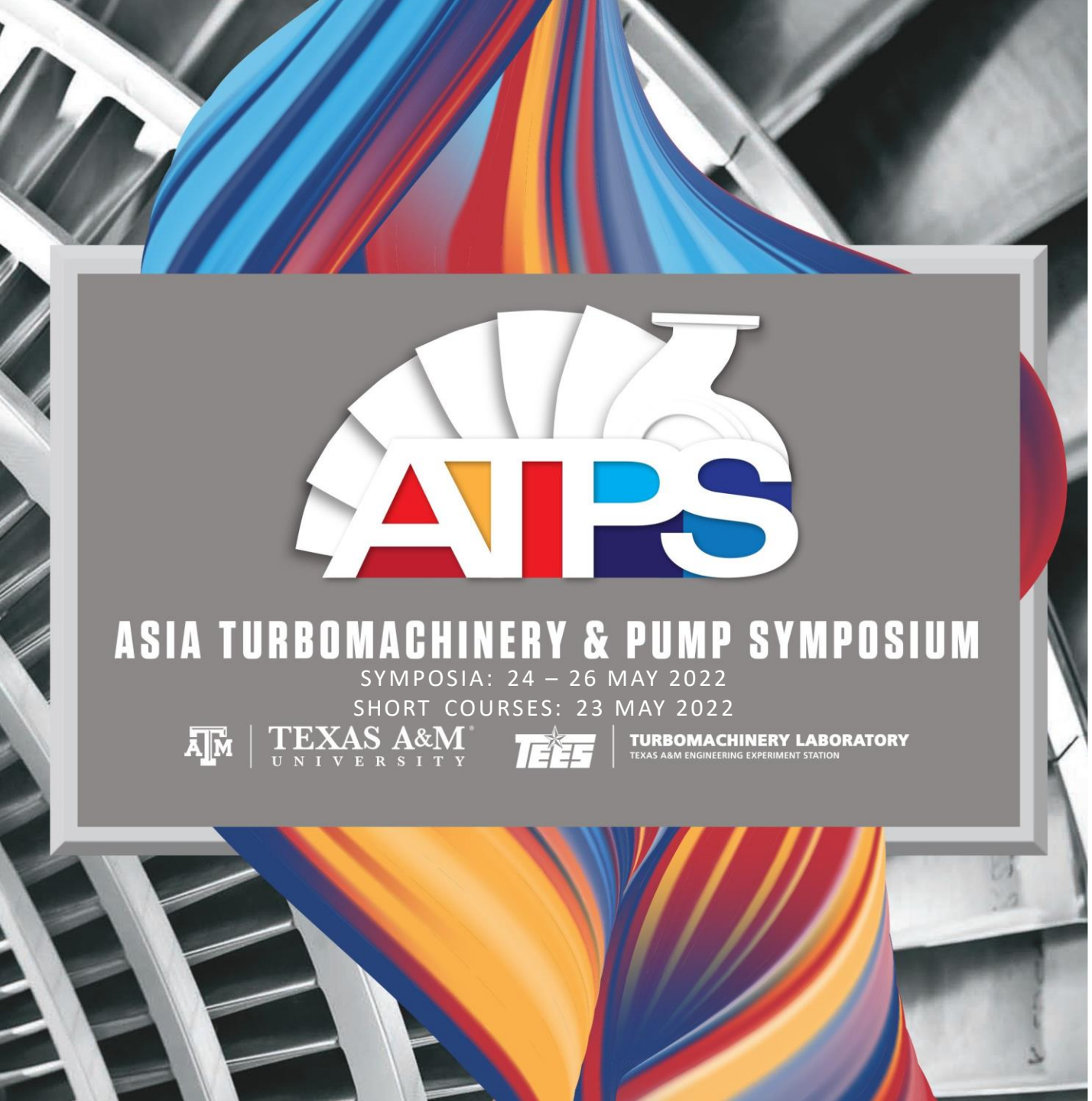

Resolution of Non-Repeatable Synchronous Rotor Response of a Power Generator Due to Sand Ingress

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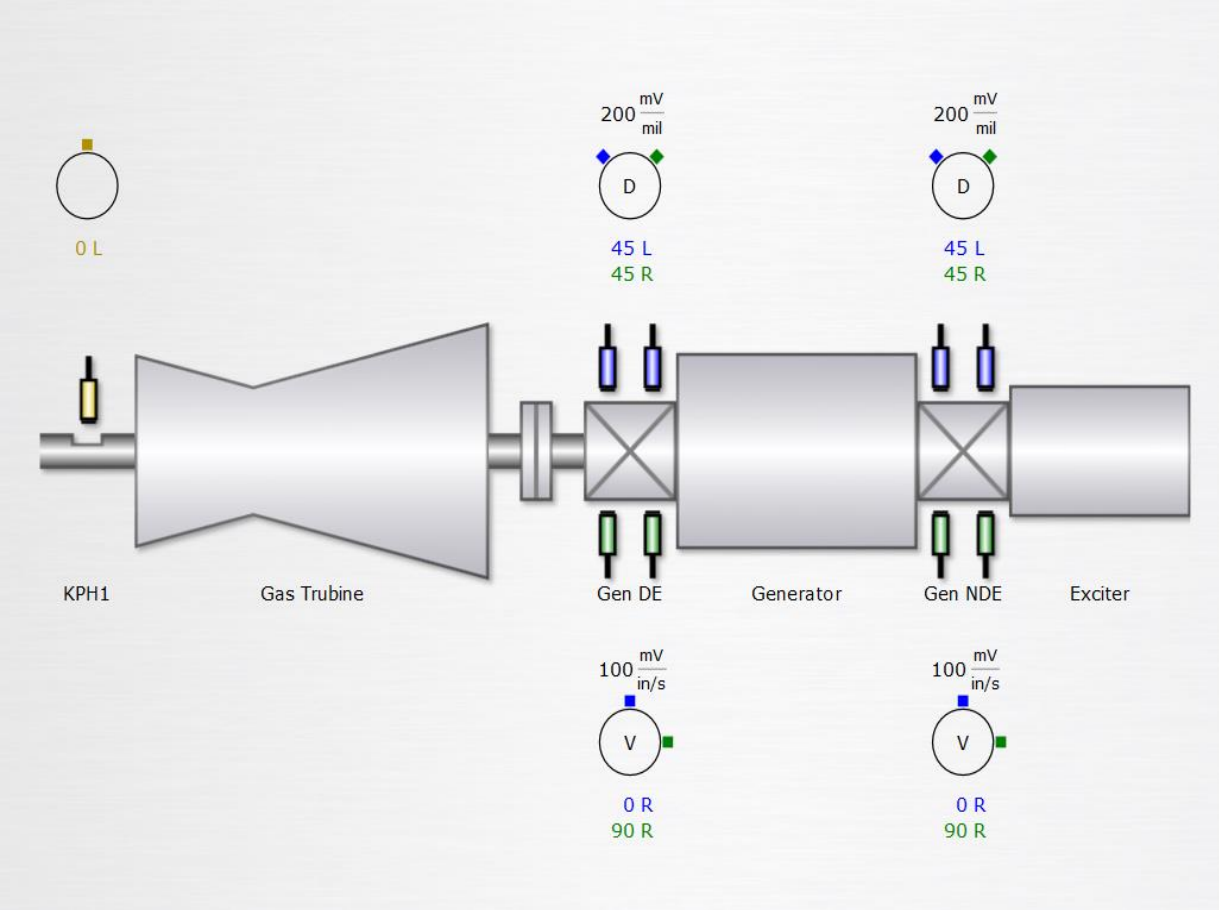
ASIA TURBOMACHINERY & PUMP SYMPOSIUM

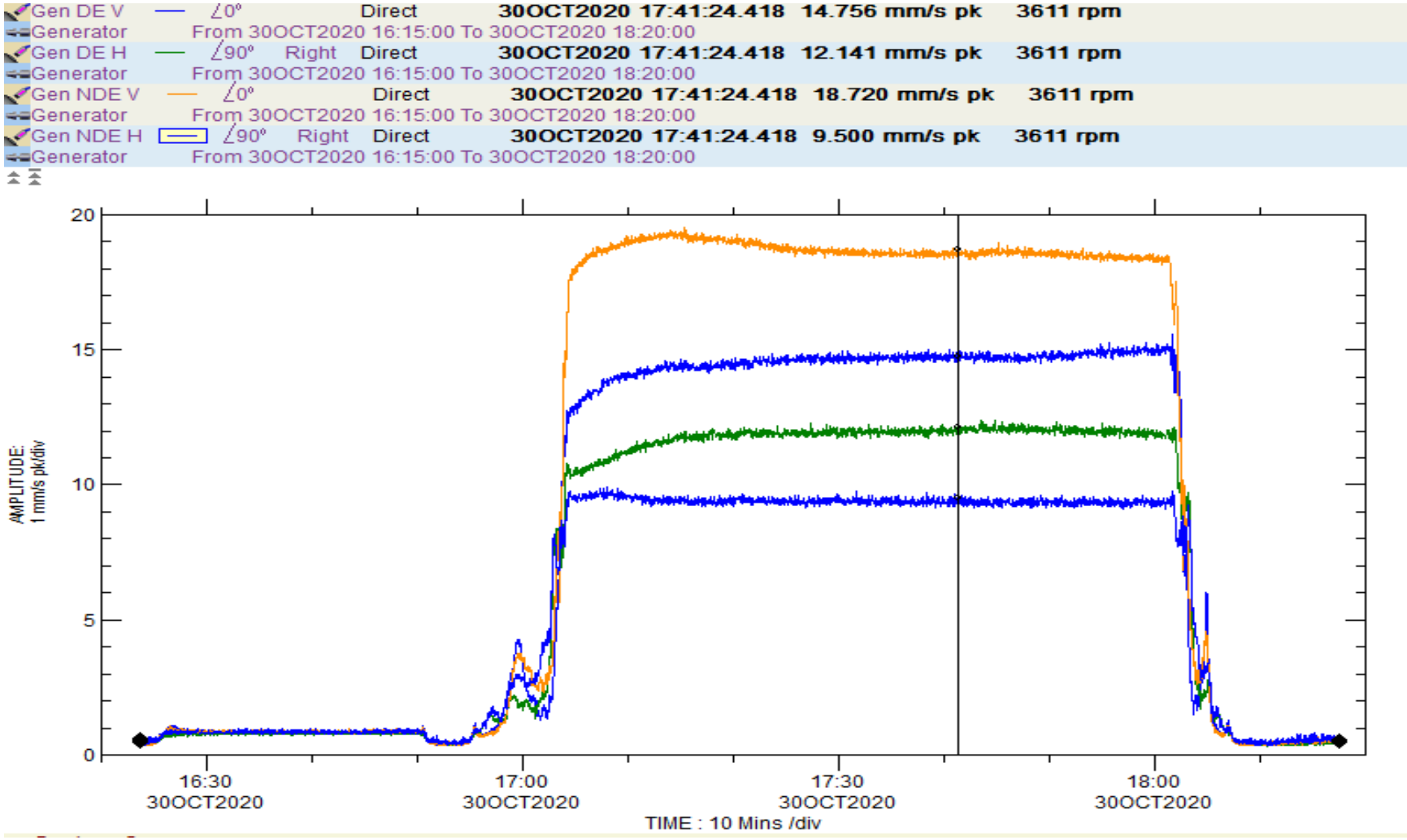
Machine Train Diagram



This is a machine train consists of gas turbine driving an air-cooled synchronous generator (3600 rpm and 80 MW rated power) Gas turbine is supported on three journal bearings, and generator is supported on two journal bearings. Each bearings is monitored by two shaft relative vibration probes installed 45 degrees left and 45 degrees right. Also, vertical seismic probe installed on each bearing. Two temporary velometers installed on each generator bearing in vertical and horizontal directions.

Problem Statement

Generator bearing showed increasing vibration levels after each shutdown/startup event starting October 2020 as reported by customer.

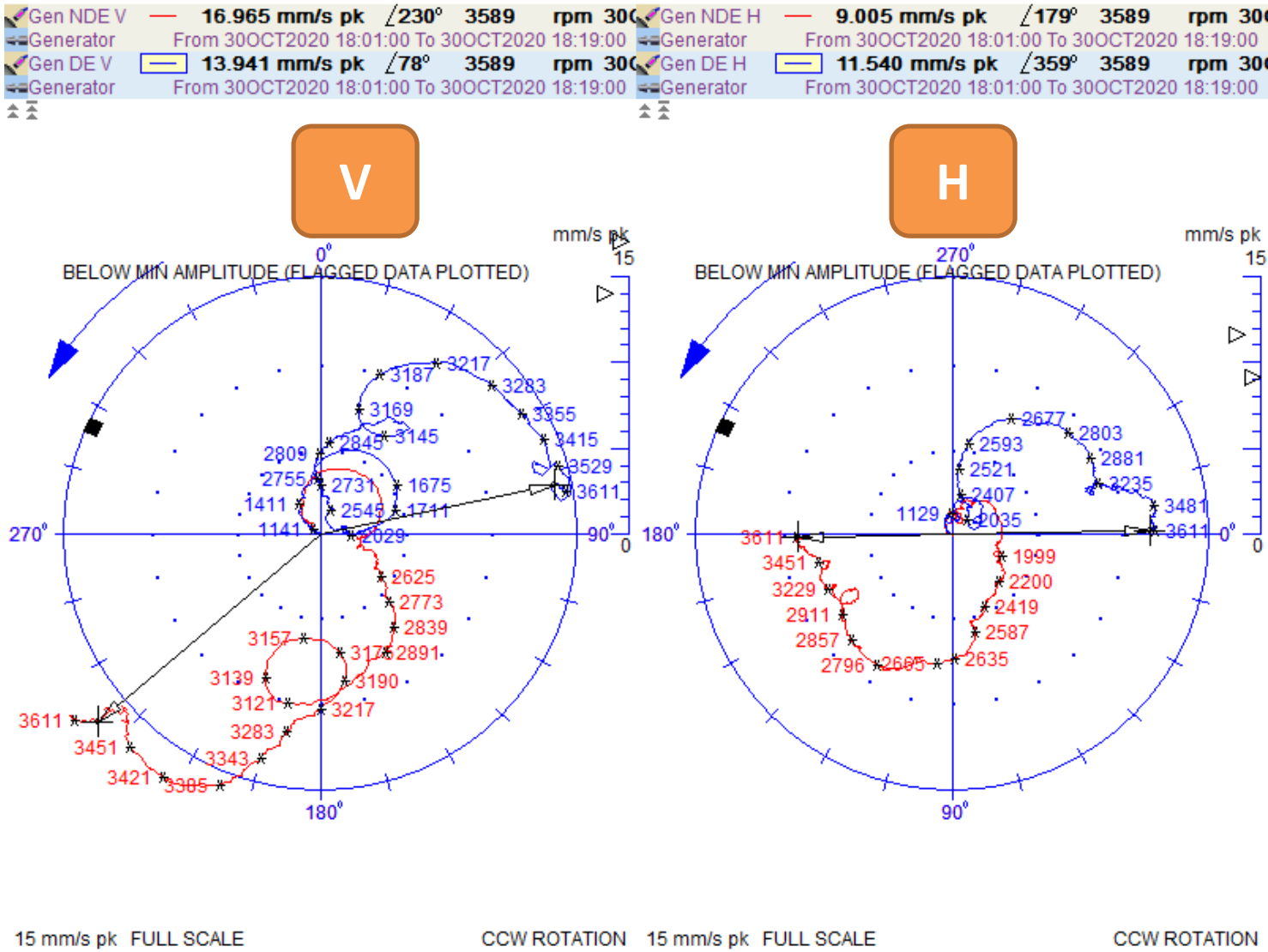


Generator bearings During Test Run after Mobilization to site showed high casing vibration levels close to alarm setpoints.

Problem Statement- Cont'd

Transient data during shutdown showed clear symptom of couple-unbalance on the generator rotor. Onsite balancing carried out to reduce the vibration levels.

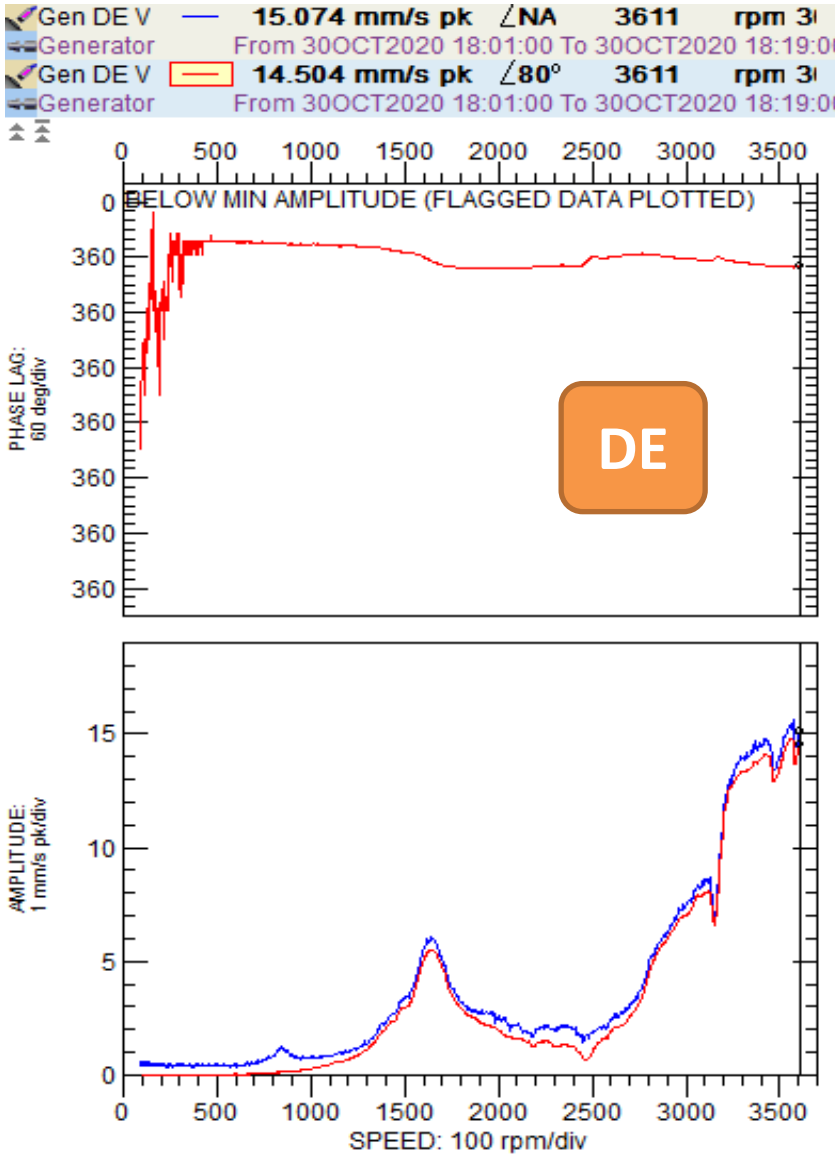
Couple unbalance: vibration vectors at full speed compared on both bearings in same direction are 180 degrees out of phase.

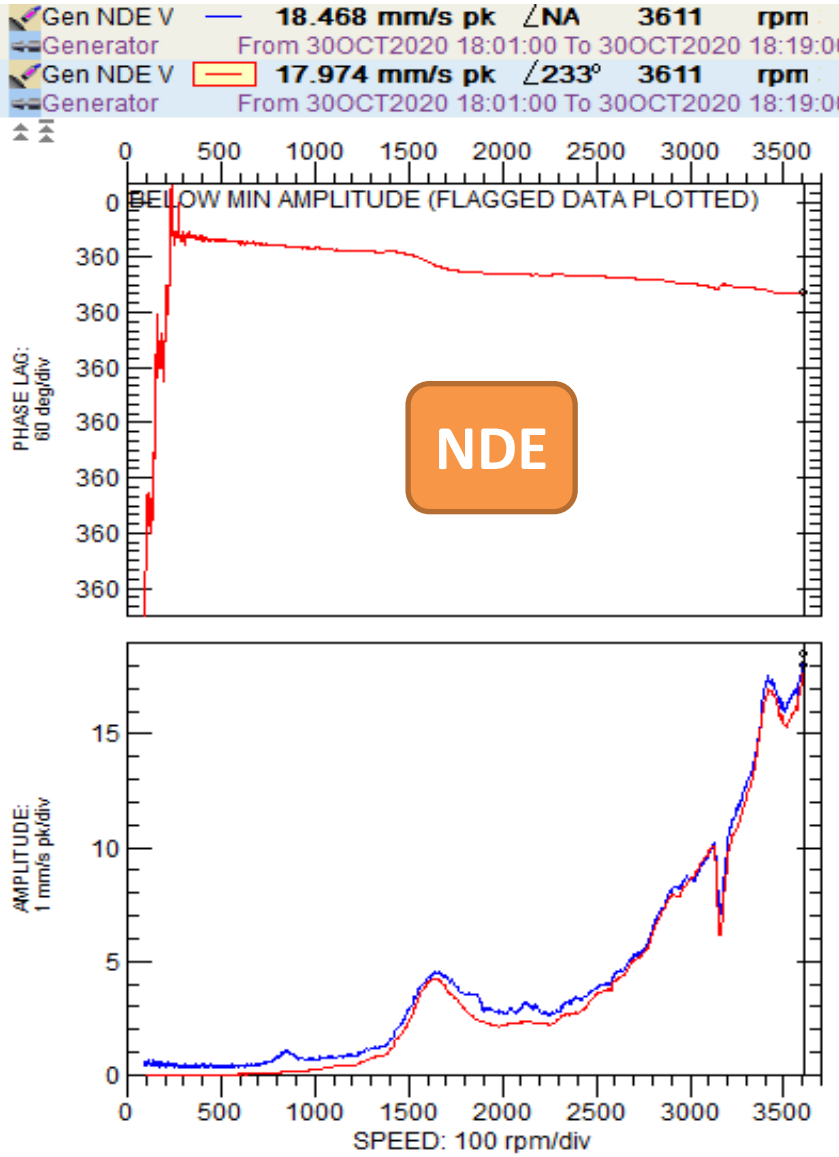


Generator Bearings Polar Plots as Found (NDE Red & DE Blue)

Problem Statement- Cont'd

Generator Bearings Direct and 1X Bode plots in the Vertical Direction Seismic vibration during shutdown as found showed unbalance behavior (increasing 1X vibration levels with speed increase in a parabolic shape).





ASIA TURBOMACHINERY & PUMP SYMPOSIUM

Initial Action Plan– Balancing Calculations

Trial weight was calculated based on an influence vector of a sister machine with same model during previous job as following:

WRT vertical probe on the DE bearing the old Influence vector

H = 1.33 in/s pk / Kg @ 30 degrees

O = 0.57 in/s pk @ 80 degrees

So, the trial weight = -O/H

= 0.57/1.33 = 426grams & 260-30 = 230 degrees

The couple weights for TR1:

426 grams @ 230 degrees WRT vertical probe on DE bearing.

426 grams @ 50 degrees WRT vertical probe on NDE bearing.

Note: The Influence Vector:

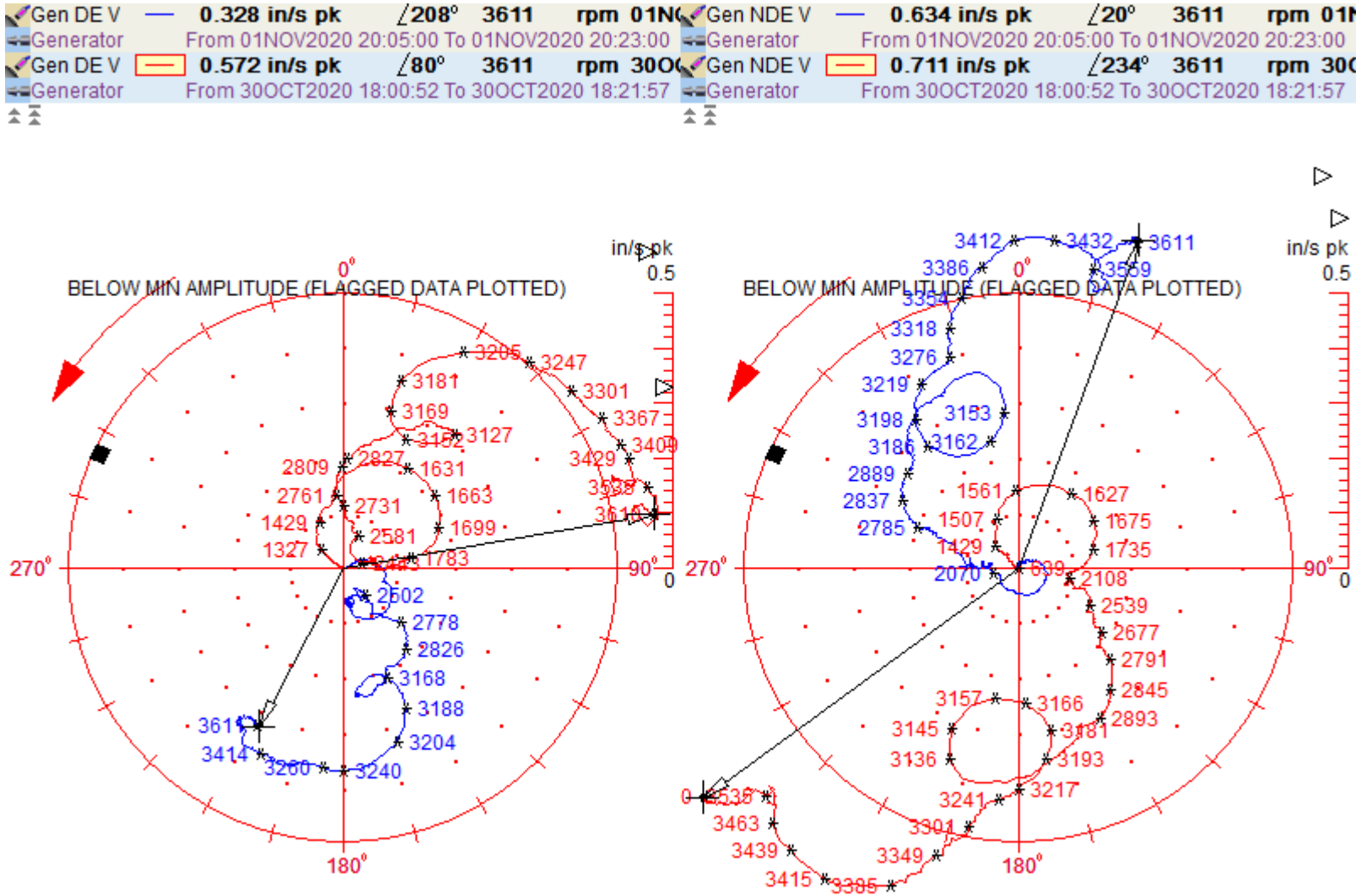
1- Independent of calibration weight.

2- Can be used in future balancing.

3- Should not change for the same operating conditions.

Initial Action Plan– Trial Run Response

Adding the previous weight showed unexpected response. the vibration vectors shifted to new location (red is the new 1X vector) compared to original vibration and a new influence vector was calculated based on this response



Blue is original Run Red is Trial Run

Initial Action Plan– Correction Weight.

Correction weight was calculated based on the trial weight response

Calculations WRT Drive End Vertical at FSNL:

Original Vector O = 0.57 in/s pk @ 80 degrees

Trial weight added = 426 grams @ 230 degrees

Effect of (Original + Trial weight) = 0.33 in/s pk @ 208 degrees

Effect of Trial Weight (T) = (O+T) – O = 0.82 in/s pk @ 241 degrees

New H vector of Trial Weight =T/Wt = 1.92 in/s per Kg @ 11 degrees

Correction weight = -O/H = 0.57/1.92 @ (260 – 11)

296 grams @ 249 degrees at DE WRT Vertical

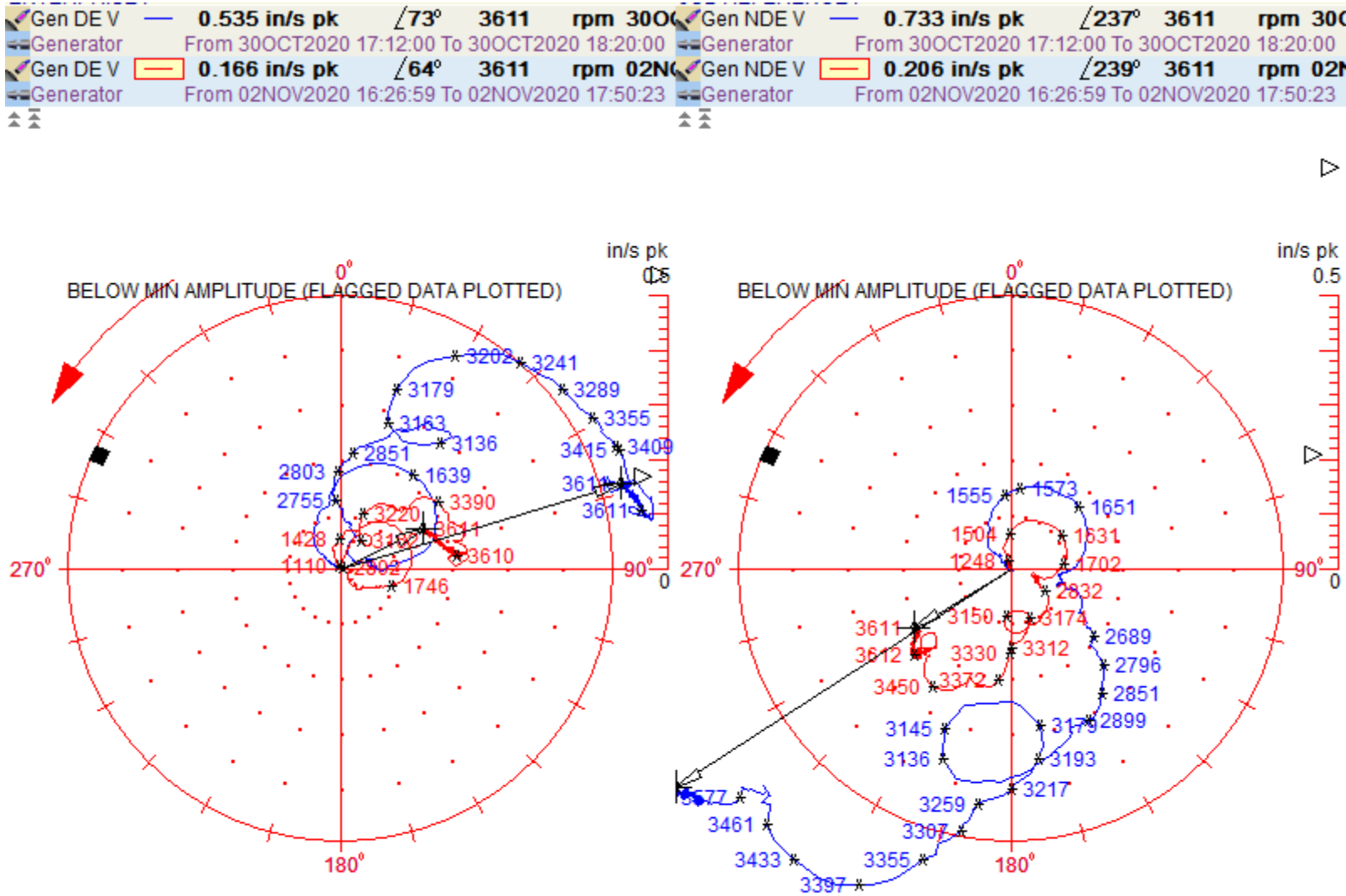
296 grams @ 69 degrees at NDE WRT Vertical

and removal of trial weight

Initial Action Plan– Correction Run Response

Perfect Response as the vibration decreased in the same direction.

Now we need to calculate the Influence coefficient based on original run and correction run and the new correction weight.



Initial Action Plan– Correction Run Influence.

Calculations WRT Drive End Vertical at FSNL:

Original Vector O = 0.57 in/s pk @ 80 degrees

Correction weight added = 296 grams @ 249 degrees

Effect of (Original + Cor. weight) = 0.212 in/s pk @ 82 degrees

Effect of Trial Weight (T) = (O+T) – O = 0.36 in/s pk @ 259 degrees

New H vector = T/Wt = 1.216 in/s per Kg @ 10 degrees

New Correction weight = -O/H = 0.57/1.216 @ (260 – 10)

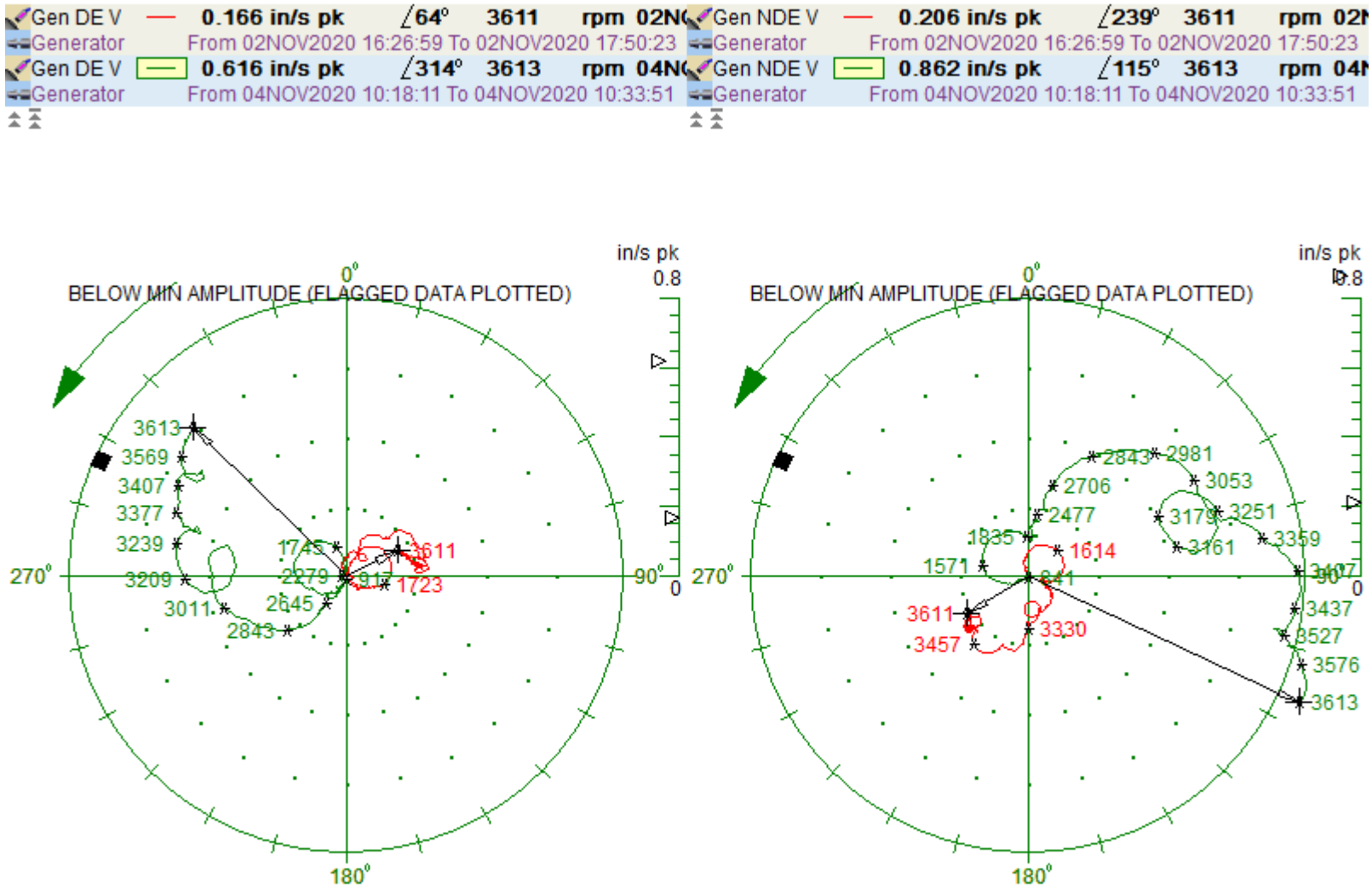
468 grams @ 250 degrees at DE WRT Vertical

468 grams @ 70 degrees at NDE WRT Vertical

And removal of previous correction weight

Initial Action Plan– Repeatability Test

it was decided to test the system repeatability by carrying out another startup without changing weights, however the generator bearing showed totally different synchronous response



Red is the Correction Run Green is the 2nd Run with same weight

0.8 in/s pk FULL SCALE CCW ROTATION 0.8 in/s pk FULL SCALE CCW ROTATION

Initial Action Plan– 2nd Run Same Weight Influence.

Calculations WRT Drive End Vertical at FSNL:

Original Vector O = 0.57 in/s pk @ 80 degrees

Correction weight added = 296 grams @ 249 degrees

Effect of (Original + Cor. weight) = 0.609 in/s pk @ 314 degrees

Effect of Trial Weight (T) = (O+T) – O = 1.05 in/s pk @ 288 degrees

New H vector of 2nd run with same weight= T/Wt = 3.55 in/s per Kg @ 39 degrees

At this step it was confirmed that the rotor system is non-repeatable and non-linear, and another factor is changing the generator rotor synchronous response each run.

Observations– All Influence Vectors Together.

Comparing the calculated influence vector of the 4 conditions, showed different values.

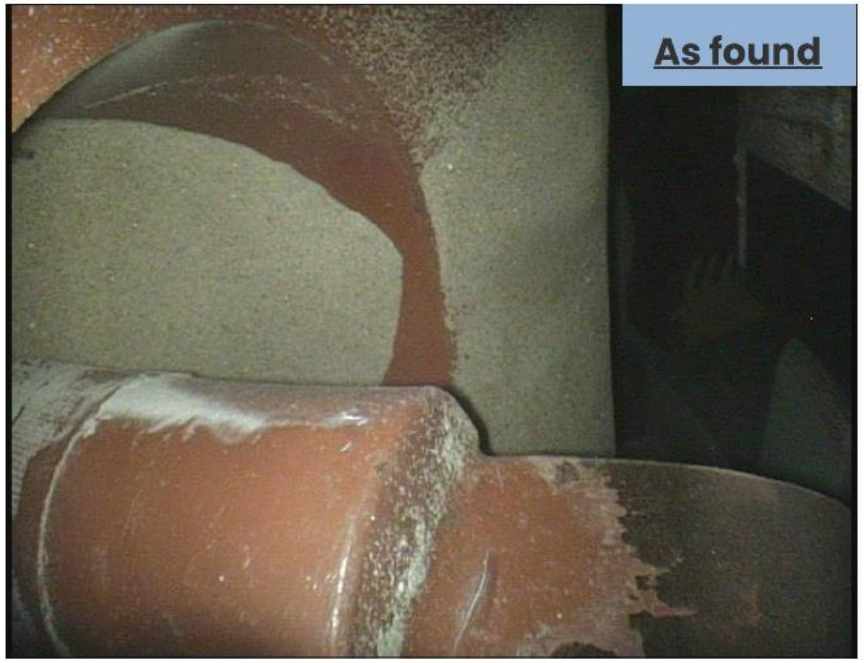
	Old Influence Vector from Previous Job on Similar Machine Design	Trial Run	Correction Run	2nd Run Without Changing Weight
Weight Condition	N/A	426 grams @ 230 Degrees AR WRT DE Vertical	296 grams @ 249 Degrees AR WRT DE Vertical	296 grams @ 249 Degrees AR WRT DE Vertical
Influence Vector (H)	**1.33 in/s pk / Kg @ 30 degrees**	**1.92 in/s pk / Kg @ 11 degrees**	**1.216 in/s pk / Kg @ 10 degrees**	**3.55 in/s per Kg @ 39 degrees**

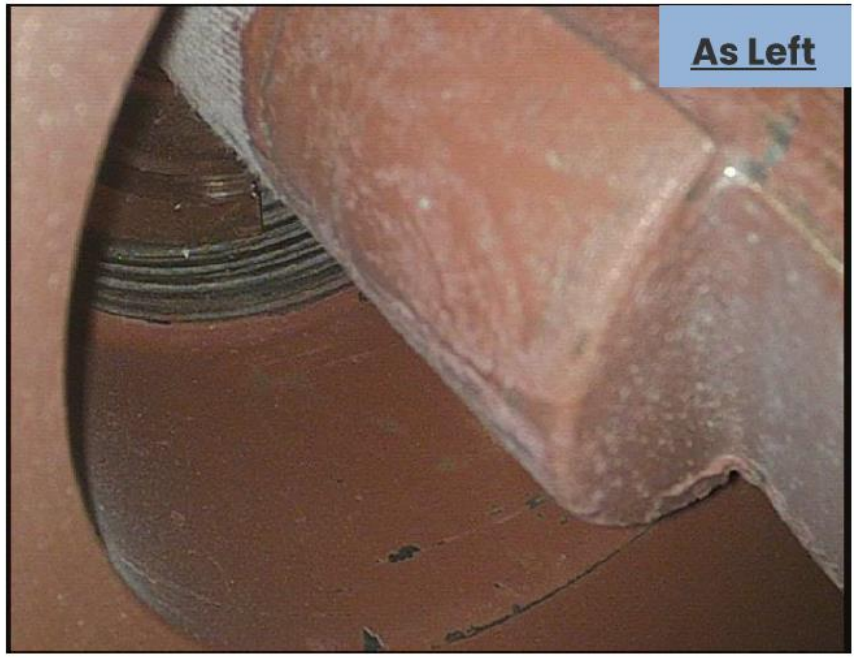
Action Plan– Inspection

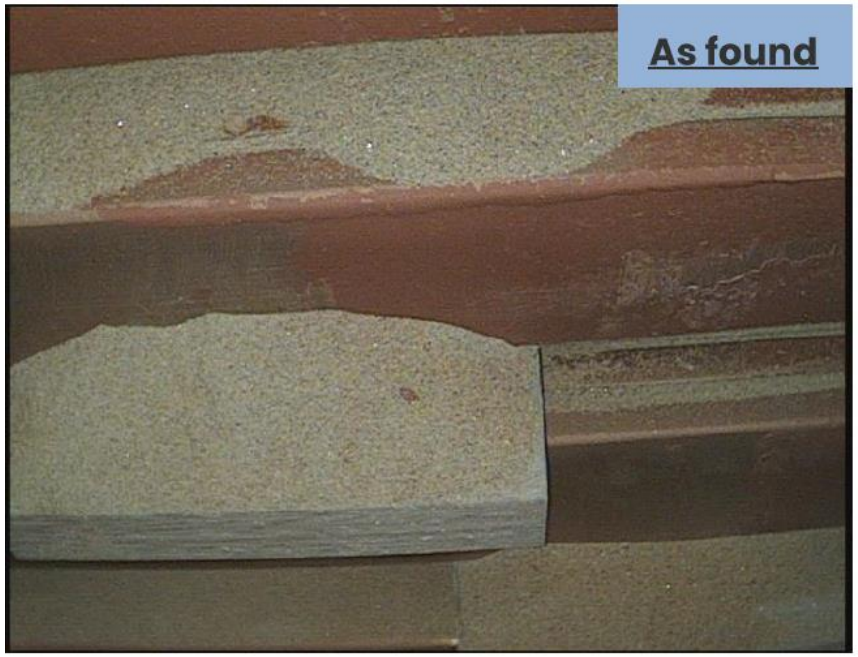
- Based on the above observations it was recommended to perform a borescope on the generator rotor.
- The investigation revealed that the root cause of the non-repeatable behavior was the sand ingress from the makeup generator air breather due to lack of proper maintenance.
- Dry cleaning of the rotor carried out and sand was removed by vacuum, then filters/gaskets replaced with new and healthy ones.
- Later, machine started with very acceptable vibration levels well below alarm setpoints.

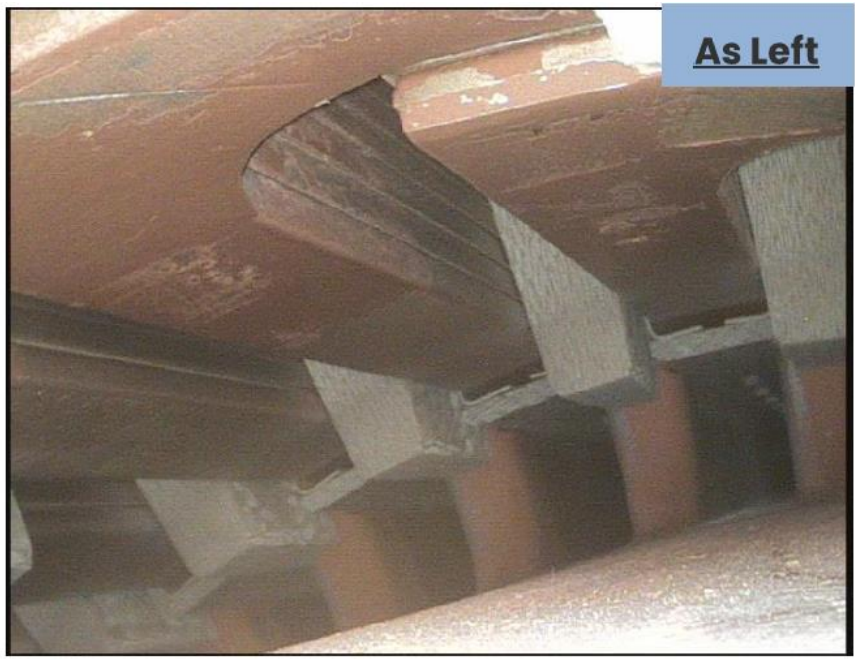
Findings

Sand ingress from the makeup generator air breather before and after cleaning







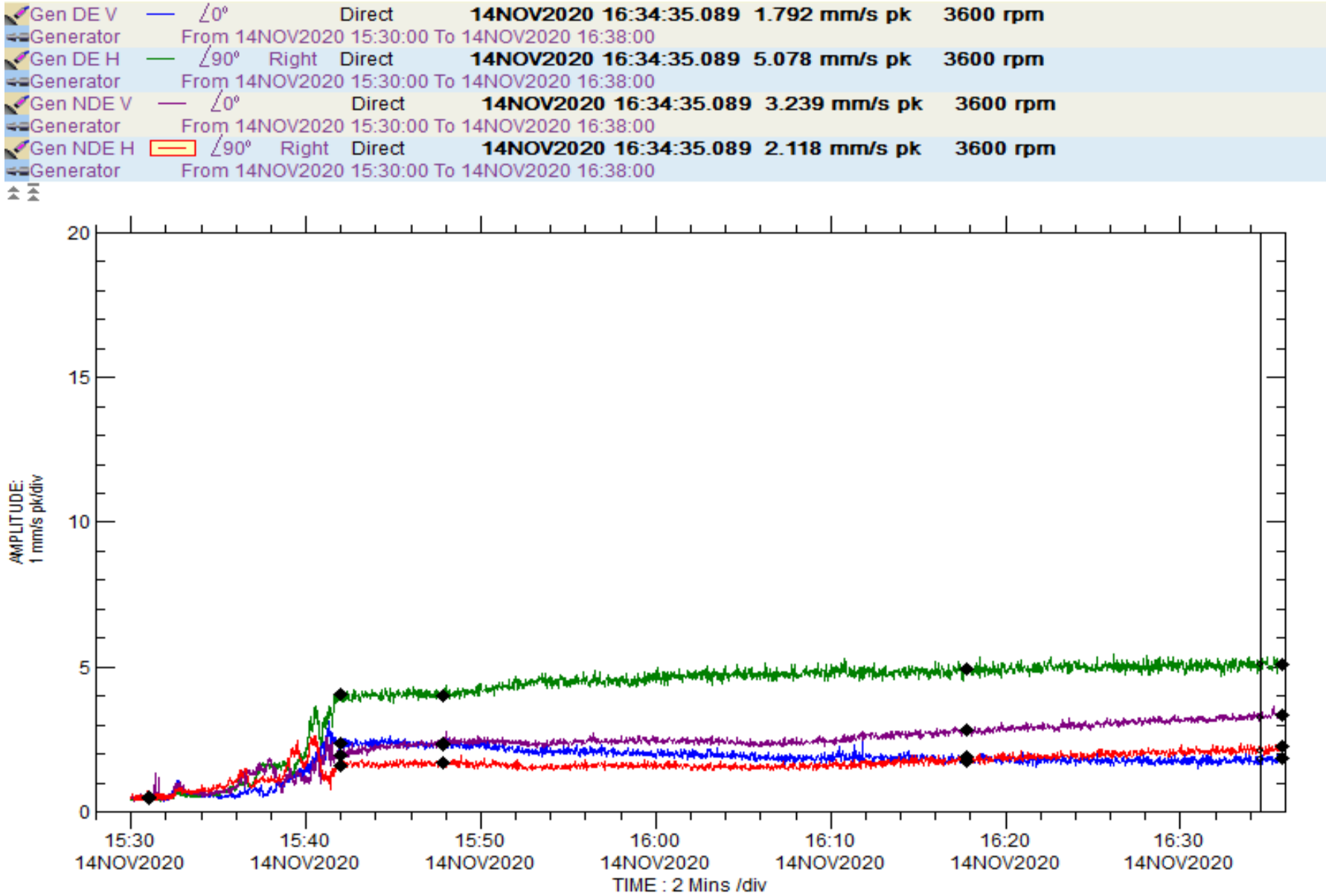


Findings

Filters/gaskets damaged

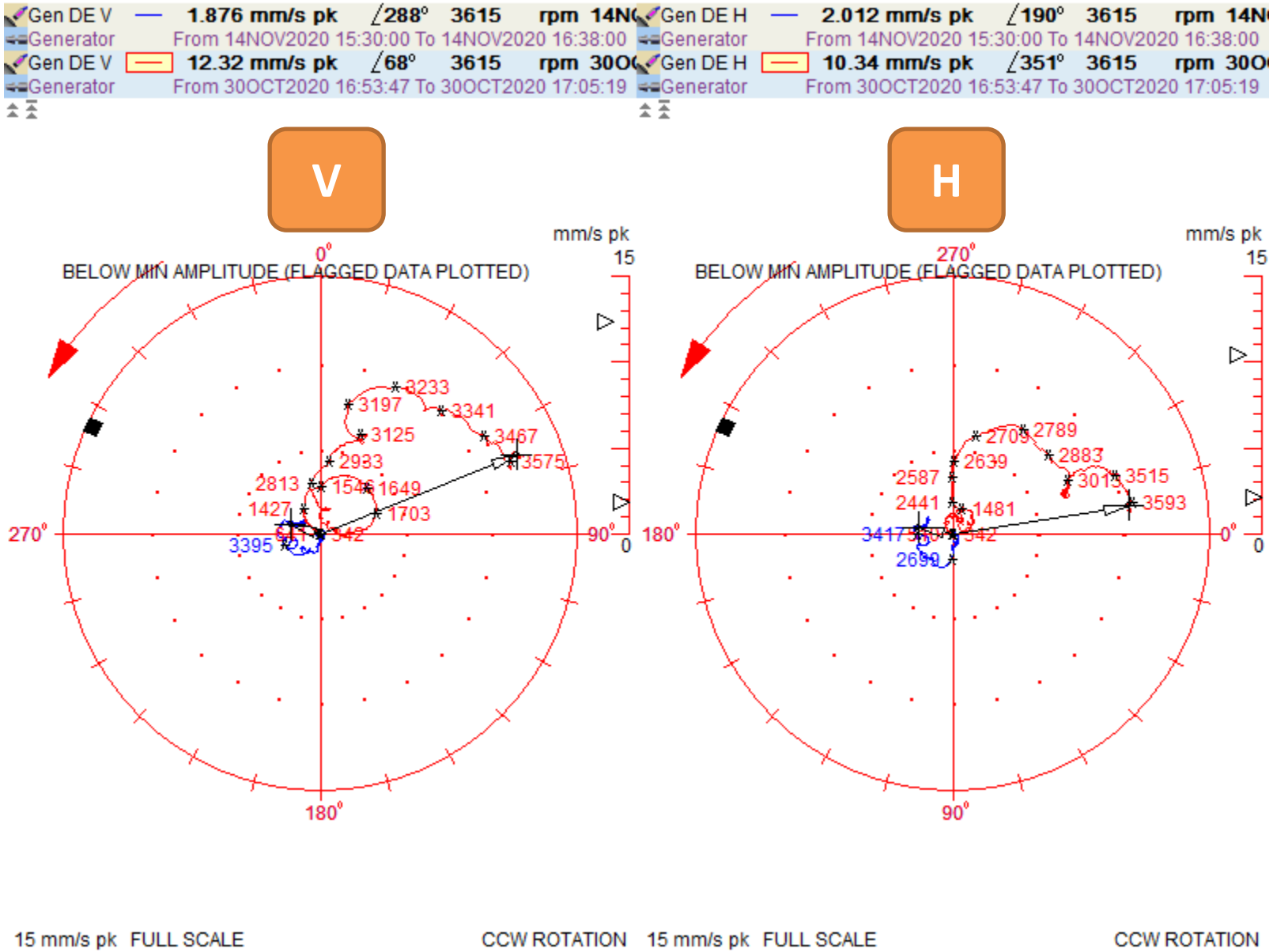
Post Analysis

Generator Bearings Seismic Vibration Trend Plots After Cleaning



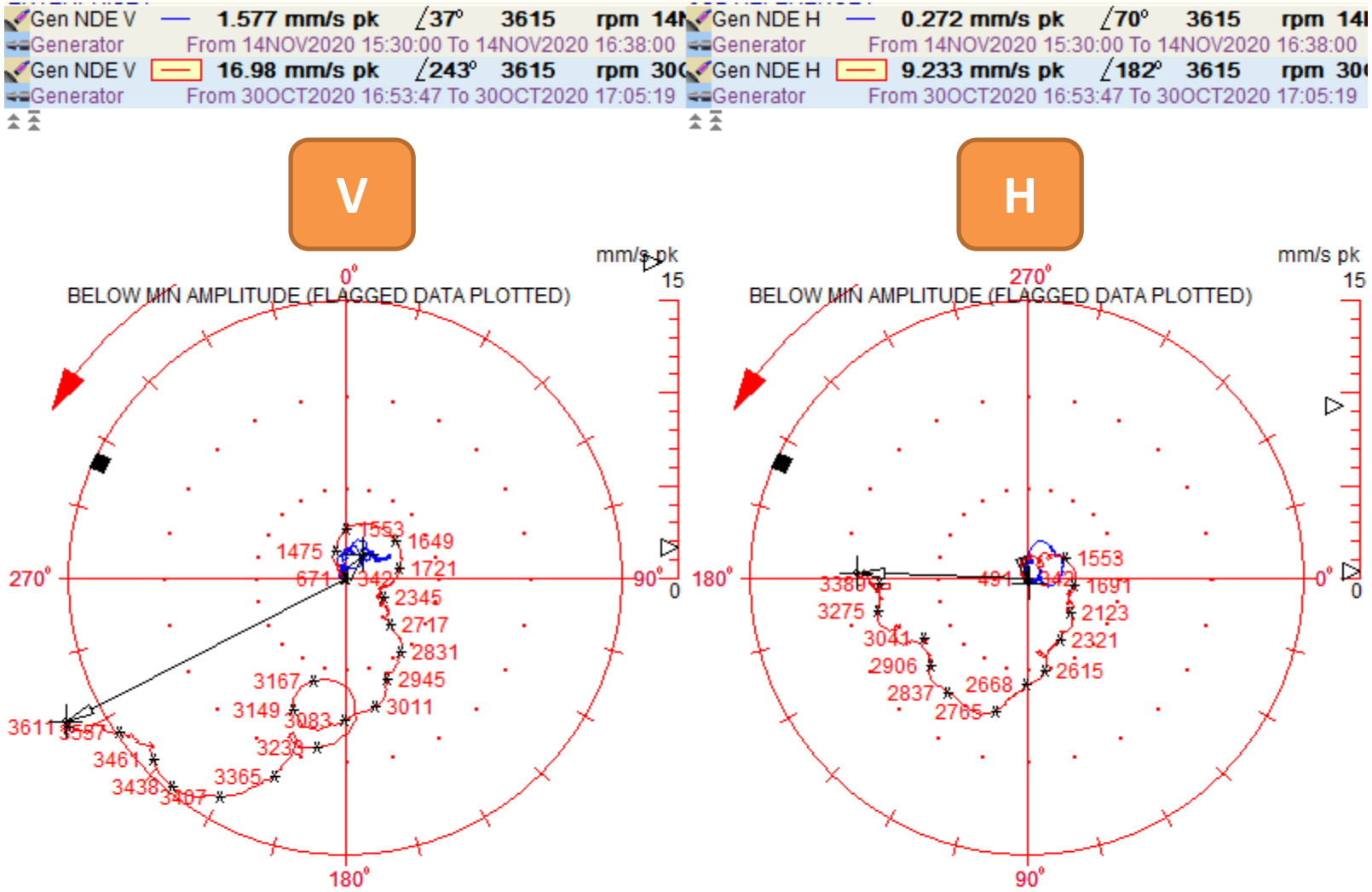
Post Analysis

Generator Drive End Bearing casing vibration 1X Polar Plots Overlaid (Blue is After & Red is Before Cleaning)



Post Analysis

Generator Non-Drive End Bearing casing vibration 1X Polar Plots Overlaid (Blue is After & Red is Before Cleaning)



Lessons Learned

- Importance of the preventive maintenance activities for the critical machines' reliability.
- Understanding how it is important to confirm the linearity and repeatability of the rotating machine systems during any balancing job.
- Understanding the influence vector calculations.