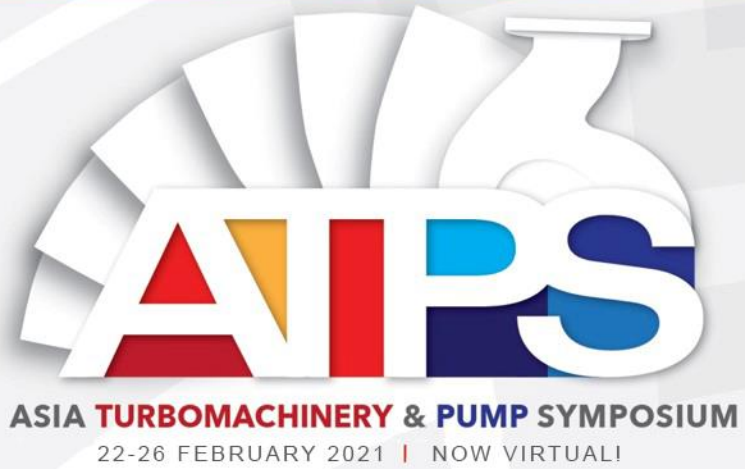

Resolution Of Vibration Step Changes On A Steam Turbine Generator

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Mustafa works as Technical Leader for Bently Nevada, Baker Hughes Machinery Diagnostics Services in Saudi Arabia, Bahrain & India. He has joined Bently Nevada, Baker Hughes company since December, 2012. He is a certified vibration analyst CAT III by Mobius Institute. He has been working in vibration diagnostics of rotating equipment for over 13 years. He started his career in 2007 as a condition monitoring engineer for rotating equipment.

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Sherif is the Technical Leader for Bently Nevada, Baker Hughes Machinery Diagnostics Services for Middle East, North Africa and Turkey. Received a Bachelor of Science in Electrical Engineering from Egypt, Mansura University in 1978. Over 30 years experience in the field of vibration and 20 years of experience with Bently Nevada, covering rotating equipment balancing, condition monitoring, vibration analysis, diagnostics and root cause analysis. Published several case studies in Orbit magazines and Turbomachinery symposiums.

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Sankar is the Technical Leader for Bently Nevada, Baker Hughes Machinery Diagnostics Services in the MENAT region. He received a Bachelor of Mechanical Engineering from Bharathidasan University, India, in 1993.

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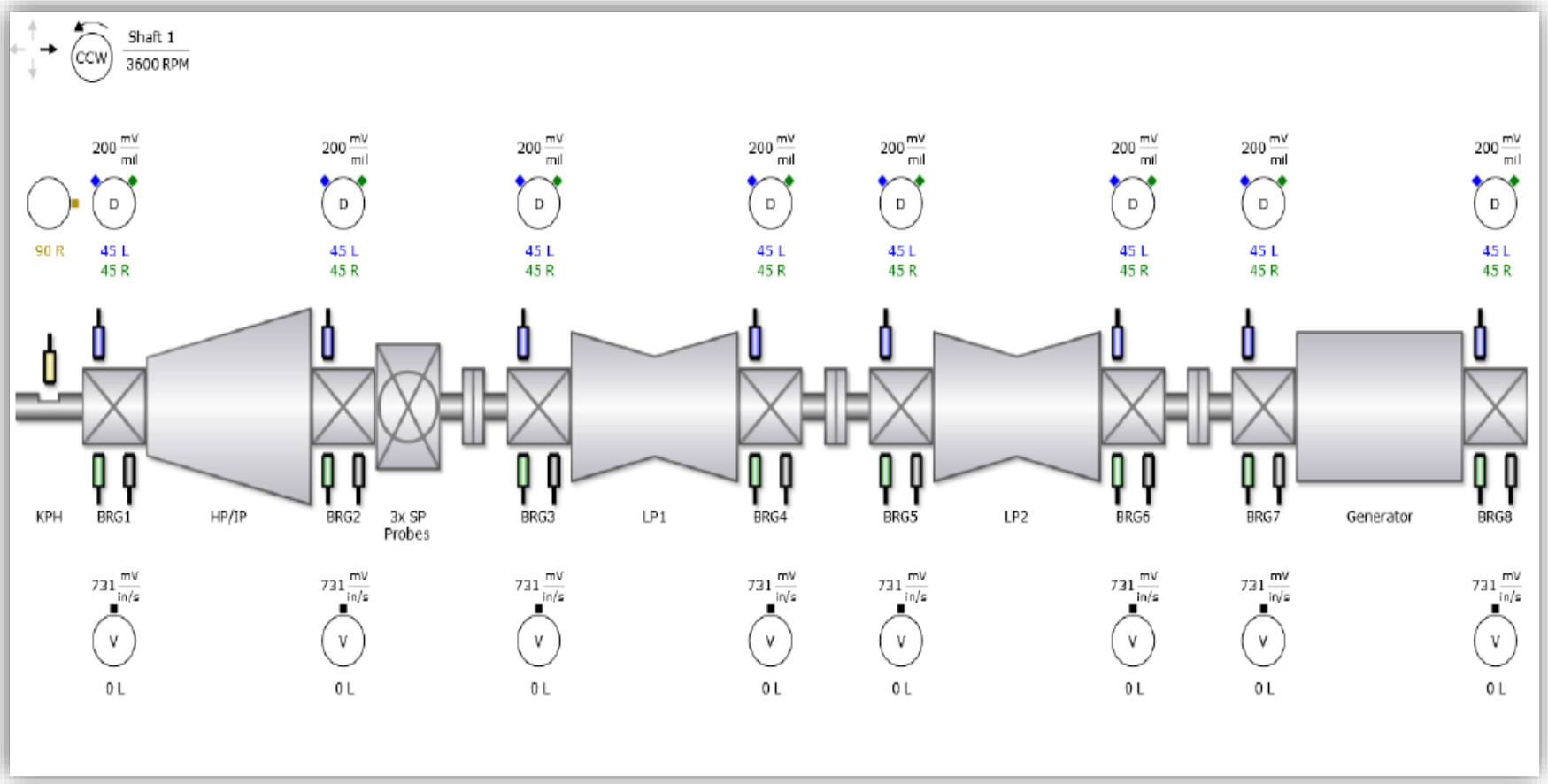
Abstract

The machine train consists of a steam turbine of three casings (HP/IP, LP1 and LP2) coupled to a Generator with a base load capacity of 660MW running at 3600RPM. Post a machine boiler event trip on October 22nd 2018, step changes in vibration were repeatedly observed, especially at LP2 and Generator bearings. The change in vibration level was mainly 1X and was evident on both rotor and seismic vibration. A change in 1X synchronous response can result from a change in unbalance force and/or a change in Dynamic Stiffness condition. In this case, unbalance was not the most suspected cause because of the nonlinear response on each time the step changes happened. The transient data further strengthened this conclusion because of the absence of expected rotor dynamic behavior. So, the most probable cause was concluded to be the change in dynamic stiffness either due to change in coupling bolts tension/tightness or foundation bolts looseness. Another interesting observation was that the step changes caused more reaction on the generator vibration and it was concluded from the transient plots that the rotor is operating close to the second critical speed. The heavy forces created during each machine trip worsened the bolt looseness and at one instant, the machine was not able to reach the full speed because of very high vibration on the generator DE bearing. It was agreed to stop the unit and undergo maintenance activities because the observed vibration was above acceptable levels for continuous operation of this unit.

Inspection of coupling bolts torque/tightness showed no change from the previous outage reading. However, inspection of the foundation bolts on LP1 and LP2 revealed looseness on all the foundation bolts without tack welds. The bolts were tightened and welded with 0.1 mm clearance as per design specification. After completion of this maintenance activity the unit was restarted, and the observed vibration levels were well below acceptable levels

Machine Details

- Onshore Steam turbine of three casings (HP/IP, LP1 and LP2) coupled to a Synchronous Generator.
- Base load capacity of 660MW running at 3600RPM
- All train components are coupled together using Rigid Coupling



Machine Details – Cont'd

- Machine train consists of four rotors, each rotor is supported between two plain journal bearings. Also, a thrust bearing is installed with bearing #2.

- Two orthogonal proximity probes are installed on each bearing of the machine train at 45L (Y probe) and 45R (X probe) angles in addition to three axial position transducers installed at bearing #2.

- A permanent Keyphasor is installed at bearing #1. In addition, one integrated velocity seismic probe is vertically mounted on each bearing. There is no online diagnostics system installed for this machine.

- Rotor vibrations limits are **125** and **250** µ pk-pk for alert and trip respectively, whereas for seismic vibrations (integrated velocity), the alarm is set at **60** µ pk-pk.

Problem Statement

- Machine was commissioned in 2014 with no significant problems reported.
- To reduce downtime during major overhauling, coupling bolts between all rotors were replaced by a hydraulically-tightened type from conventional ones.
- The unit was taken for outage in Feb 2018 and after the outage, the vibration levels were within the limits with maximum of 76um PP at BRG 7 (Gen DE) Y probe.
- Repeated vibration step changes were observed after a boiler trip event happened on 22nd April 2018 especially at BRG 5,6 and 7.
- A multichannel vibration analyzer was hooked to the online monitoring system to capture the second significant step change occurred on 9th June 2018.

Problem Statement – Cont'd

- Further significant vibration step changes were also captured on 10th Oct 2018, followed by a major change in vibration reaching close to the danger set point on the Generator bearings after a process trip event.

- Overall vibration levels at BRG#6, BRG#7 and BRG#8 increased and the generator bearing overall vibration levels reached above alarm levels after the step changes happened during Oct 2018.

- Shaft vibration on bearing #7 Y reached 231 µ pk-pk (Alarm 125 µ pk-pk).

- Casing vibration velocity were also collected by using portable instrument, which showed high amplitude with maximum of 14.5 mm/sec rms at generator DE side.

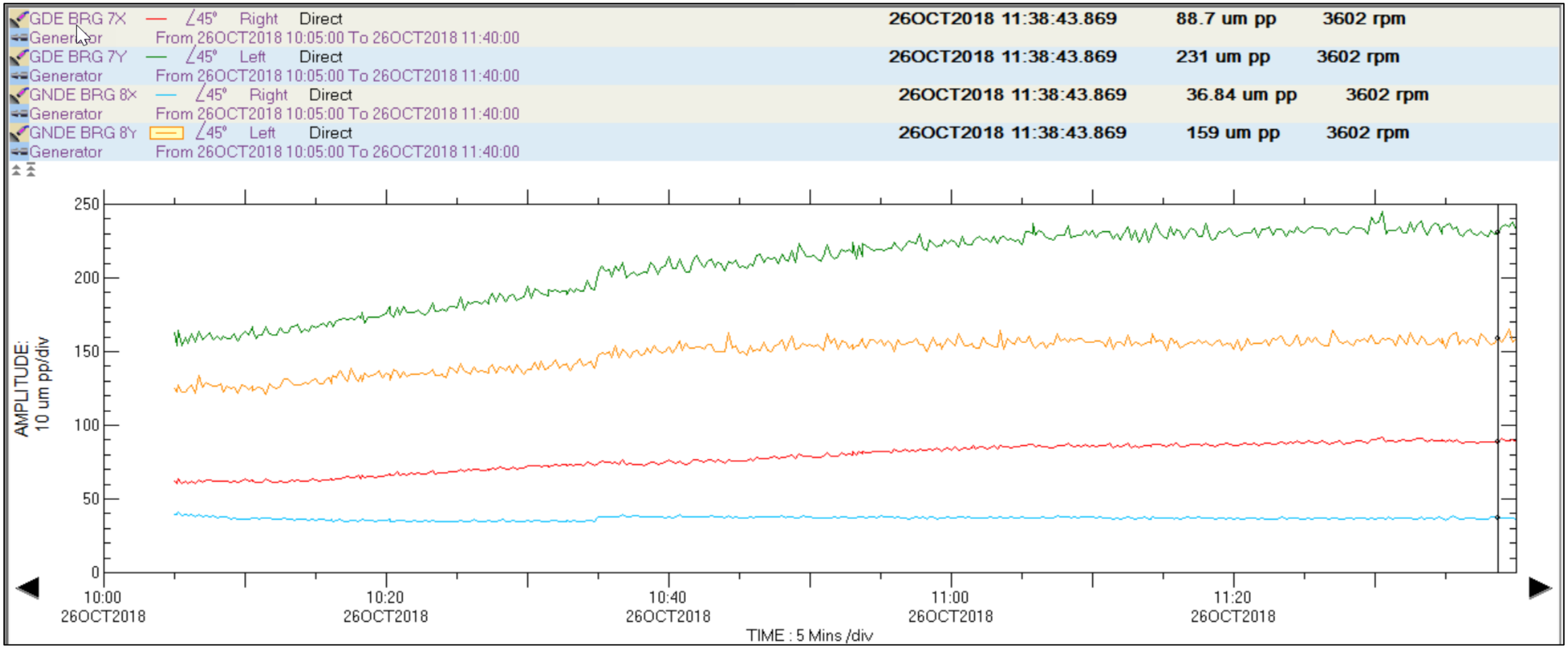
Data Analysis

- The change in vibration level was mainly 1X and was evident on both rotor and seismic vibration. Below is the comparison of shaft vibration levels at different occasions.

		Mar-18			23-Apr-18			10th June 2018			10th oct 2018			24th oct 2018		
		Direct	1X	Phase	Direct	1X	Phase	Direct	1X	Phase	Direct	1X	Phase	Direct	1X	Phase
Brg 1	X	54.9	41.93	100	66.4	57.7	97	70.2	58.9	99	70.4	55.6	108	56	48	106
	Y	63.2	51.3	18	102	81.8	18	91.5	74.2	25	75.5	61.4	34	61	54	24
Brg 2	X	73.6	49.36	96	61	42.83	123	61.1	38.89	119	48.7	29.6	102	58	43	101
	Y	67.5	53.1	17	72.3	54.6	52	62.2	44.85	44	50.8	35.26	24	56	44	31
Brg 3	X	29.72	10.85	159	46.79	31.79	159	43.69	28.1	167	39.4	25.2	188	41	26	186
	Y	30.37	10.56	51	61.2	54	33	56.1	43.77	45	52.3	36	73	58	43	68
Brg 4	X	29.89	16.44	204	34.78	22.22	217	34.31	19.88	218	31.63	17	222	30	14	227
	Y	38.31	26.19	90	47.07	41.14	95	47.79	37.81	99	43	32	117	43	26	122
Brg 5	X	31.88	7.985	242	84.7	59.6	160	76.5	53.9	174	57	45	199	73	59	189
	Y	36.36	19.84	190	139	123	45	123	101	64	88.5	79	112	107	91	99
Brg 6	X	23.31	15.61	226	38.66	26.43	21	23.14	12.54	99	BAD Signal			BAD Signal		
	Y	24.93	15.05	128	71	58.3	247	33.04	22.08	275	55.6	46	62	60	51	91
Brg 7	X	42.29	27.88	230	43.22	30.06	223	50.4	37.83	221	62.3	52	237	88	83	236
	Y	76.1	64.3	121	85.9	76.9	122	106	96.5	117	145	133	113	231	220	114
Brg 8	X	27.87	12.5	240	30.2	15.15	244	31.59	15.58	247	33	18	257	37	24	257
	Y	78.3	54.3	212	75.5	60	193	93.7	75.5	187	114	98	183	155	145	165

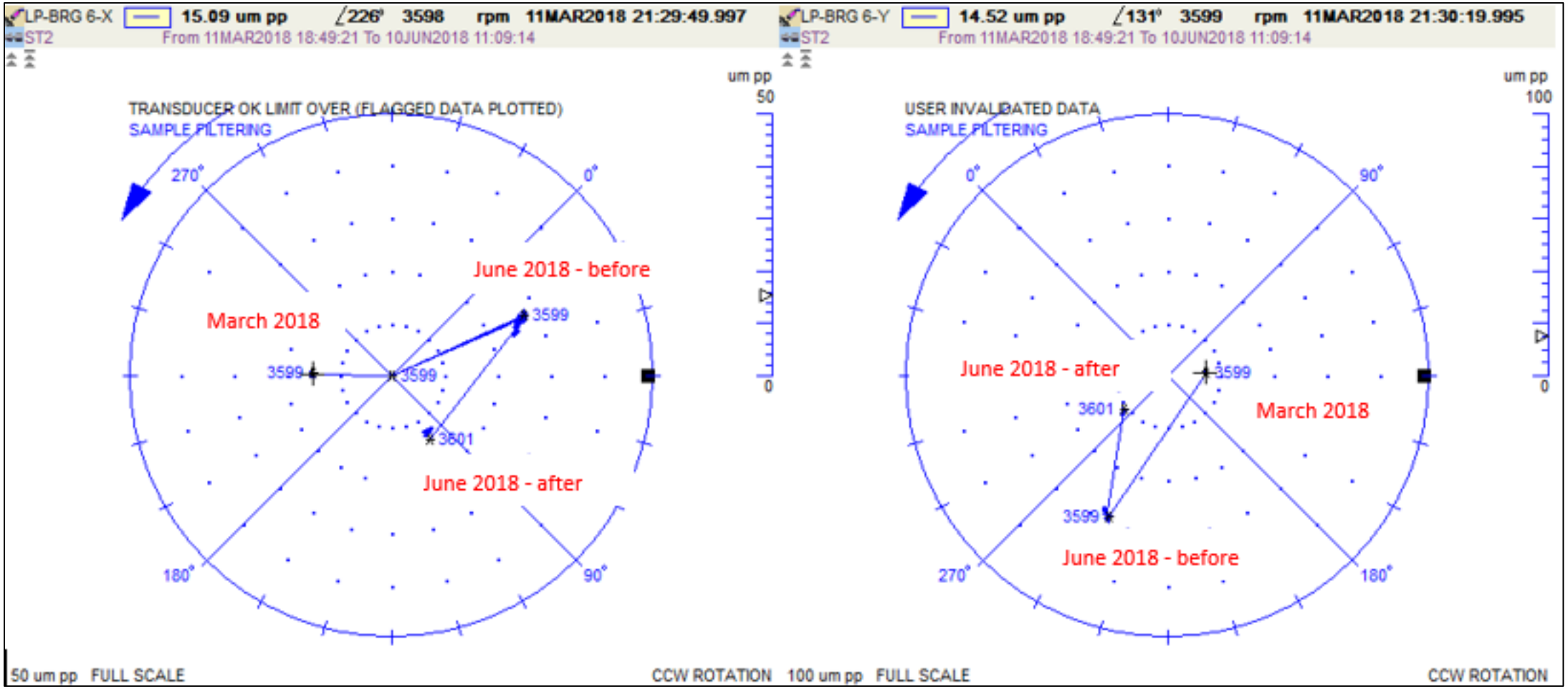
Normal – After Outage → 1st Step Change → 2nd Step Change → 3rd Step Change → 4th Step Change, then stopped for Action.

Data Analysis – Cont'd



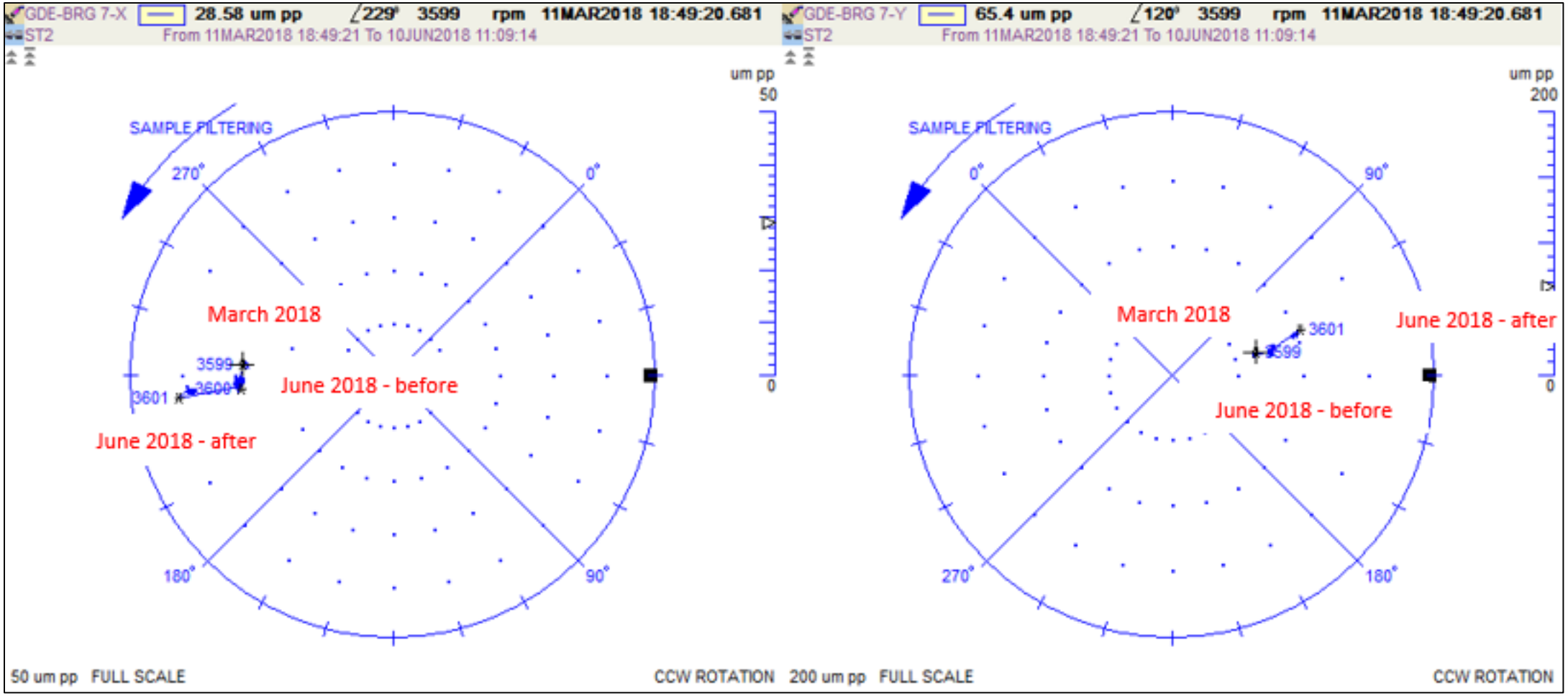
Overall Vibration on Generator DE Bearing#7 reached close to the Danger set point of 231 µm pk-pk

Data Analysis- Steady State Polar Plots – Cont'd



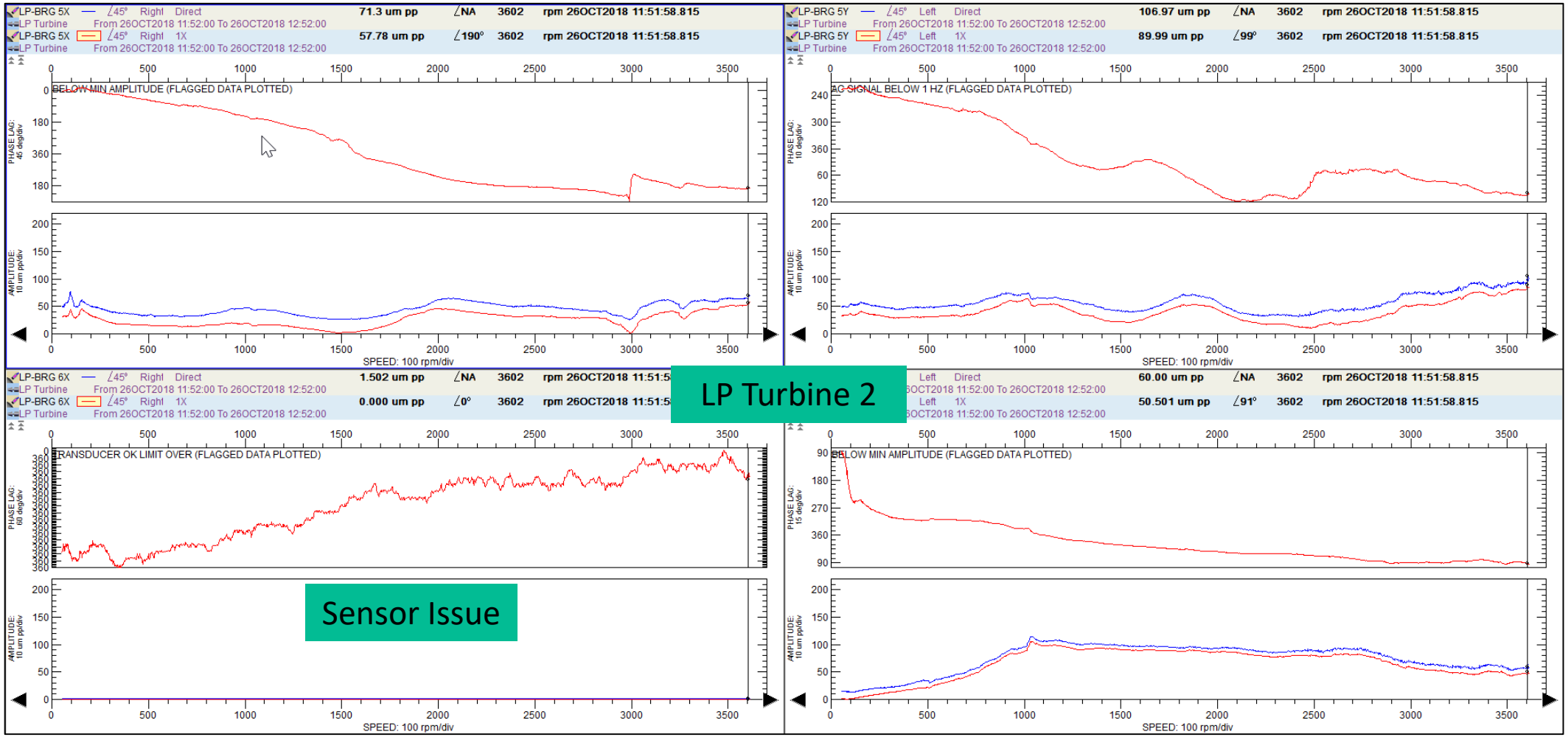
1X vibration/phase random step changes on BRG #6 (March, June)

Data Analysis- Steady State Polar Plots – Cont'd



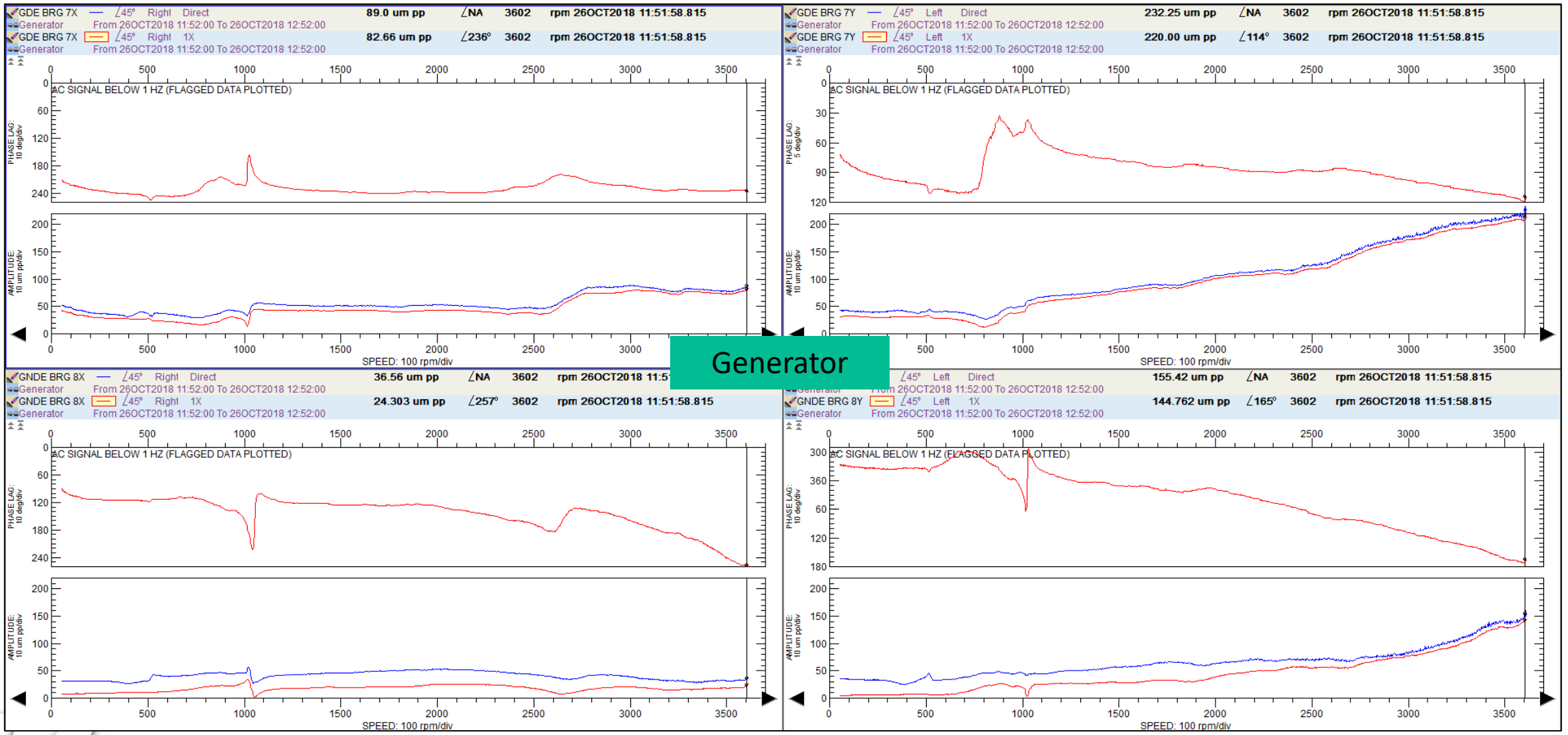
1X vibration/phase random step changes on BRG #7 (March, June)

Data Analysis- Shut Down Bode Plots 26th Oct 2018



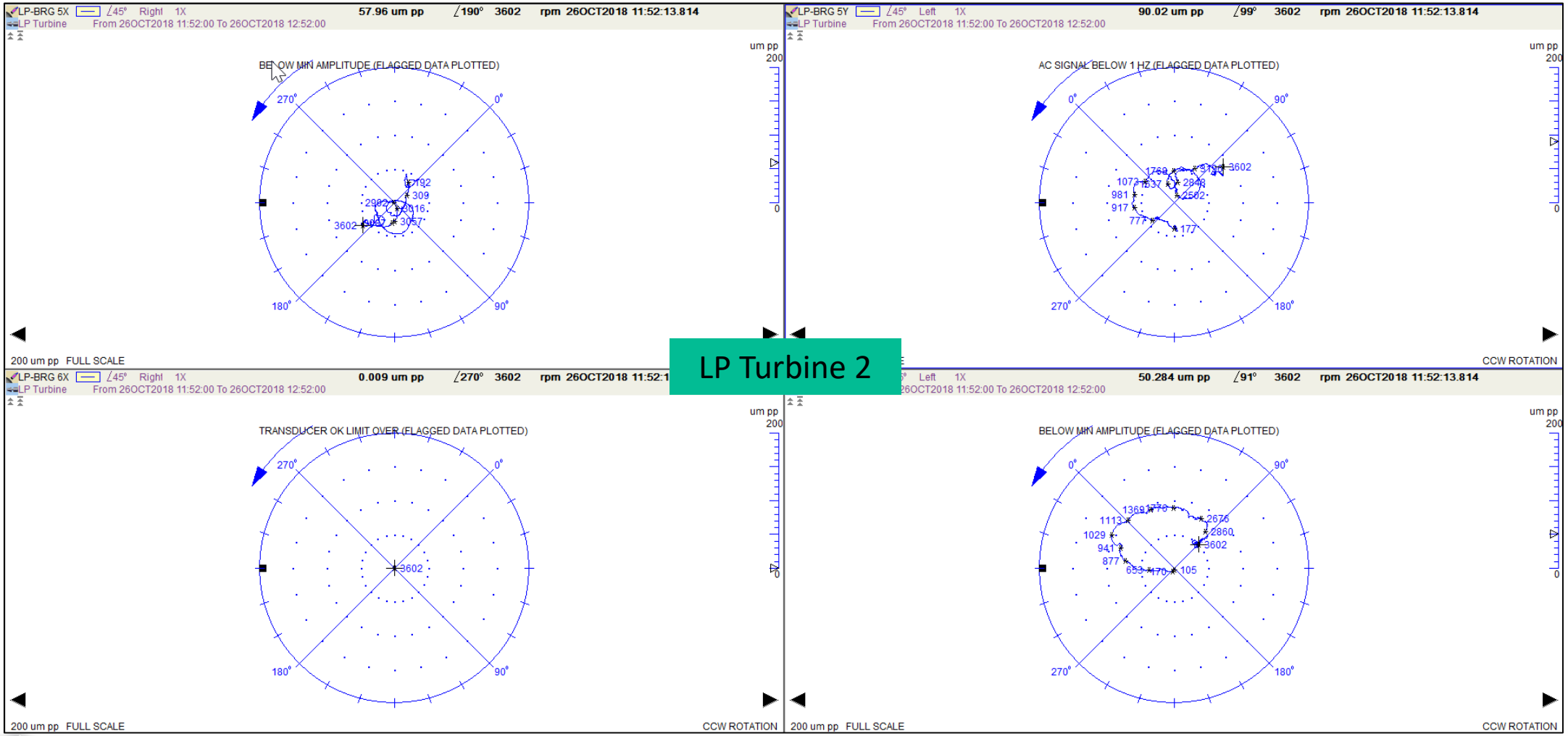
No evidence of elevated critical speed amplitude due to unbalance on the LP Rotor

Data Analysis- Shut Down Bode Plots 26th Oct 2018 – Cont'd



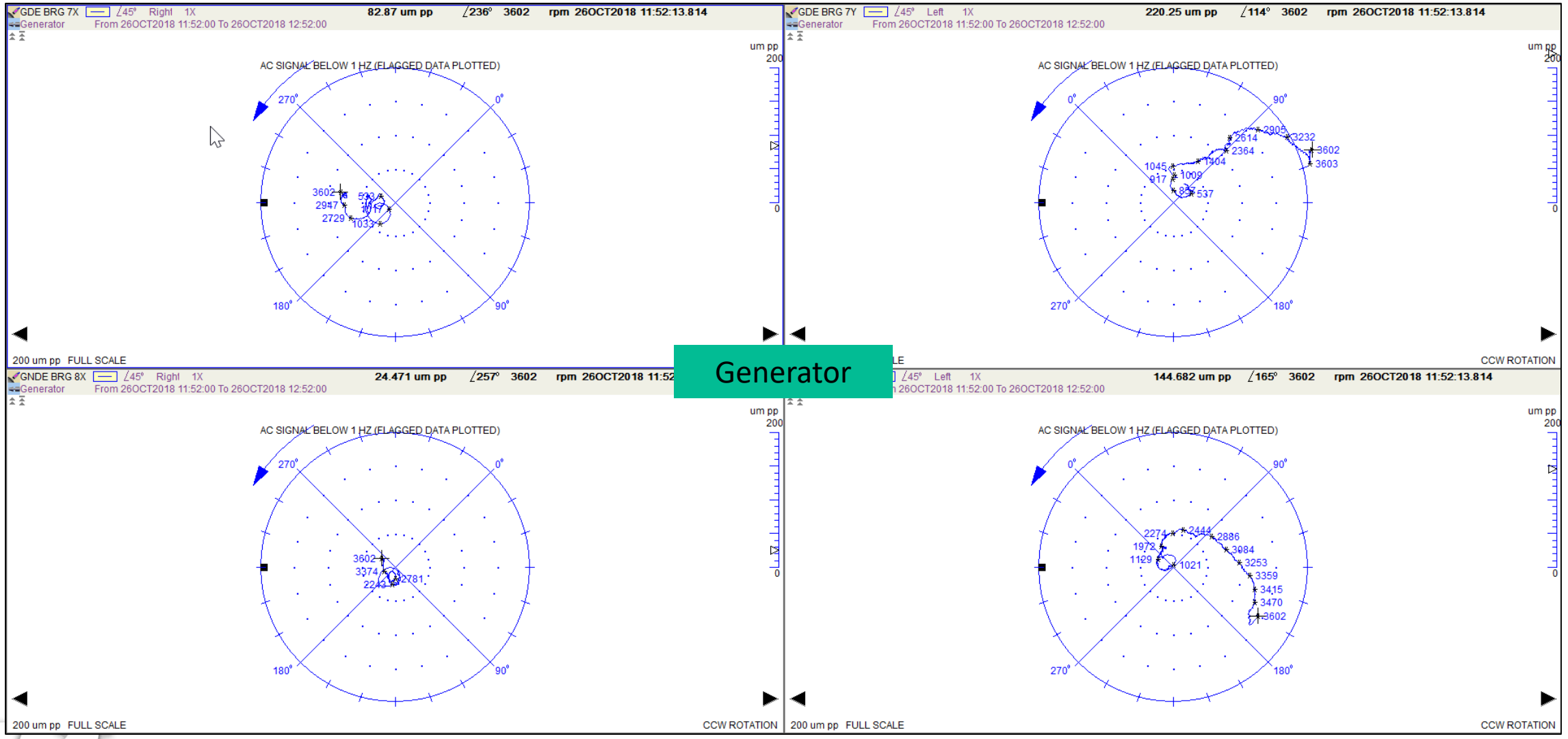
No evidence of unbalance, but symptom of rotor running close to the second critical speed

Data Analysis- Shut Down Polar Plots 26th Oct 2018



No evidence of elevated critical speed amplitude due to unbalance on the LP Rotor

Data Analysis- Shut Down Polar Plots 26th Oct 2018 – Cont'd

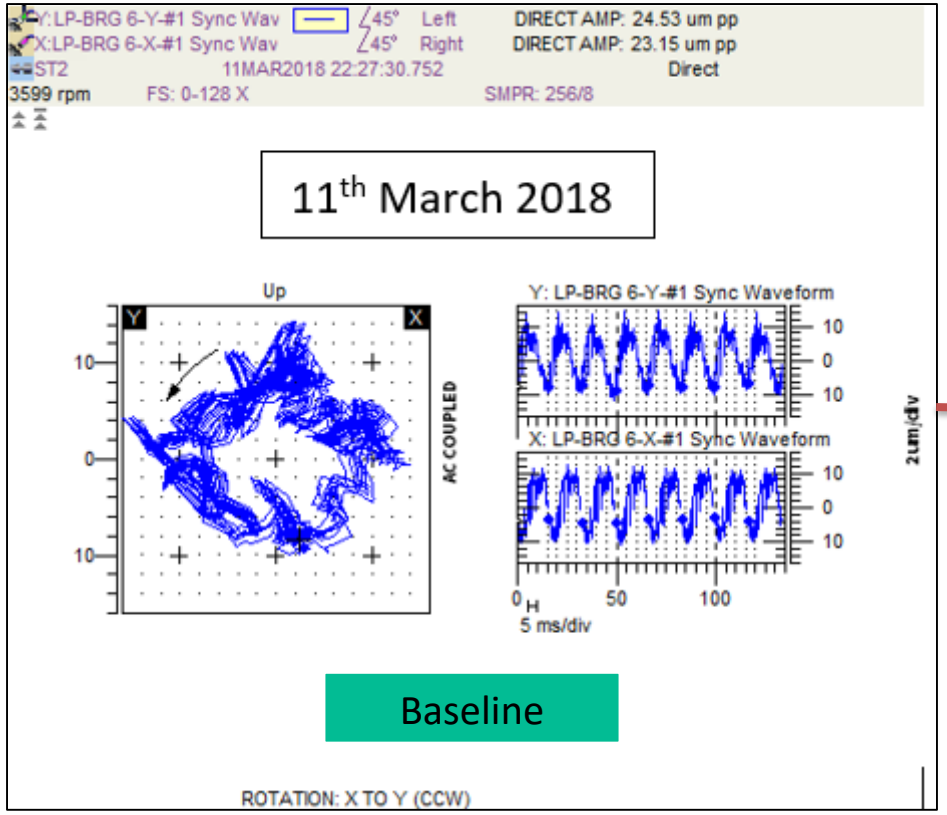


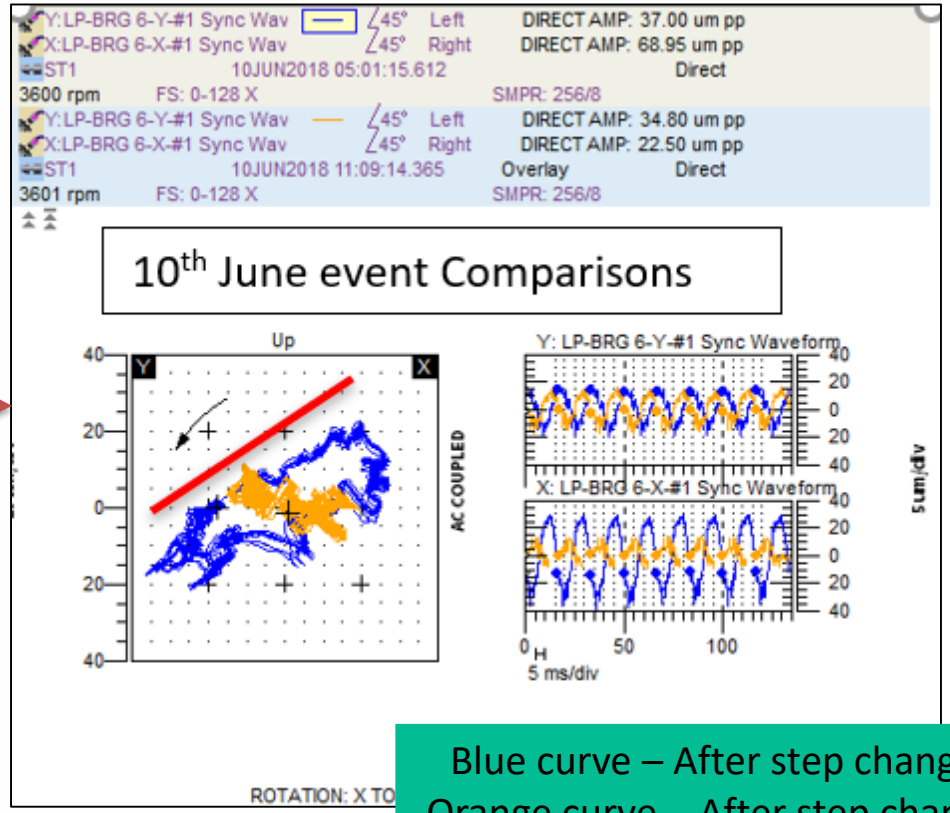
Generator

No evidence of unbalance, but symptom of rotor running close to the second critical speed

Data Analysis- Cont'd

Comparison of Direct Orbits at Bearing 6 for different periods step changes



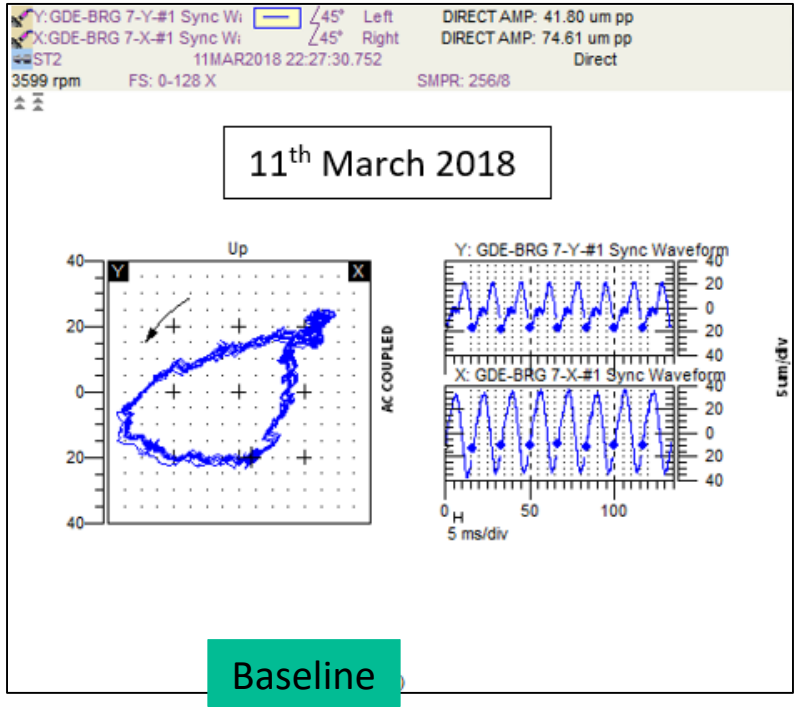


Blue curve – After step change in April'18
Orange curve – After step change in June'18

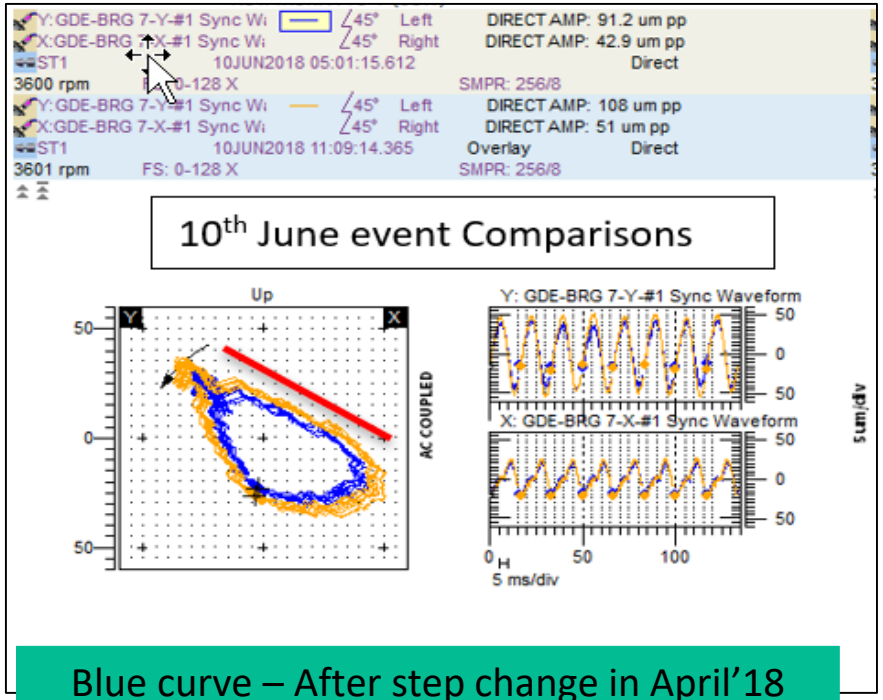
Orbit shape changed - highly elliptical on Brg#6

Data Analysis- Cont'd

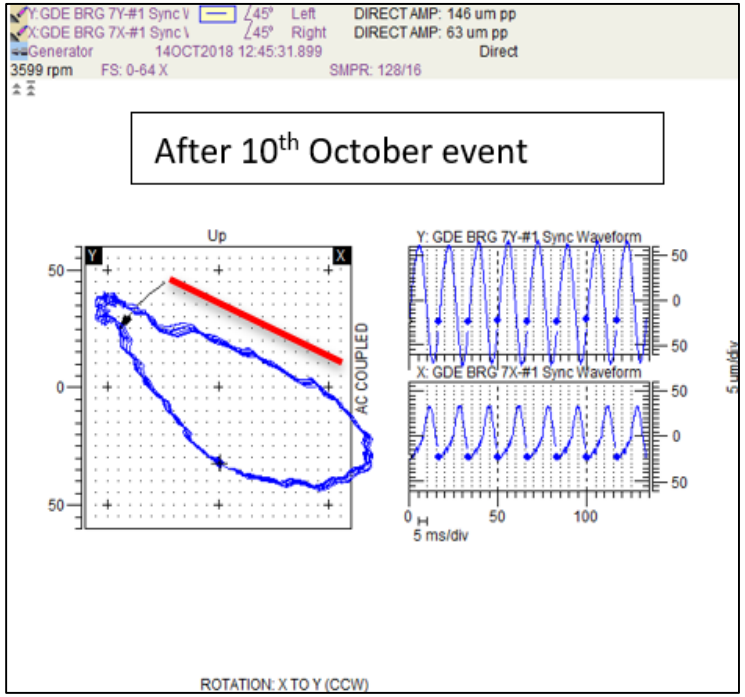
Comparison of Direct Orbits at Bearing#7 for different periods/ step changes



Baseline



Blue curve – After step change in April'18
Orange curve – After step change in June'18



Preload condition changing every step change on Brg#7, also vibration amplified on 10th October event with the same shape

Data Analysis – Cont'd

A change in 1X synchronous response can result from a change in Unbalance Force and/or a change in Dynamic Stiffness condition.

- Unbalance was not the first suspected cause because of:
  - ✓ The nonlinear response on each time the step changes happened.
  - ✓ Material loss from ST turbine should have shown elevated amplitudes at critical speeds.
  - ✓ The step changes caused more reaction on the generator vibration whereas the ST vibrations were still within the alarm limits.

Conclusion & Recommendations

Conclusions:

- Vibration step changes occurred on the machine train is suspected to be due to Stiffness changes.
- This stiffness change is highly affecting all vibration levels specially the LP2 bearings (5 & 6) and Generator bearings (7 & 8).
- Preload forces are changing every step change specially on both sides of the coupling between the LP2 and Generator.

Recommendations:

1. Inspect the coupling bolts for the design Torque tightness values.
2. Overall inspection for all Machine train supports structure including the foundation, baseplates, soleplates, bearing pedestals, grout condition, etc.
3. Verify that all support leg bolts, base to pedestal bolts, anchor bolts and pedestal hold down bolts are torqued properly.

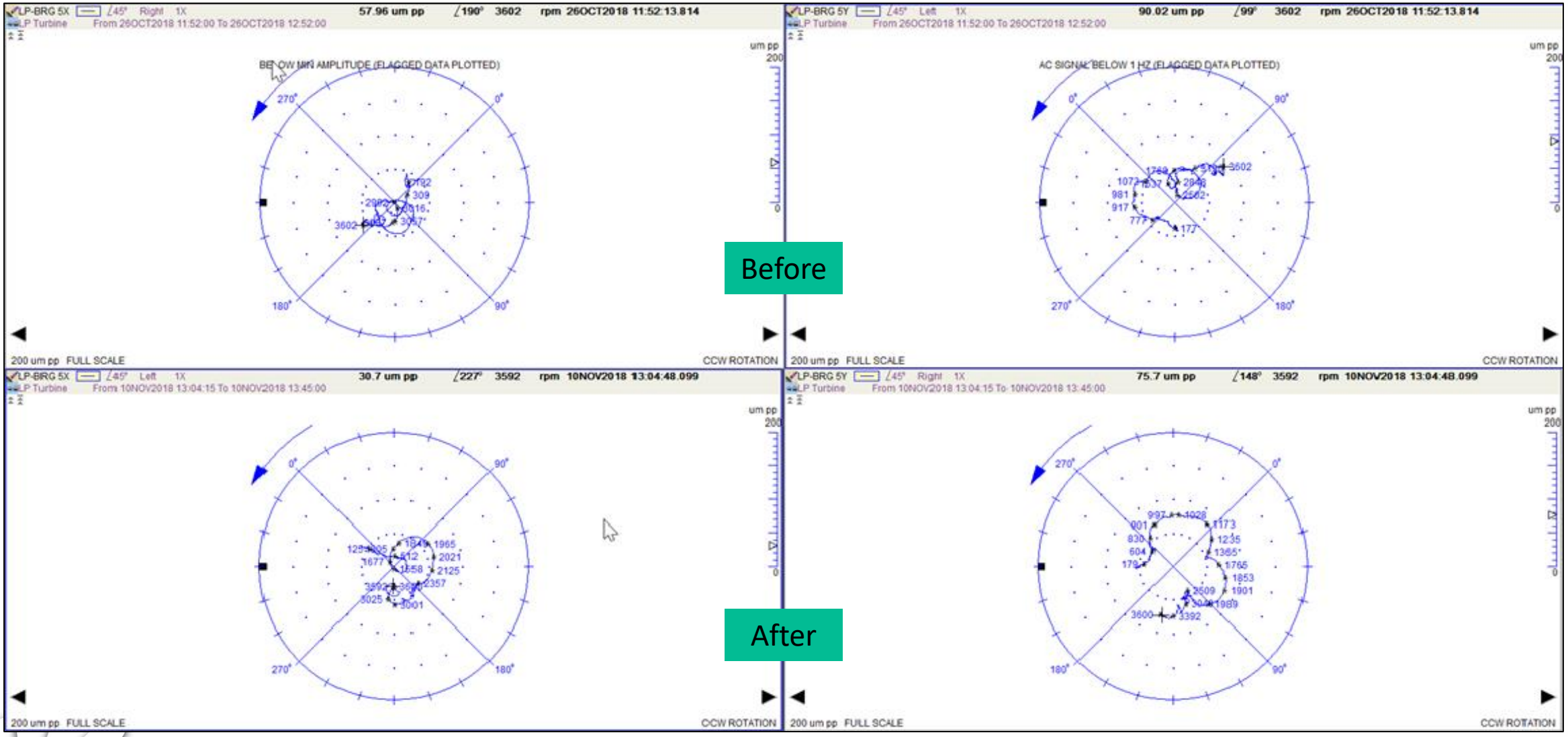
Action Taken

- Inspection of coupling bolts torque/tightness showed no change from the previous outage reading.
- Inspection of the foundation bolts on LP1 and LP2 revealed looseness on all the foundation bolts without tack welds. The bolts were tightened and welded with 0.1 mm clearance as per design specification.
- During the inspection, LP Turbines bearings pedestal bolts found loose without tack welds, so retightening applied according to the OEM recommendations.

Post Analysis

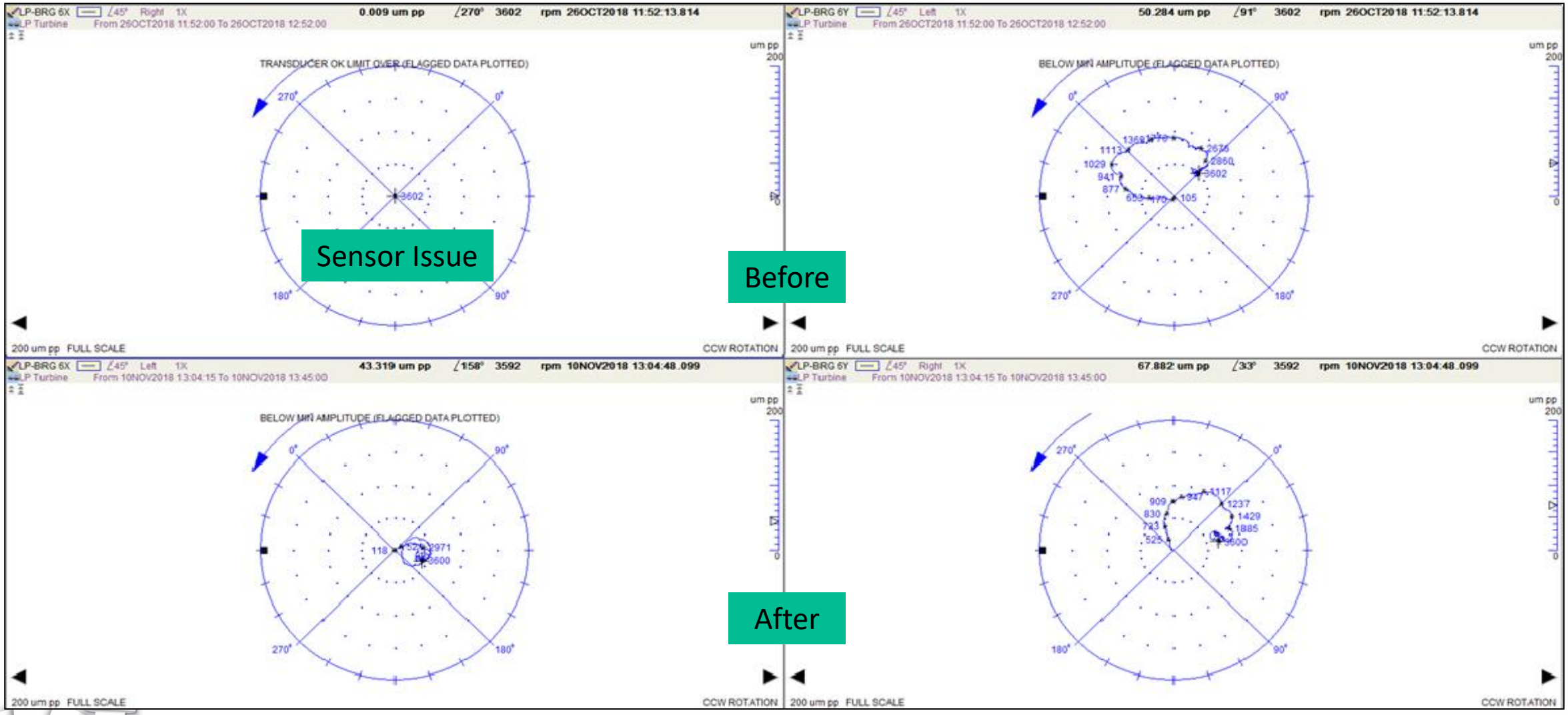
		Before Action Plan			After Action Plan		
		Direct	1X	Phase	Direct	1X	Phase
Brg 1	X	56	48	106	52.8	42	97
	Y	61	54	24	57.3	44	31
Brg 2	X	58	43	101	65	46	92
	Y	56	44	31	56	45	5
Brg 3	X	41	26	186	28	12	196
	Y	58	43	68	38	23	99
Brg 4	X	30	14	227	27	11	215
	Y	43	26	122	36	20	111
Brg 5	X	73	59	189	42	27	221
	Y	107	91	99	77.4	67	144
Brg 6	X	Bad Signal (Sensor Issue)			51	42	163
	Y	60	51	91	77	68	34
Brg 7	X	88	83	236	46	38	195
	Y	231	220	114	84	78	94
Brg 8	X	37	24	257	26	11	240
	Y	155	145	165	59	43	173

Post Analysis- Shut Down Polar Plots



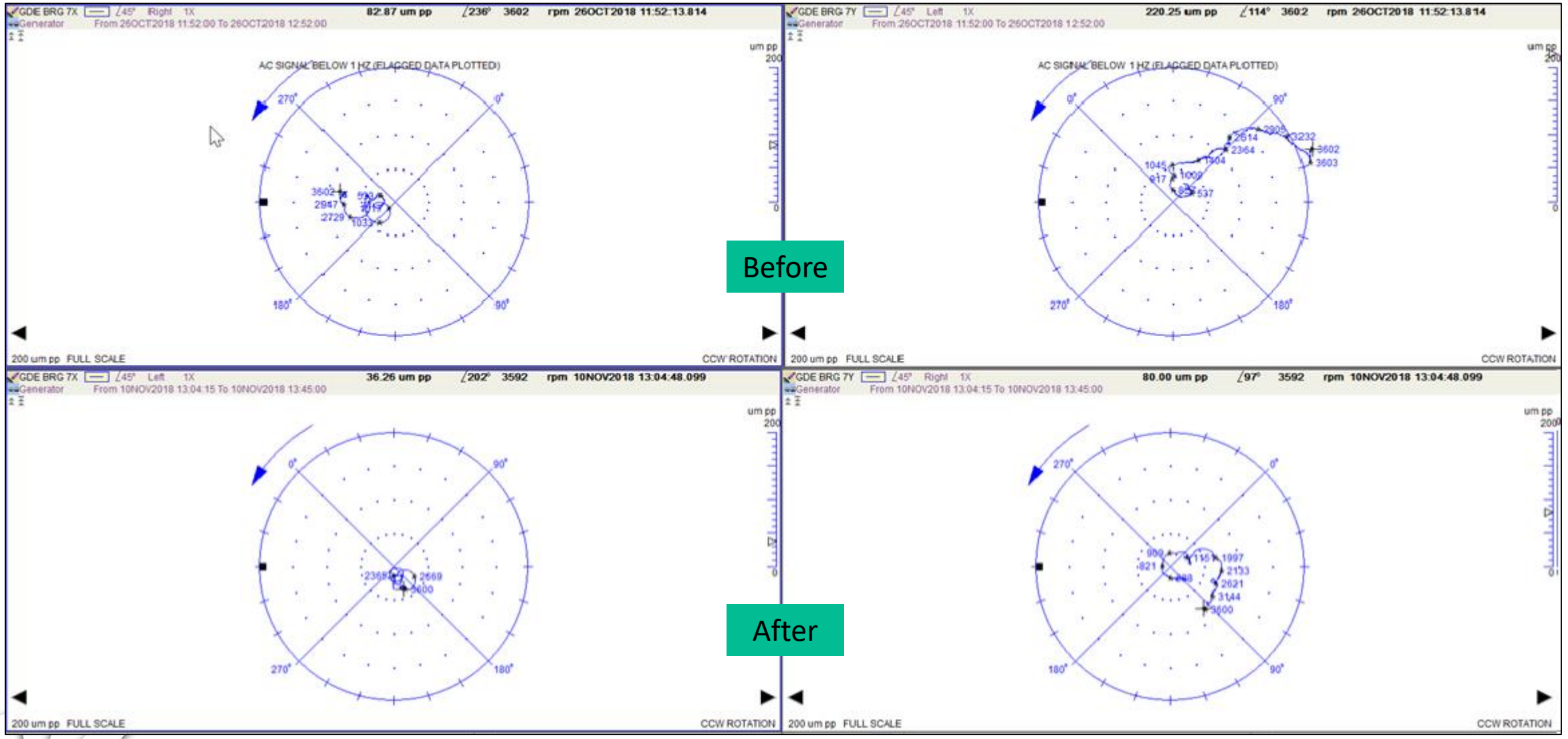
Bearing#5 Polar Plots During Shutdown Mode (Before and After Maintenance)

Post Analysis- Shut Down Polar Plots – Cont'd



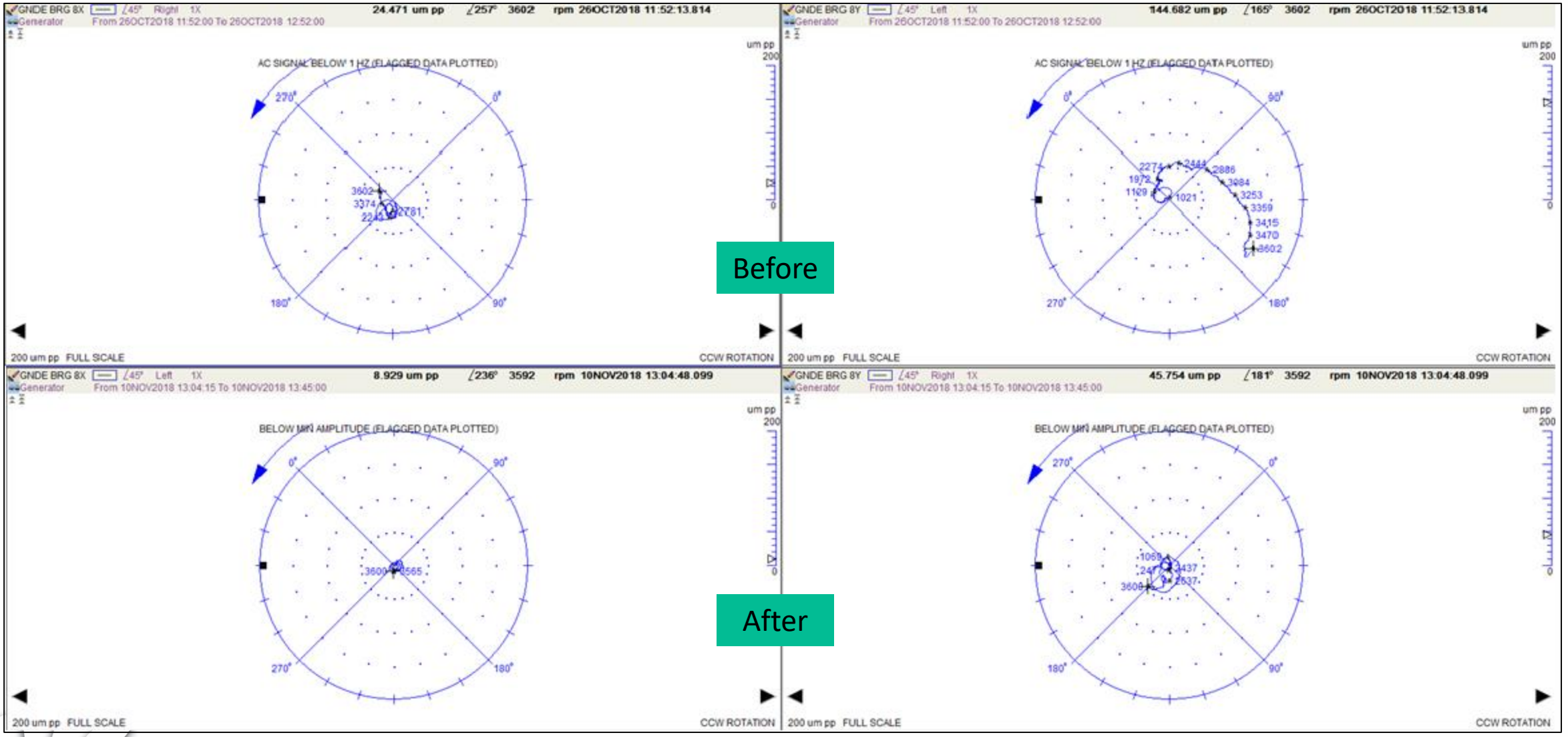
Bearing#6 Polar Plots during Shutdown Mode (Before and After Maintenance)

Post Analysis- Shut Down Polar Plots – Cont'd



Bearing#7 Polar Plots during Shutdown (Before and After Maintenance)

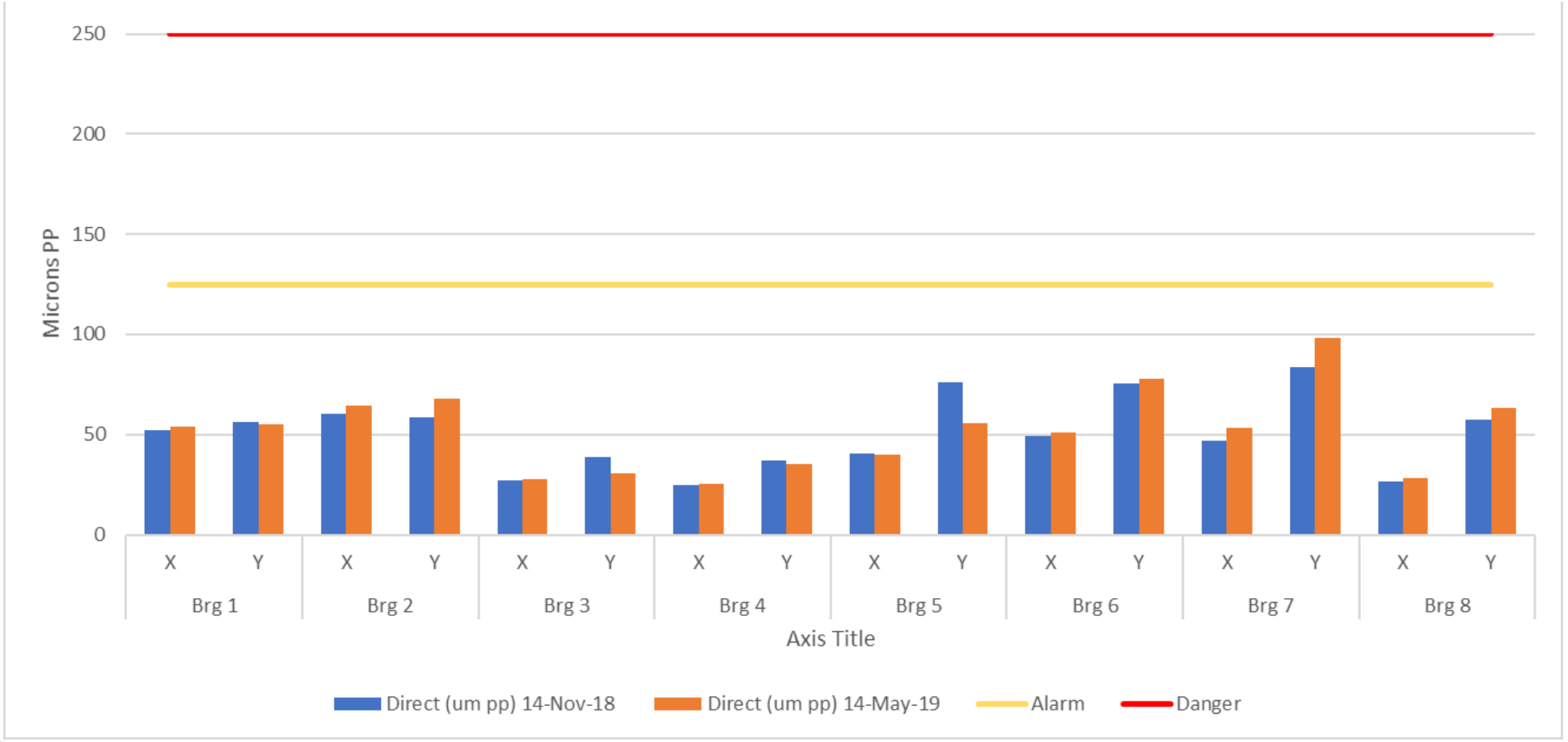
Post Analysis- Shut Down Polar Plots – Cont'd



Bearing#8 Polar Plots during Shutdown (Before and After Maintenance)

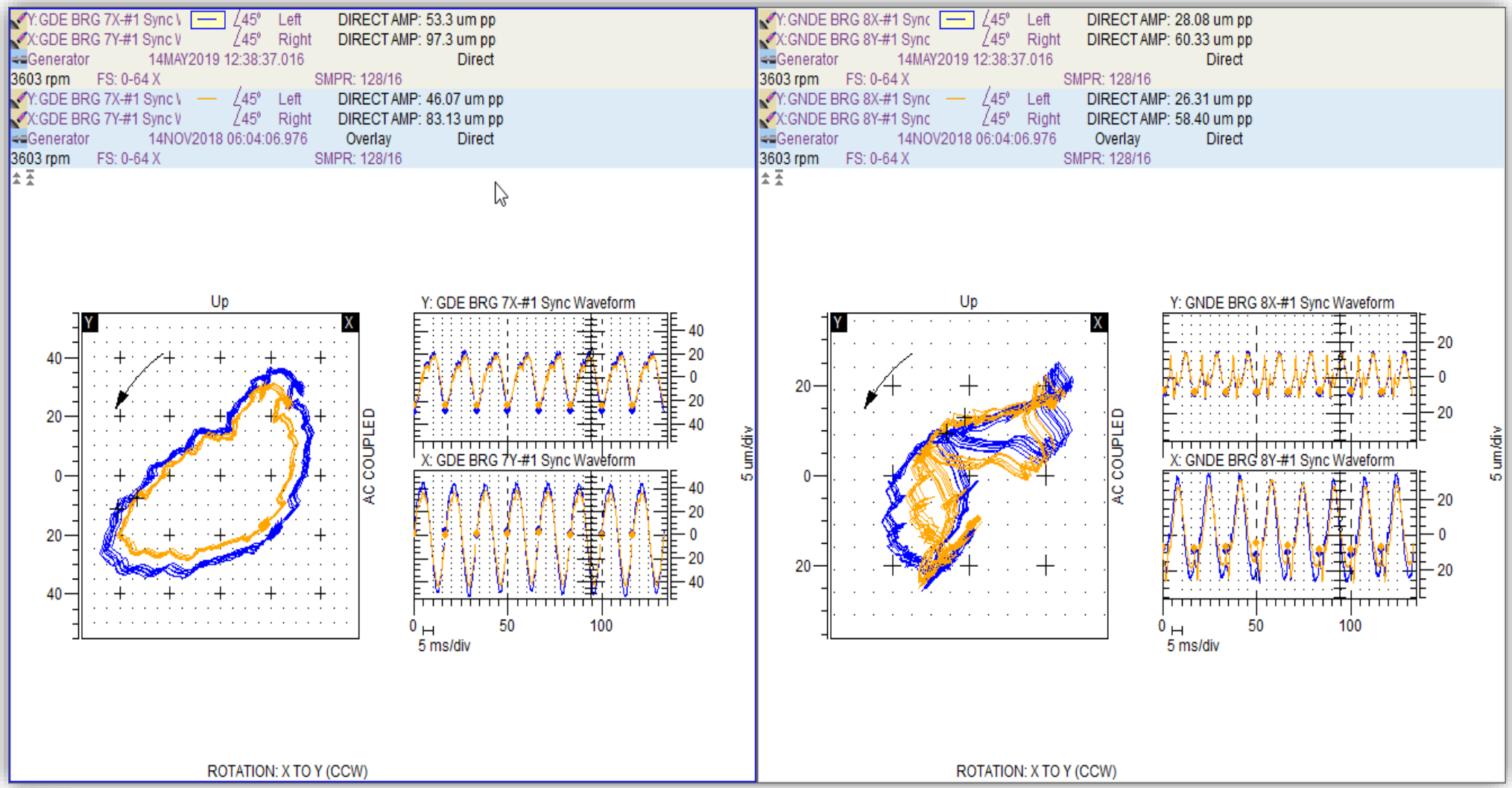
Post Analysis – 6 months later

Later on, after 6 months of continuous operation, vibration data recorded showed comparable readings (no change).



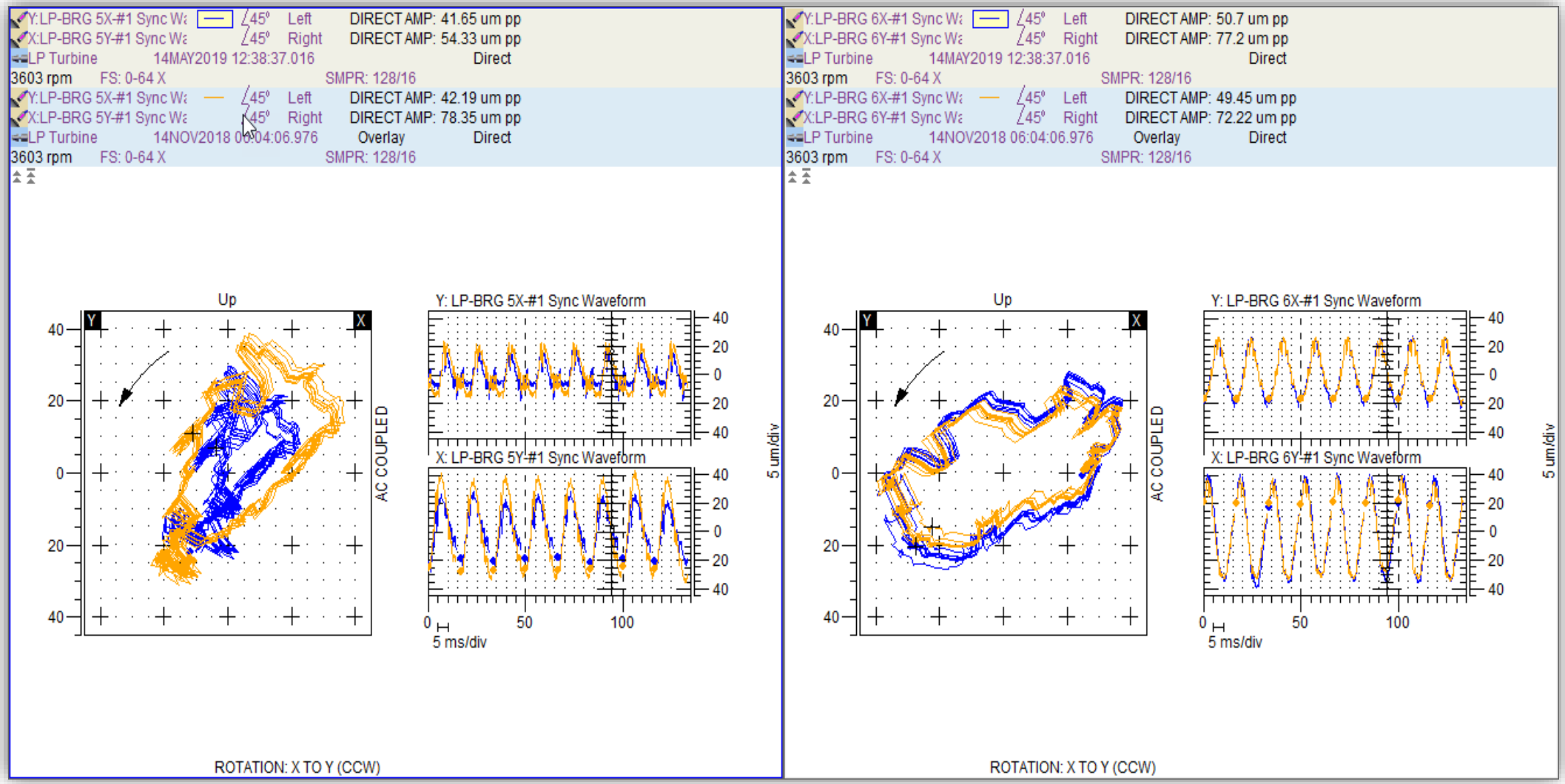
Direct Vibration Levels Comparison at Base Load Condition

Post Analysis – 6 months later – Cont'd



Generator Orbit Plot Comparison between November 2018 (Orange) & May 2019 (Blue)

Post Analysis – 6 months later – Cont'd



LPB Turbine Orbit Plot Comparison between November 2018 (Orange) & May 2019 (Blue)

Questions ??