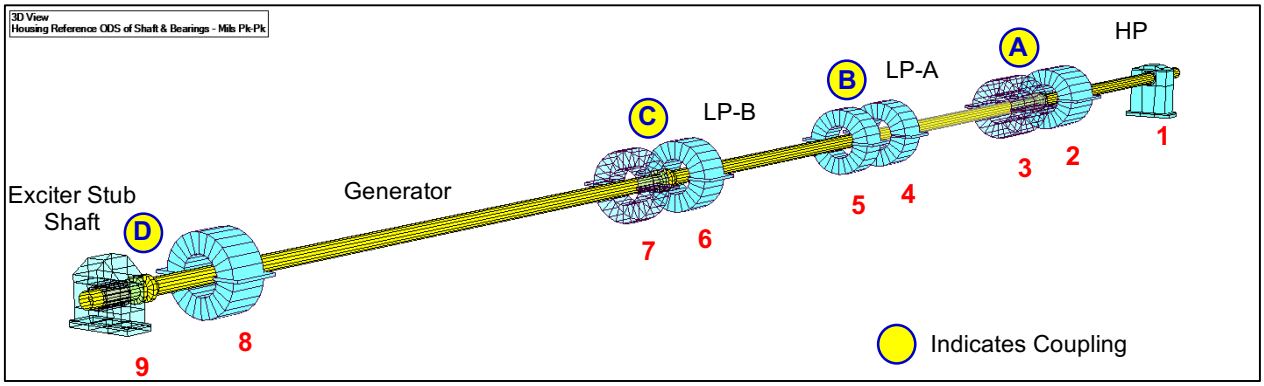


Figure 8
XXXXXX TG, ODS Undeformed Structure Drawing
(Shafts, Bearings & Couplings)

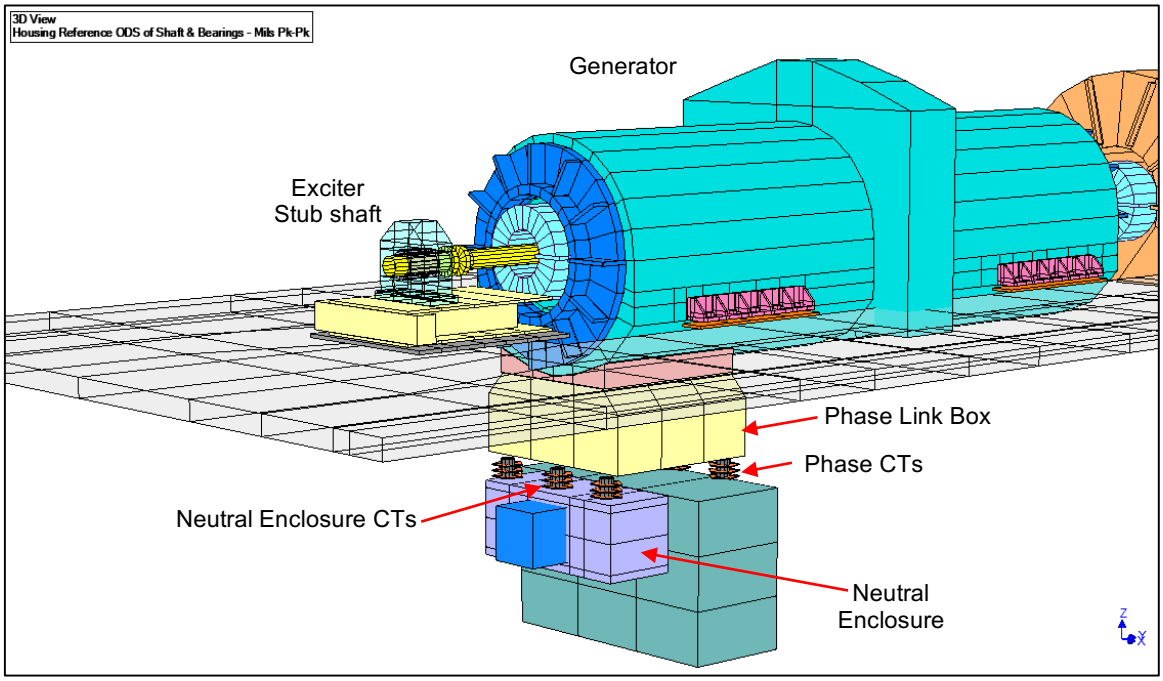


Figure 9
XXXXXX TG, ODS Undeformed Structure Drawing
(CTs and Neutral Enclosure Below the Generator)

5.1 Figure 10 is an overlay of all 2,428 ODS Frequency Response Function measurements in displacement (mils pk-pk). The forcing frequencies of interest for the ODS were 1X and 2X shaft speed.

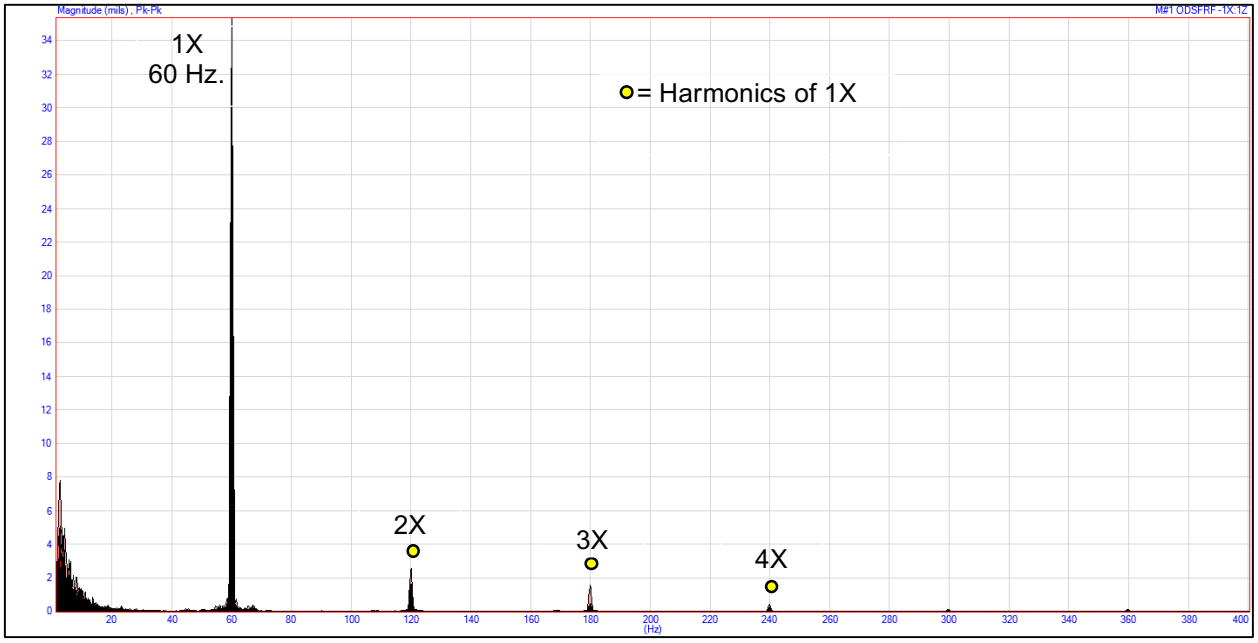


Figure 10
XXXXXX TG, Overlay of 2,428 ODS Frequency Response Functions

4.2 ODS animation movies are hyperlinked in this document[1].

1X rotational speed ODS animation movies of the complete structure are here:

1-XXXXXX ODS, 60 Hz (1X), Complete Unit (all components).Avi

2-XXXXXX ODS, 60 Hz (1X), Complete Unit (doghouse removed, gen & LP skirts removed).Avi

4.3 The ODS indicates the generator housing is rocking 180 degrees out of phase vertically from end-to-end with displacement of 3.9 mils pk-pk at 1X rotational speed (3600 times per minute). Generator housing vibration does not carry over to the LP-B or exciter stub shaft. The generator housing rocking motion supports a conclusion of shaft misalignment. Figure 11 illustrates the generator housing rocking motion.

ODS animation movies of the generator rocking motion are here:

3-XXXXXX ODS, 60 Hz (1X), Close-up of rotating components.Avi

4-XXXXXX ODS, 60 Hz (1X), Close-up of rotating components, contour colors in mils pk-pk.Avi

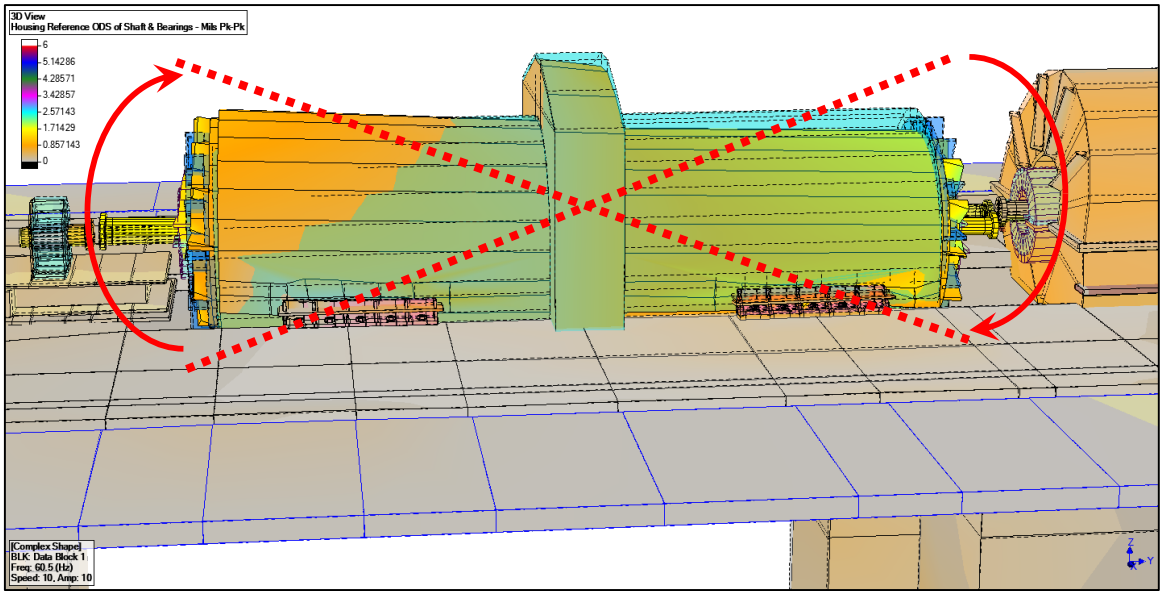


Figure 11
XXXXXX TG, 1X ODS Deformation Shape of Generator Vertical Rocking Motion

4.4 The end plate on the LP-B turbine at bearing 5 is resonating in the Y direction (axially). The end plate has oil canning mode shape with larger displacement near the center than at the circumference (Figure 12). The maximum end plate displacement is 7 mils pk-pk.

An ODS animation movie of the bearing 5 end plate resonance is here:

5-XXXXXX ODS, 60 Hz (1X), West side view of LPA, LPB and Generator.Avi

[1] Mouse over a hyperlink and left click to play the move (if supported by your PDF player). Read the Read Me! Playing ODS and Modal Animation Movies.pdf for instructions on configuring your movie player to "loop" or "repeat" to play continuously.

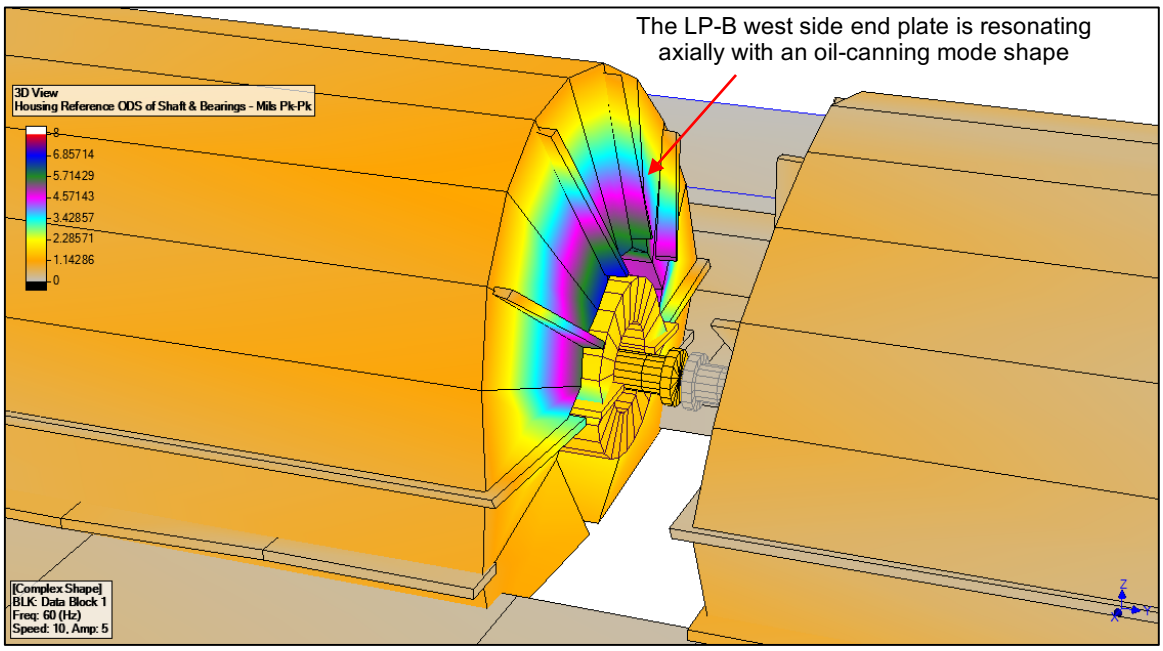


Figure 12
XXXXXX TG, 1X ODS Resonance of LP-B Turbine End Plate at Bearing 5

4.5 Generator housing vertical rocking motion is causing the transformers and neutral enclosure hanging from the bottom of the generator to vibrate with exaggerated response.

- Displacement levels up to 35 mils pk-pk were measured on the CTs which explains the broken wire connections that have caused machine trips. Vibration on these components will subside once the generator housing is no longer rocking.
- Up to 10 mils displacement was observed on the neutral enclosure.
- Vibration on the large structure directly behind the neutral enclosure to the west was vibrating much less than the neutral enclosure because it is supported from below.

ODS animations of the neutral enclosure, and CTs and are here:

6a-XXXXXX ODS, 60 Hz (1X), View of Generator, Neutral Enclosure - CTs hidden.Avi

6b -XXXXXX ODS, 60 Hz (1X), Closeup view of CTs (vibrating up to 34 mils).Avi

4.6 Sole plates, concrete columns and concrete floors supporting the generator are vibrating in response to the generator housing vibration.

- The two west generator sole plates appear to be loose in the concrete. The ODS identified about 1.5 mils relative vibration between the sole plates and concrete foundation (Figure 13). ODS animation move 8c provides the best view of the sole plate to concrete relative motion. Sole plate looseness may not be an issue if the generator housing vibration is reduced or eliminated.

- Vertical vibration on the machine level isolated concrete floor was .10 mils or less at the HP end and .50 mils at the generator end. A few localized sections of the floor were vibrating at higher levels of up to 1.7 mils pk-pk (Figure 14).
- Concrete columns under the generator were vibrating 1.0 mil pk-pk.
- Vertical vibration on the basement isolated concrete floor was up to .42 mils pk-pk on the generator end and much lower on the HP end.

ODS animations of the support structure under XXXXXX TG are here.

7a-XXXXXX ODS, 60 Hz (1X), North side view of gen & LP sole plates & concrete support structures, contour colors.Avi

7b-XXXXXX ODS, 60 Hz (1X), South side view of gen & LP sole plates & concrete support structures, contour colors.Avi

7c-XXXXXX ODS, 60 Hz (1X), North side Close-up view of gen & LP sole plates, undeformed background image, contour colors.Avi

8a-XXXXXX ODS, 60 Hz (1X), Southeast view of gen feet & gen sole plates, undeformed background image.Avi

8b-XXXXXX ODS, 60 Hz (1X), Southeast view of gen feet & gen sole plates, undeformed background image, contour colors.Avi

8c-XXXXXX ODS, 60 Hz (1X), Close-up view of SW gen foot & sole plate, undeformed background image, contour colors.Avi

9a-XXXXXX ODS, 60 Hz (1X), 3rd Floor Concrete Vibration (machine level), contour colors.Avi

9b-XXXXXX ODS, 60 Hz (1X), Concrete Columns and Basement Floor, undeformed background image, contour colors.Avi

9c-XXXXXX ODS, 60 Hz (1X), Isolated and non-isolated Basement Floor, contour colors.Avi

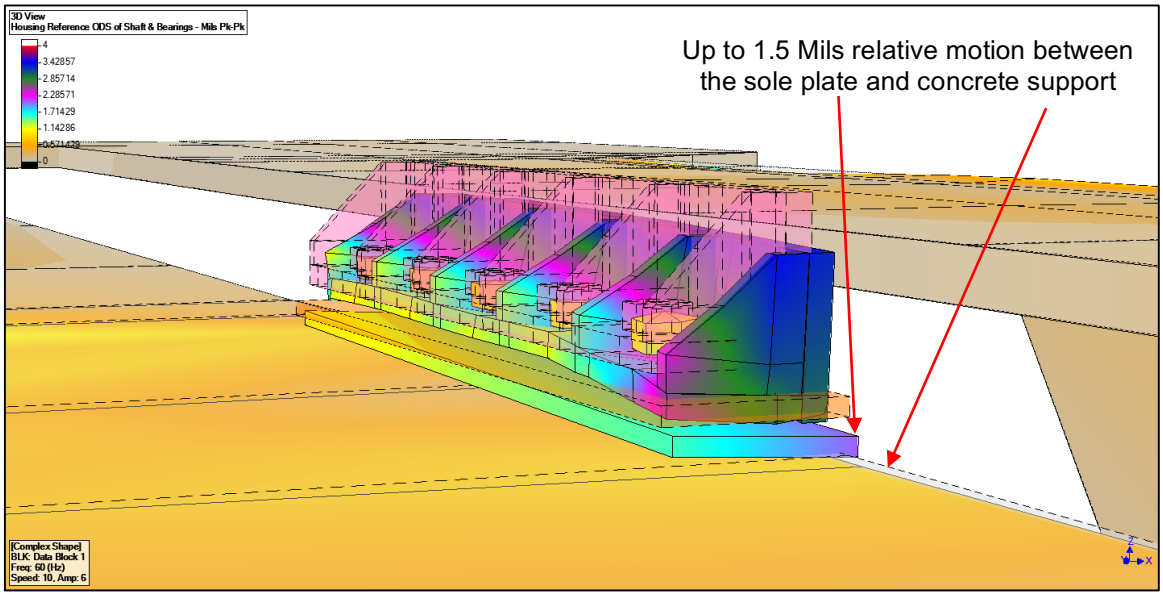


Figure 13
XXXXXX TG, 1X ODS Deformation of West Generator Foot, Soleplate & Concrete Support
Looseness between Sole Plate and Concrete Support
(dotted line image is the undeformed structure)

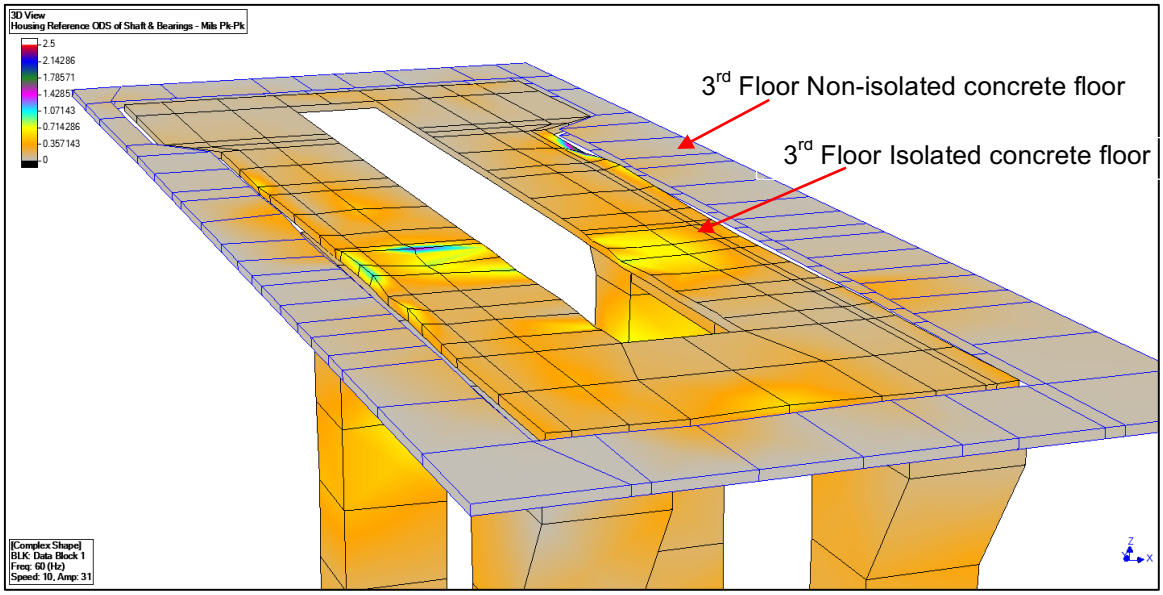


Figure 14
XXXXXX TG, 1X ODS Deformation of Machine Level Isolated and Non-Isolated Concrete Floors

6. Shaft Vibration from full ODS Test

Radial Proximity Probe data, measured from the Bently 3500 rack was included in the ODS test of the complete machine structure.

ODS animations of the shafts and bearings clearly indicate dynamic shaft misalignment. The largest shaft vibration was on the generator (bearings 7 & 8). The most dynamic misalignment was observed on couplings C and D (both ends of the generator shaft).

- The ODS shows the generator shaft vibrating out of phase from end-to-end. Generator shaft vibration lifts the generator bearings and housing (Figure 15).
- Generator shaft vibration was 3.4 mils pk-pk at bearing 7 and 5.3 mils pk-pk at bearing 8.
- Generator housing vibration was 4.4 mils at bearing 7 and 3.5 mils at brg. 8.
- Exciter stub shaft vibration was 1.4 mils pk-pk at bearing 9
- Vibration on the LP-B shaft was .58 mils pk-pk at bearing 6.
- 2X shaft vibration was less than 1.0 mil pk-pk on the generator shafts, 0.4 or less on the exciter stub shaft and much lower on the turbines.

ODS animation movies of 1X vibration on the shafts and bearing housings are here:

10a-XXXXXX ODS, 60 Hz (1X), Shaft & Bearing Vibration.Avi

10b-XXXXXX ODS, 60 Hz (1X), Shaft & Bearing Vibration, contour colors.Avi

ODS animation movies of 2X vibration on the shafts and bearing housings are here:

10c-XXXXXX ODS, 120 Hz (2X), Shaft & Bearing Vibration.Avi

10d-XXXXXX ODS, 120 Hz (2X), Shaft & Bearing Vibration, contour colors.Avi

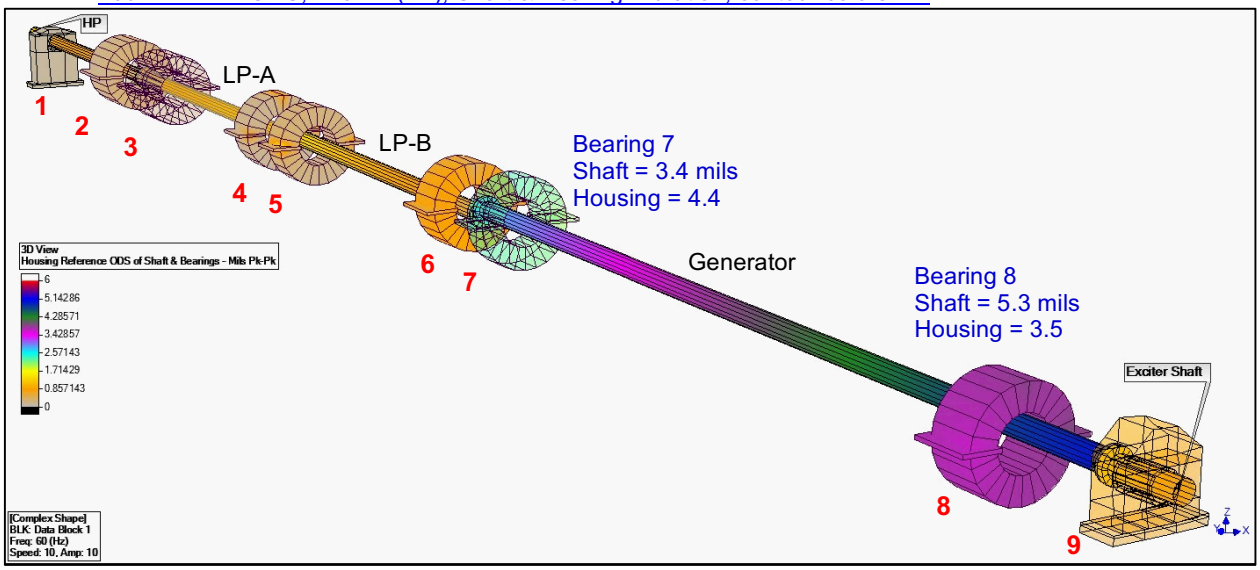


Figure 15
XXXXXX TG, 1X ODS Deformation of Shafts and Bearings
(all other components are hidden from view)

7. Additional Shaft ODSs from the Bently 3500 Rack

Three additional ODSs of the shafts were completed on different days and MW loads using radial Proximity Probe measurements acquired from the Bently 3500 rack. For these ODSs, the Bently Keyphasor was used as the reference. Test dates were XXXXX, 24 and 25.

The ODSs show the same shaft motion and misalignment described in Section 6.

Shaft ODS animation movies from the Bently 3500 rack are here:

11a-XXXXXX ODS, 60 Hz (1X), Shaft Vibration (from prox probes & keyphasor), XX-XX-20XX, 570 MW.Avi

11b-XXXXXX ODS, 60 Hz (1X), Shaft Vibration (from prox probes & keyphasor), XX-XX-20XX, 332 MW.Avi

11c-XXXXXX ODS, 60 Hz (1X), Shaft Vibration (from prox probes & keyphasor), XX-XX-20XX, 333 MW.Avi

An animation movie comparing the 570 MW and 333 MW ODSs is here:

11d-XXXXXX ODS, 60 Hz (1X), Shaft Vibration Comparison Overlay (from prox probes & keyphasor), XX-XX (570MW) vs XX-XX (333 MW).Avi

8. **Shaft Position Operational Deflection Shape Test**

A Shaft Position Operational Deflection Shape (SP-ODS) was completed using radial Proximity Probe DC (gap) voltage data. The SP-ODS identifies dynamic change in shaft position after rotation begins. The SP-ODS does not take into account static shaft misalignment or alignment compensation for thermal growth.

The dataset used for the SP-ODS contains 1200 DC gap voltage points per channel extracted from the Bently System 1 from a hot roll-up on XXXXX , 20XX after a trip caused by a broken CT lug. This startup was prior to 4X Diagnostics' testing. The dataset includes run-up to full speed, heat up and applied load. Trend Plots of the DC data used for the SP-ODS test are shown in Figure 16. Trace data prior to roll-up has been normalized to zero.

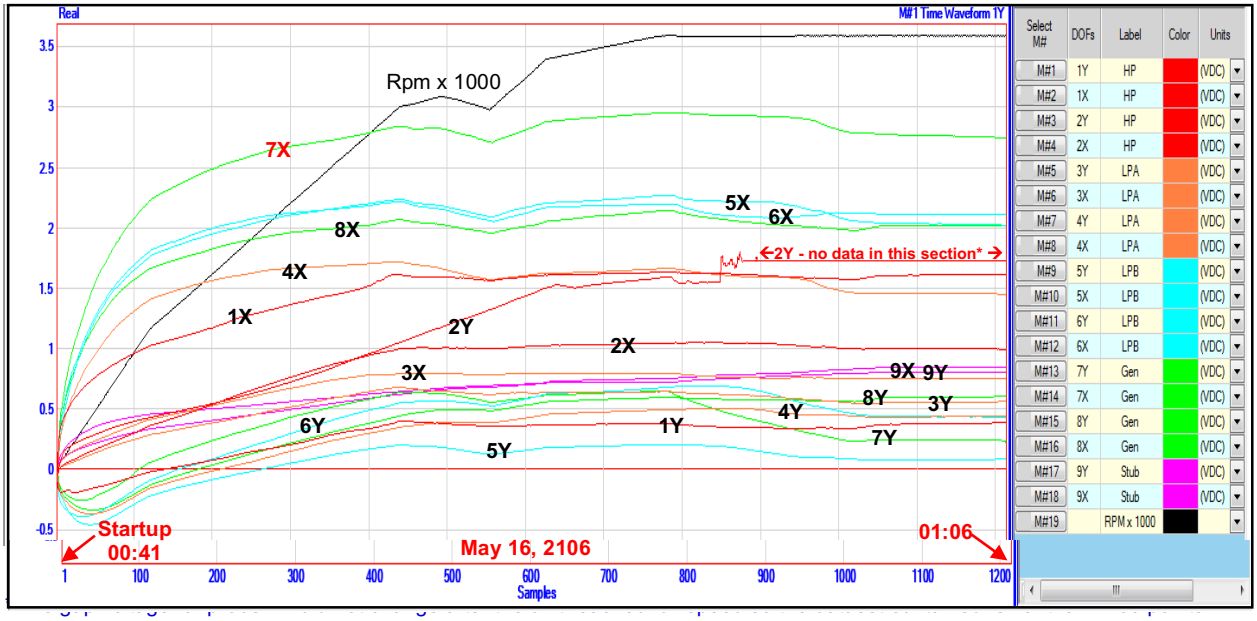


Figure 16
XXXXXX TG, Radial Proximity Probe DC Gap Voltage Data
Hot Roll-up, XX-XX-20XX - this data was used for DC Shaft Position ODS

The Shaft Position ODS SP-ODS illustrates the following:

- Up/Down Shaft Movement – Immediately after startup, all shafts move upwards towards the X direction radial Proximity Probes (Figure 17 - top).

  The generator shaft moved upwards more than the other shafts. It moved 15 mils (3.0 VDC) towards probe 7X and 11 mils (2.2 VDC) towards probe 8X.

LP-B shaft moved upwards 11 mils (2.3 VDC) towards probes 5X and 6X.

Shaft movement was less towards the Y direction Proximity Probes except at bearing 2 where the shaft moved about 9 mils (1.8 VDC) towards probe 2Y.

The exciter stub shaft moved upwards less than all other shafts.

A SP-ODS side view movie showing up/down shaft movement is here:

12a-XXXXXX DC ODS, Shaft Position from Hot Roll-up to Full Speed & Load, XX-XX-16 System 1 Data, SIDE VIEW.Avi

- North/South Shaft Movement – Immediately after startup, all shafts move south except for the exciter stub shaft and the HP shaft at bearing 2.

  As the unit reaches full speed and load is applied, shaft parallel and angular offset increases (Figure 17 - bottom).

  After reaching full speed, the shaft at HP bearing 2 continues to move north increasing parallel and angular offset at coupling A.

  The LP-A shaft at bearing 3 hardly moves at all in the north/south direction.

  A SP-ODS top view movie showing north/south shaft movement is here:

  12b-XXXXXX DC ODS, Shaft Position from Hot Roll-up to Full Speed & Load, XX-XX-16 System 1 Data, TOP VIEW.Avi

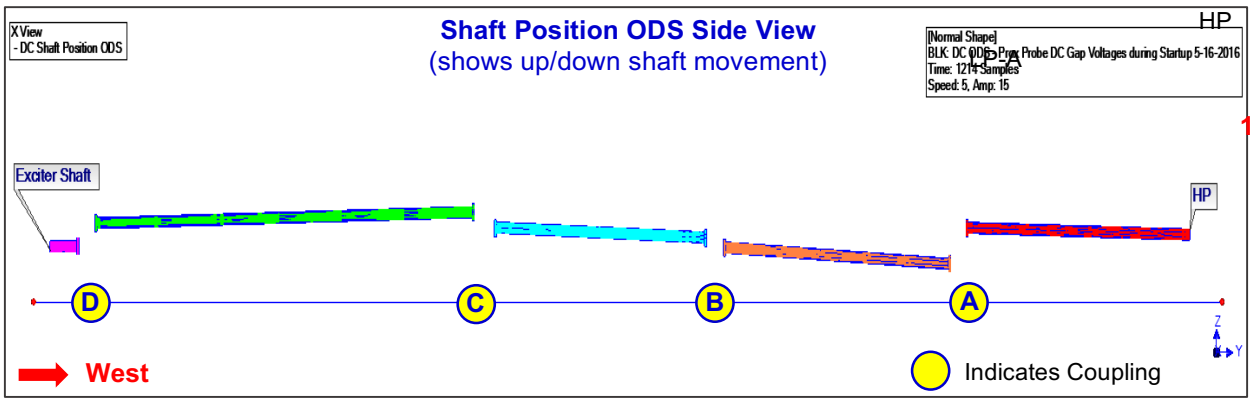
- Other Shaft Position ODS Comments

  The shaft position ODSs suggests dynamic shaft misalignment across the machine train.

  Other SP-ODS animation movies are here:

  12c-XXXXXX DC ODS, Shaft Position from Hot Roll-up to Full Speed & Load, XX-XX-16 System 1 Data, TOP & FRONT VIEWS.Avi

  12d-XXXXXX DC ODS, Shaft Position from Hot Roll-up to Full Speed & Load, XX-XX-16 System 1 Data, 3D View.Avi



Shaft Position ODS Top View
(shows north/south shaft movement)

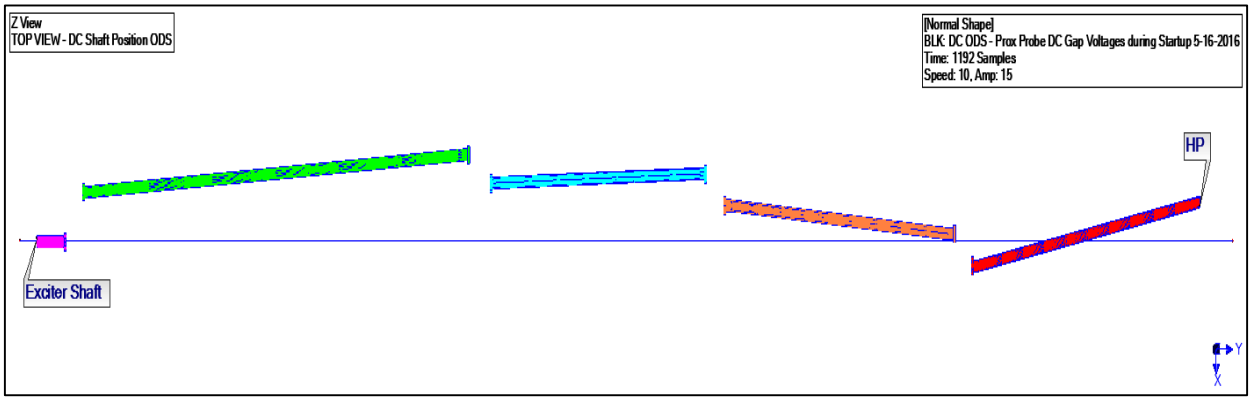


Figure 17

XXXXXX TG, DC Shaft Position ODS

Picture illustrates shaft movement after reaching full speed and load

Up/down view (top plot), N/S view (bottom plot)