



## ASIA TURBOMACHINERY & PUMP SYMPOSIUM

SYMPOSIA: 24 – 26 MAY 2022  
SHORT COURSES: 23 MAY 2022



TEXAS A&M  
UNIVERSITY



TURBOMACHINERY LABORATORY  
TEXAS A&M ENGINEERING EXPERIMENT STATION

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

Mohammed Ashour – Bently Nevada a Baker Hughes Business

Mustafa Shalabi – Bently Nevada a Baker Hughes Business



**Bently Nevada**

a Baker Hughes business

# Presenter/Author Bios

## **Mohammed Ashour**

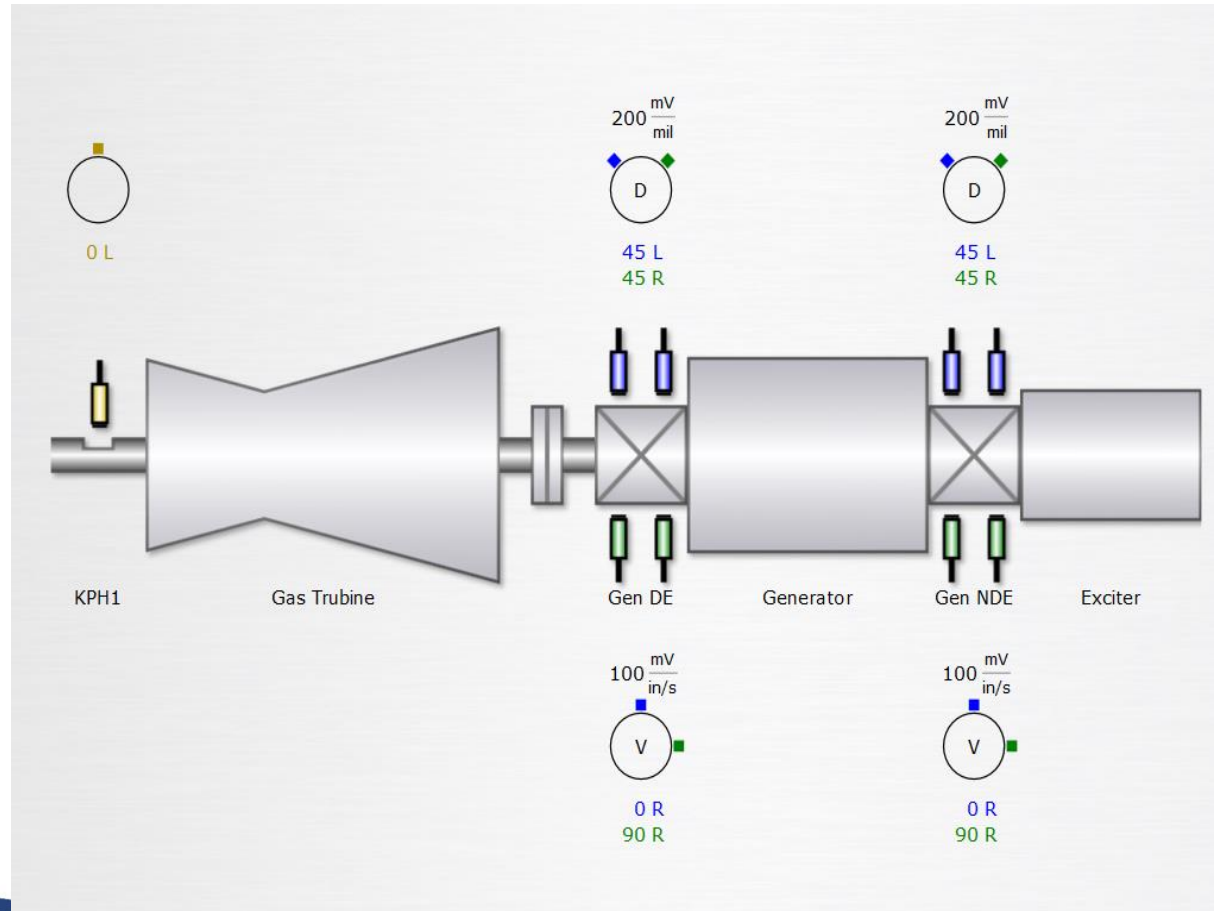
Is A Lead Engineer For Bently Nevada Machinery Diagnostics Services in Saudi Arabia & Bahrain With a Mechanical Power Engineering Degree From Alexandria University, Egypt Having 11+ Years of Experience in Services, Power Generation, And Petrochemical Fields.

## **Mustafa Shalabi**

Is technical team Leader for Bently Nevada machinery diagnostics services in Saudi Arabia & Bahrain with a Mechanical Power Engineering From Alexandria University, Egypt Having 14+ Years of Experience In Both Services and Petrochemical Fields.



# Machine Train Diagram

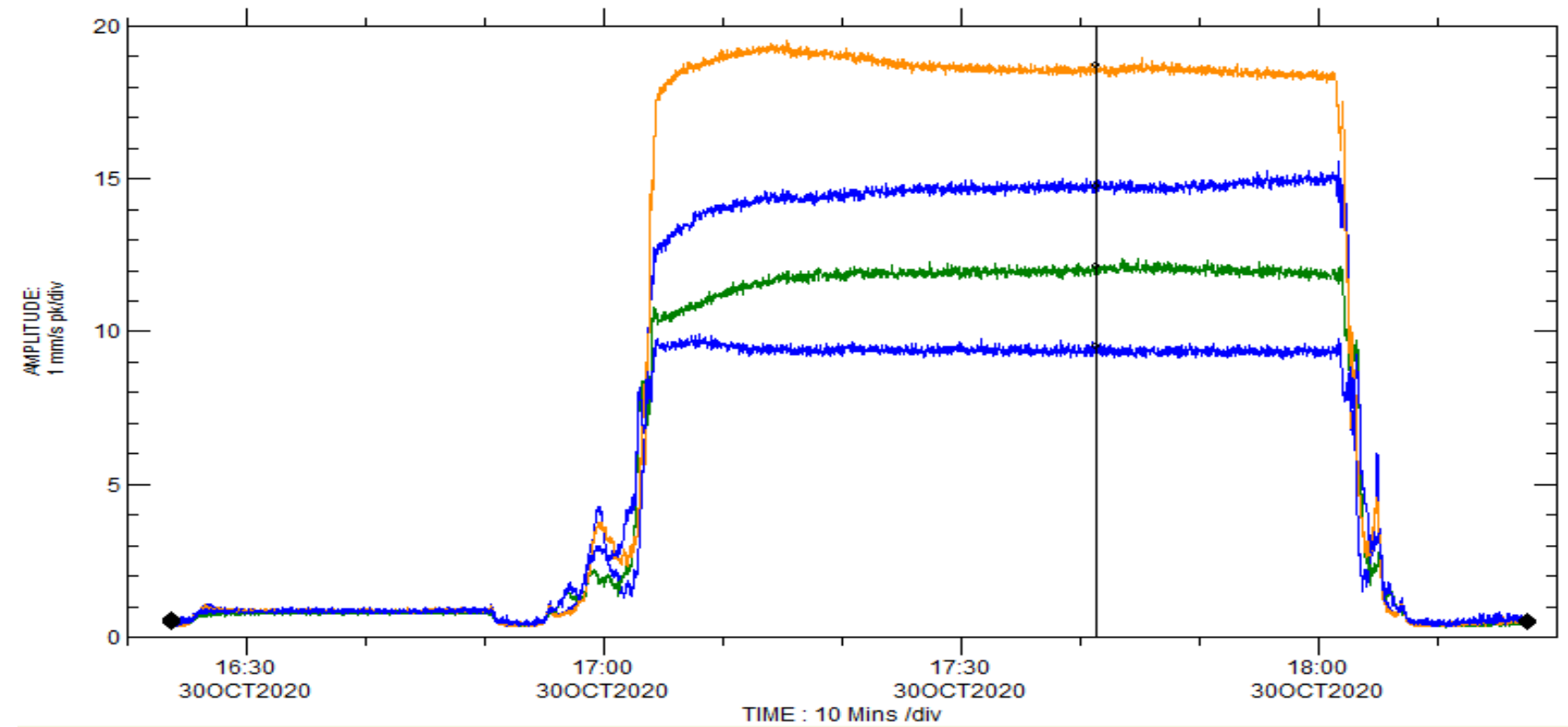


This is a machine train consists of gas turbine driving an air-cooled synchronous generator (3600 rpm and 80 MW rated power) Gas turbine is supported on three journal bearings, and generator is supported on two journal bearings. Each bearings is monitored by two shaft relative vibration probes installed 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.

Gen DE V	∠0°	Direct	30OCT2020 17:41:24.418	14.756 mm/s pk	3611 rpm
Generator	From 30OCT2020 16:15:00 To 30OCT2020 18:20:00				
Gen DE H	∠90°	Right Direct	30OCT2020 17:41:24.418	12.141 mm/s pk	3611 rpm
Generator	From 30OCT2020 16:15:00 To 30OCT2020 18:20:00				
Gen NDE V	∠0°	Direct	30OCT2020 17:41:24.418	18.720 mm/s pk	3611 rpm
Generator	From 30OCT2020 16:15:00 To 30OCT2020 18:20:00				
Gen NDE H	∠90°	Right Direct	30OCT2020 17:41:24.418	9.500 mm/s pk	3611 rpm
Generator	From 30OCT2020 16:15:00 To 30OCT2020 18:20:00				



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

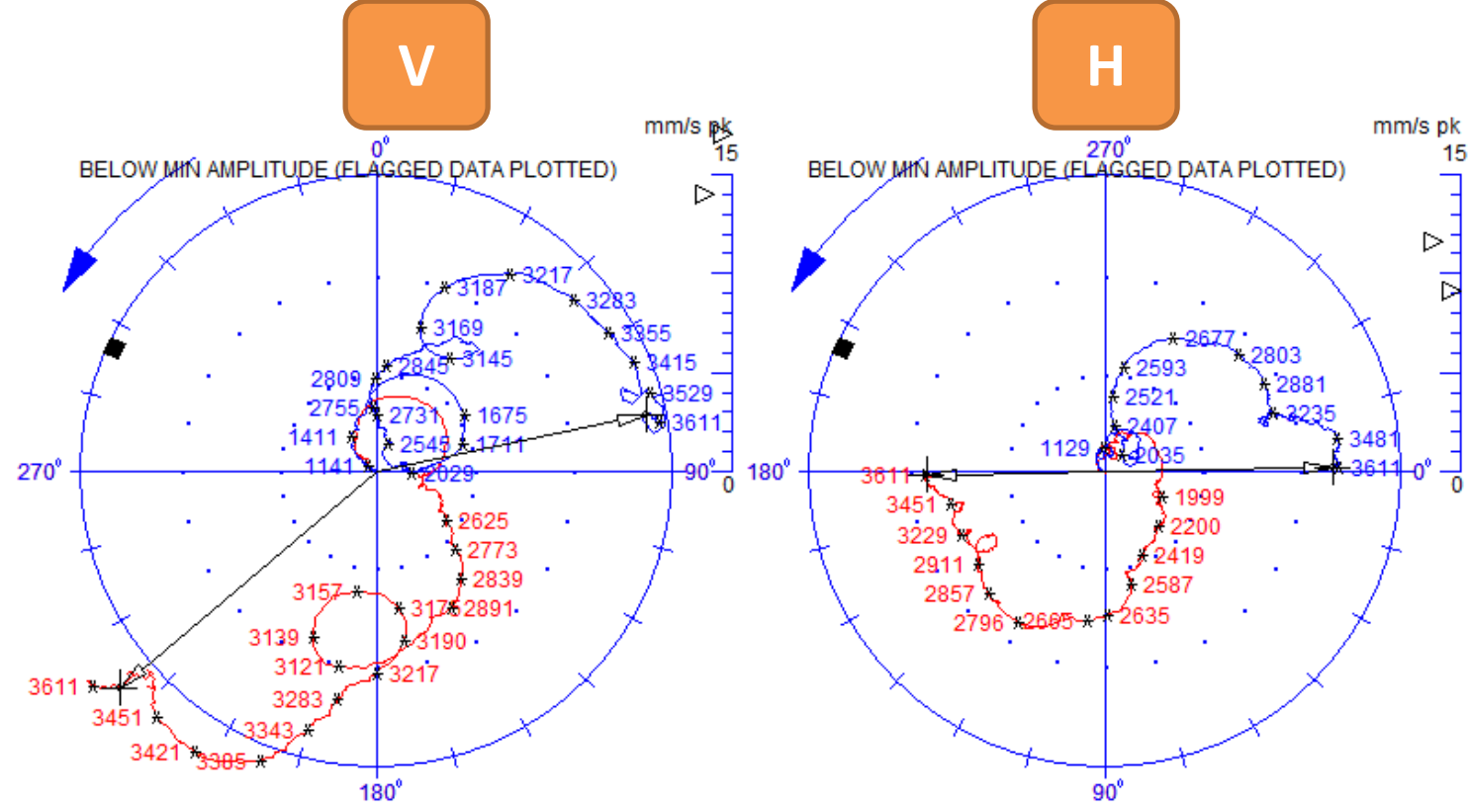


# Problem Statement- Cont'd

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.

Gen NDE V	16.965 mm/s pk	∠230°	3589 rpm	30C	Gen NDE H	9.005 mm/s pk	∠179°	3589 rpm	30C
Generator	From 30OCT2020 18:01:00 To 30OCT2020 18:19:00				Generator	From 30OCT2020 18:01:00 To 30OCT2020 18:19:00			
Gen DE V	13.941 mm/s pk	∠78°	3589 rpm	30C	Gen DE H	11.540 mm/s pk	∠359°	3589 rpm	30C
Generator	From 30OCT2020 18:01:00 To 30OCT2020 18:19:00				Generator	From 30OCT2020 18:01:00 To 30OCT2020 18:19:00			

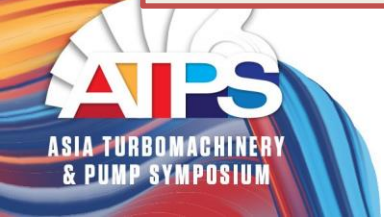


15 mm/s pk FULL SCALE

CCW ROTATION 15 mm/s pk FULL SCALE

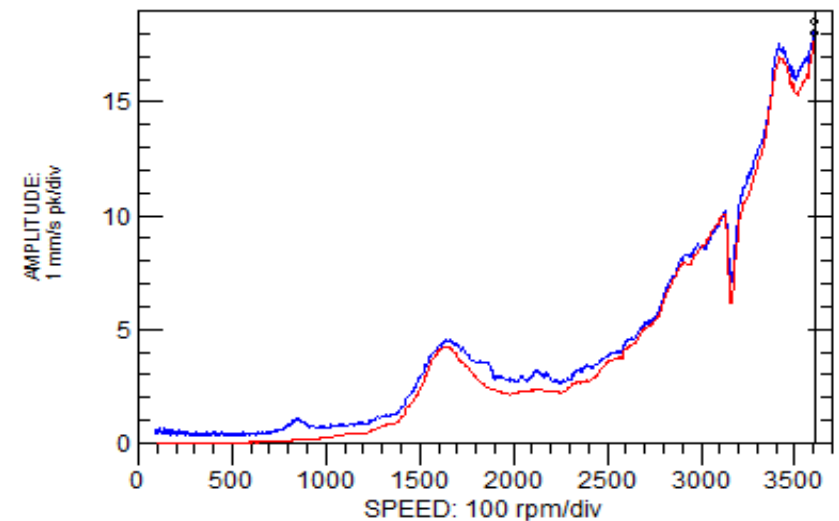
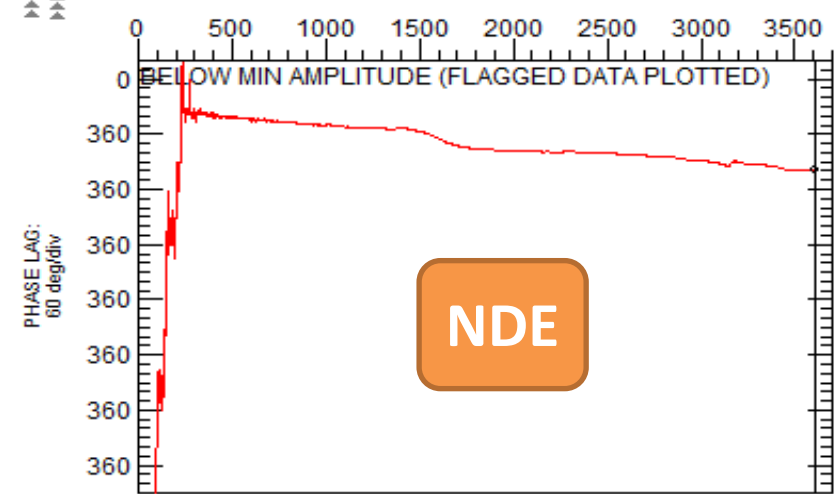
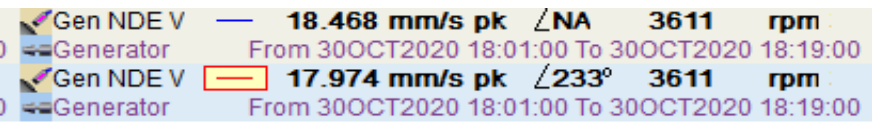
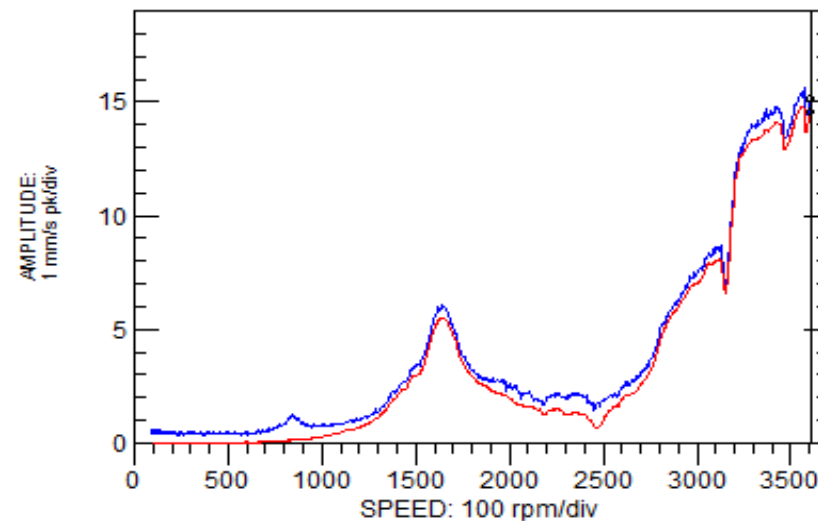
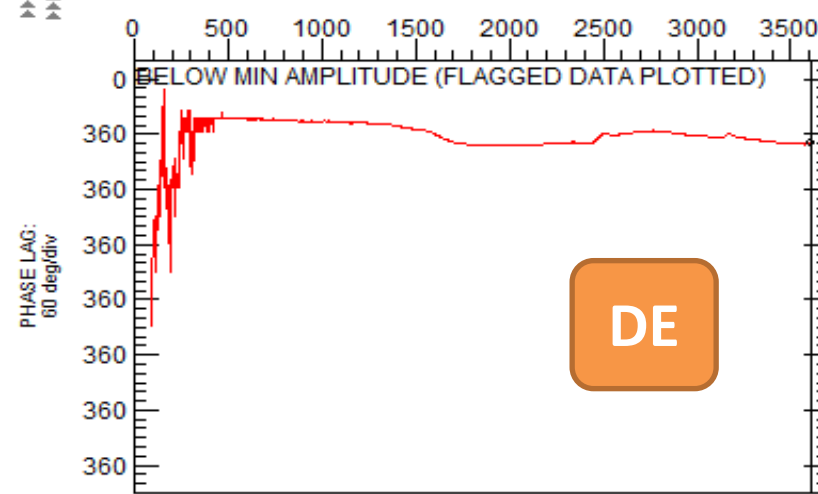
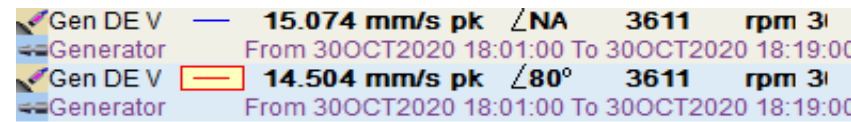
CCW ROTATION

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).



# 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:

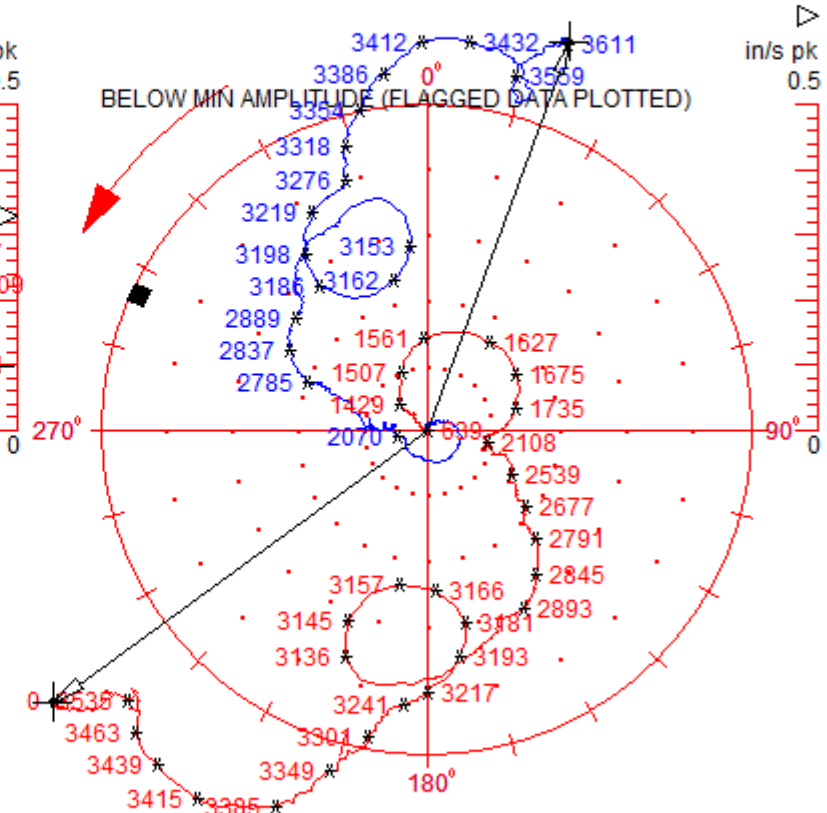
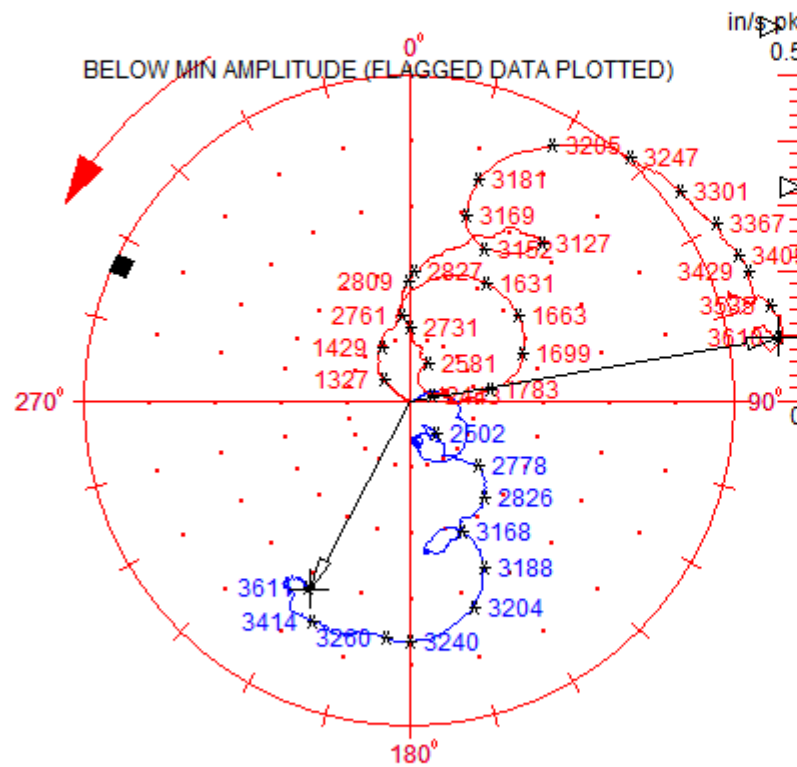
- 1- Independent of calibration weight.
- 2- Can be used in future balancing.
- 3- Should not change for the same operating conditions.



# 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

Gen DE V	0.328 in/s pk	∠208°	3611 rpm	01NOV20	Gen NDE V	0.634 in/s pk	∠20°	3611 rpm	01NOV20
Generator	From 01NOV2020 20:05:00 To 01NOV2020 20:23:00				Generator	From 01NOV2020 20:05:00 To 01NOV2020 20:23:00			
Gen DE V	0.572 in/s pk	∠80°	3611 rpm	30OCT20	Gen NDE V	0.711 in/s pk	∠234°	3611 rpm	30OCT20
Generator	From 30OCT2020 18:00:52 To 30OCT2020 18:21:57				Generator	From 30OCT2020 18:00:52 To 30OCT2020 18:21:57			



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

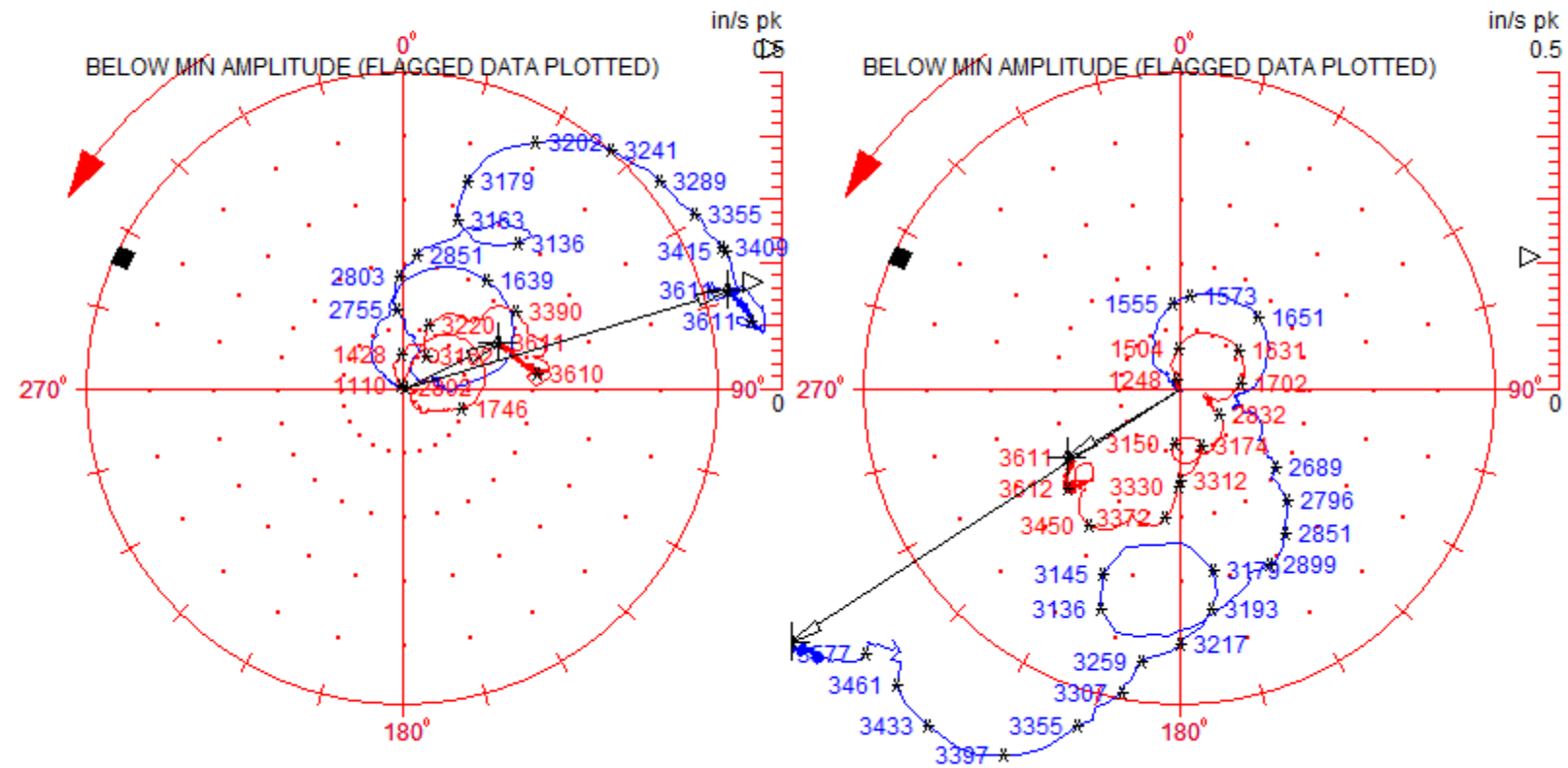
and removal of trial weight



# 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.

Gen DE V	0.535 in/s pk	∠73°	3611 rpm	300	Gen NDE V	0.733 in/s pk	∠237°	3611 rpm	300
Generator	From 30OCT2020 17:12:00 To 30OCT2020 18:20:00				Generator	From 30OCT2020 17:12:00 To 30OCT2020 18:20:00			
Gen DE V	0.166 in/s pk	∠64°	3611 rpm	02N	Gen NDE V	0.206 in/s pk	∠239°	3611 rpm	02N
Generator	From 02NOV2020 16:26:59 To 02NOV2020 17:50:23				Generator	From 02NOV2020 16:26:59 To 02NOV2020 17:50:23			



Blue is original Run Red is Correction Run

0.5 in/s pk FULL SCALE

CCW ROTATION 0.5 in/s pk FULL SCALE

CCW ROTATION



# 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

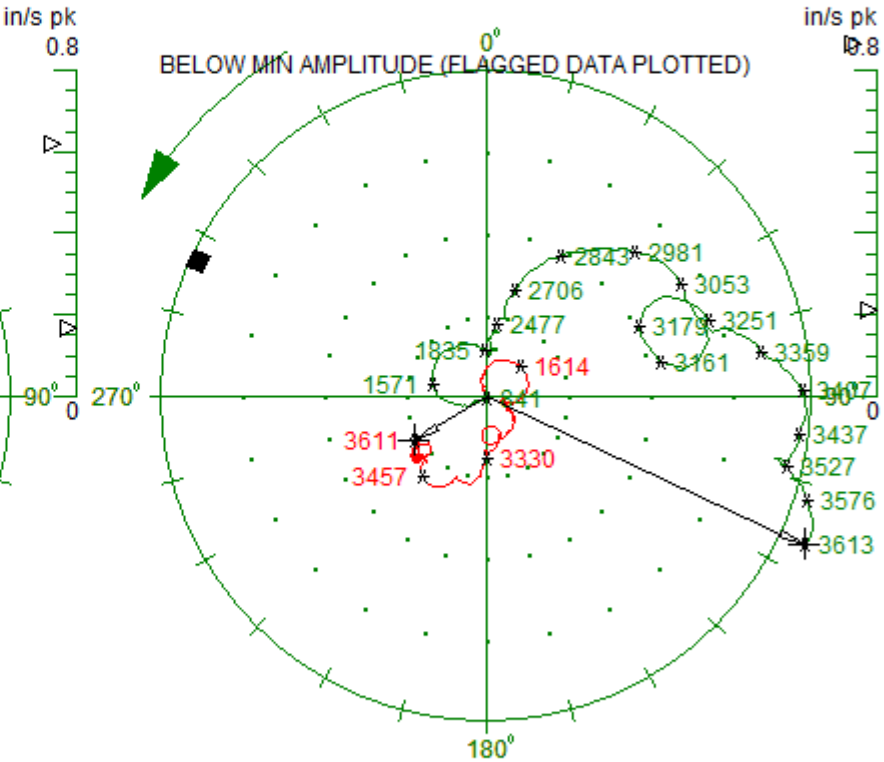
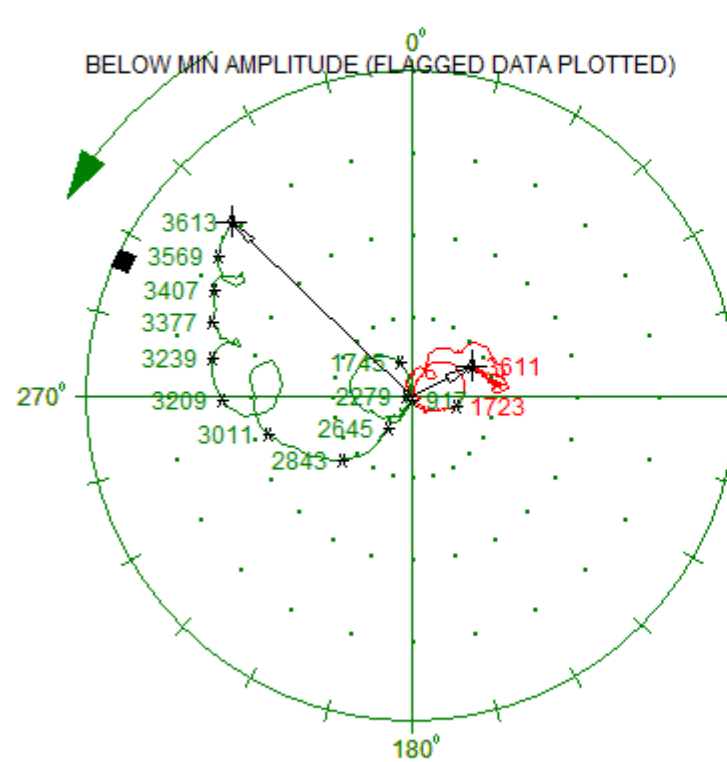
468 grams @ 70 degrees at NDE WRT Vertical

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

Gen DE V	0.166 in/s pk	64°	3611 rpm	02NOV2020	Gen NDE V	0.206 in/s pk	239°	3611 rpm	02NOV2020
Generator	From 02NOV2020 16:26:59 To 02NOV2020 17:50:23				Generator	From 02NOV2020 16:26:59 To 02NOV2020 17:50:23			
Gen DE V	0.616 in/s pk	314°	3613 rpm	04NOV2020	Gen NDE V	0.862 in/s pk	115°	3613 rpm	04NOV2020
Generator	From 04NOV2020 10:18:11 To 04NOV2020 10:33:51				Generator	From 04NOV2020 10:18:11 To 04NOV2020 10:33:51			



Red is the Correction Run Green is the 2<sup>nd</sup> Run with same weight



# Initial Action Plan— 2<sup>nd</sup> 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.

	<b>Old Influence Vector from Previous Job on Similar Machine Design</b>	<b>Trial Run</b>	<b>Correction Run</b>	<b>2<sup>nd</sup> Run Without Changing Weight</b>
<b><u>Weight Condition</u></b>	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
<b><u>Influence Vector (H)</u></b>	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

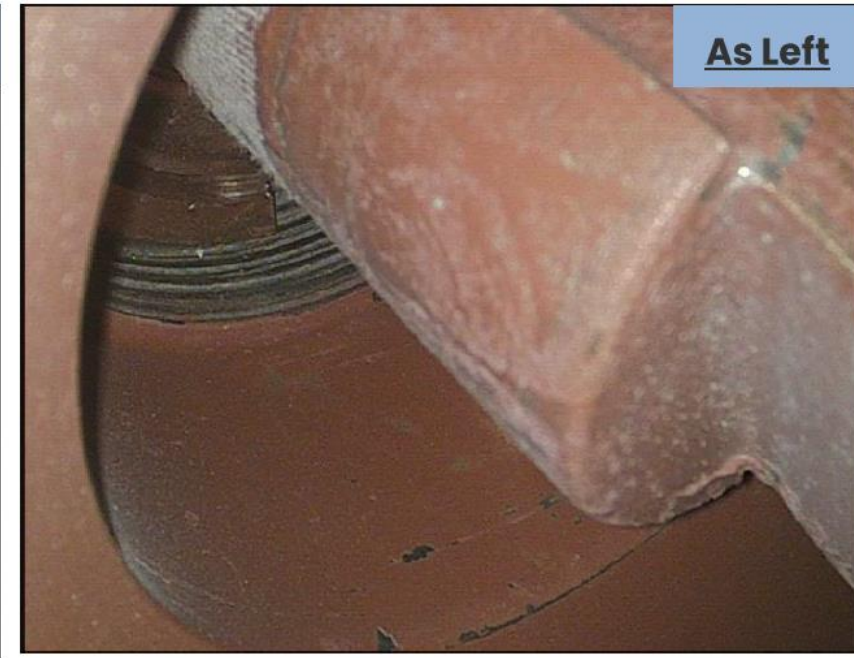
# Action Plan – Inspection

- 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

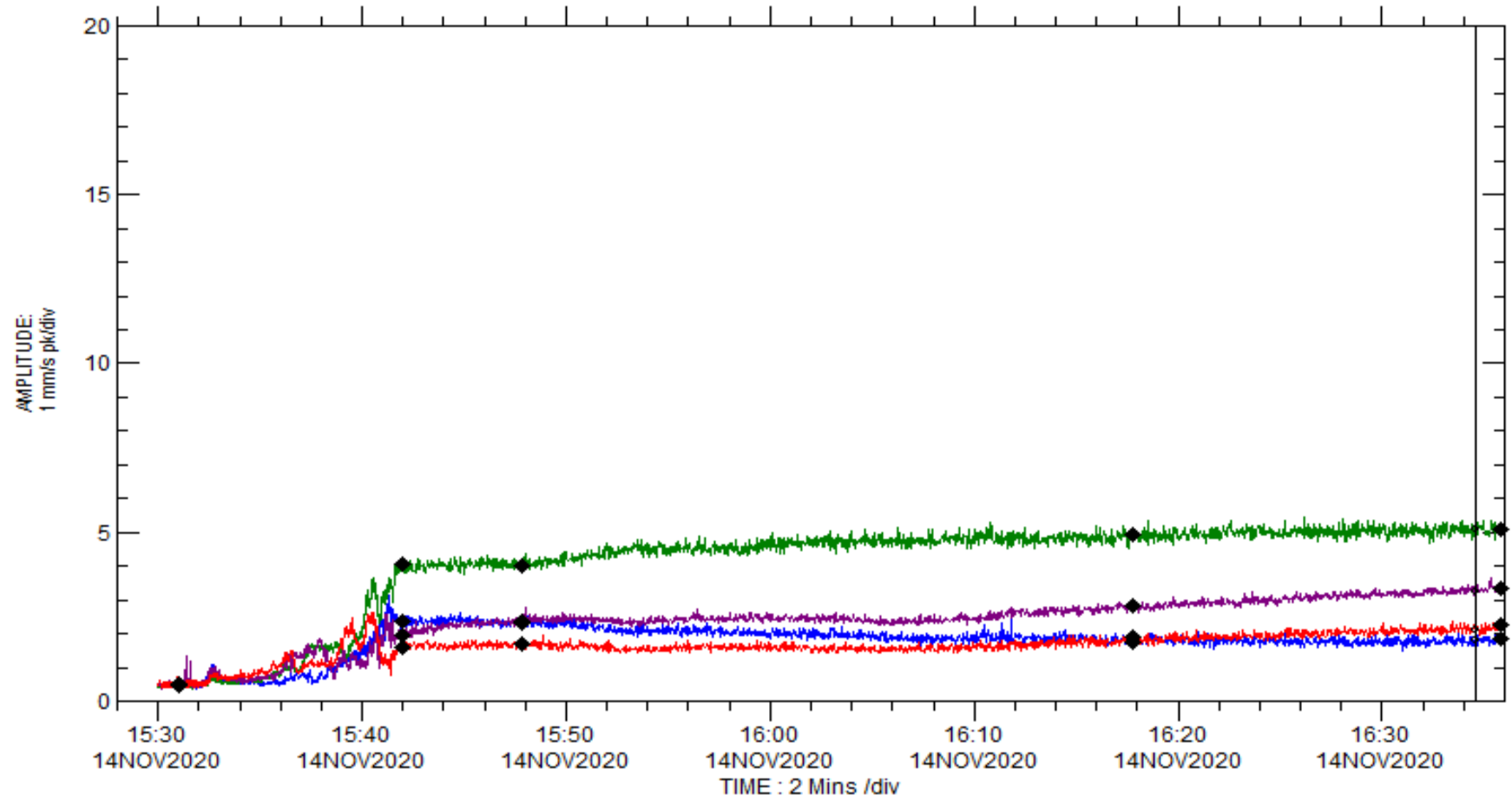


Filters/gaskets damaged

# Post Analysis

Gen DE V	∠0°	Direct	14NOV2020 16:34:35.089	1.792 mm/s pk	3600 rpm
Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00				
Gen DE H	∠90°	Right Direct	14NOV2020 16:34:35.089	5.078 mm/s pk	3600 rpm
Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00				
Gen NDE V	∠0°	Direct	14NOV2020 16:34:35.089	3.239 mm/s pk	3600 rpm
Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00				
Gen NDE H	∠90°	Right Direct	14NOV2020 16:34:35.089	2.118 mm/s pk	3600 rpm
Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00				

▲ ▼

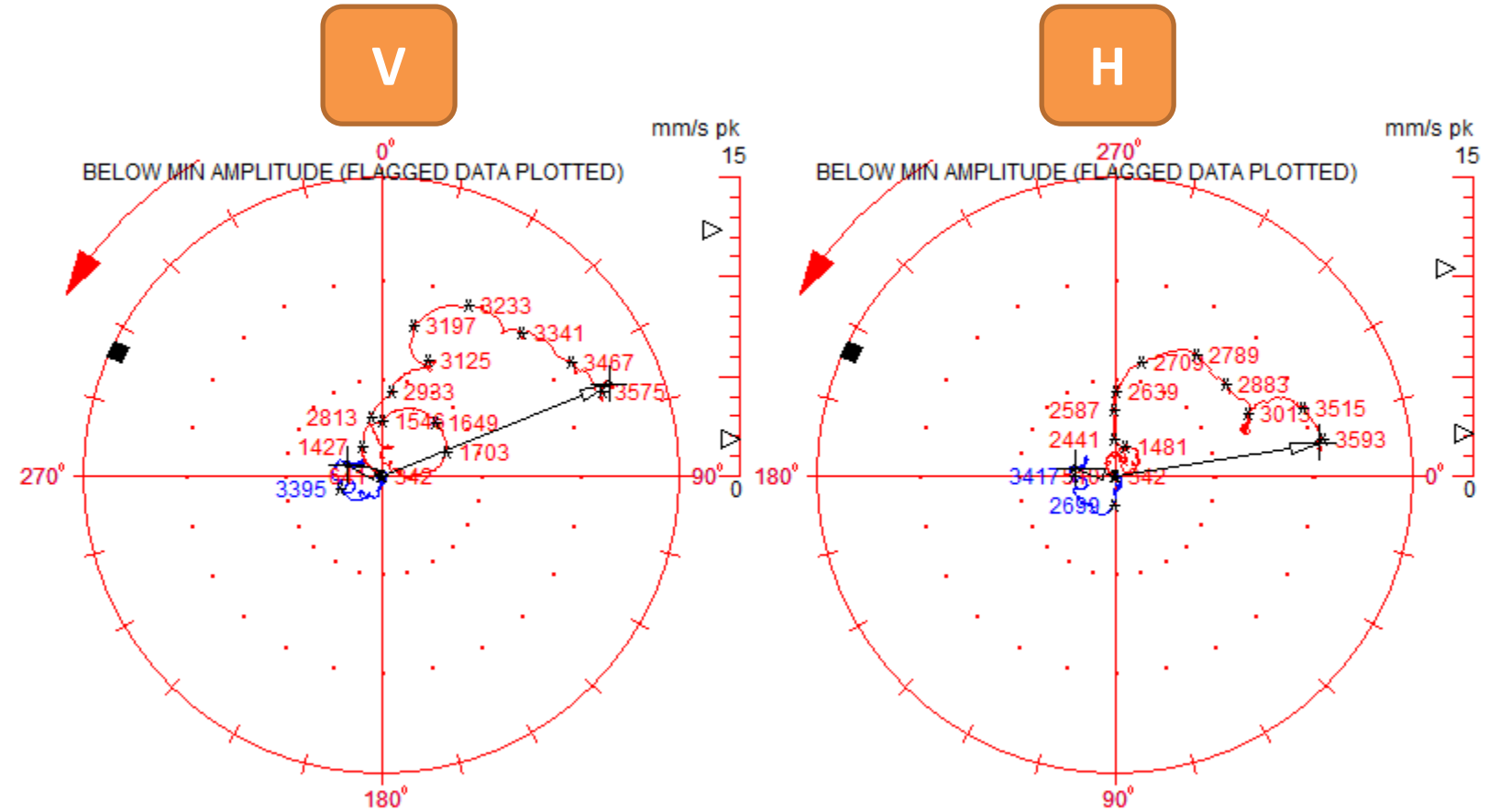


Generator Bearings  
Seismic Vibration  
Trend Plots After  
Cleaning

# Post Analysis

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

Gen DE V	1.876 mm/s pk	∠288°	3615 rpm	14N	Gen DE H	2.012 mm/s pk	∠190°	3615 rpm	14N
Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00				Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00			
Gen DE V	12.32 mm/s pk	∠68°	3615 rpm	300	Gen DE H	10.34 mm/s pk	∠351°	3615 rpm	300
Generator	From 30OCT2020 16:53:47 To 30OCT2020 17:05:19				Generator	From 30OCT2020 16:53:47 To 30OCT2020 17:05:19			



15 mm/s pk FULL SCALE

CCW ROTATION 15 mm/s pk FULL SCALE

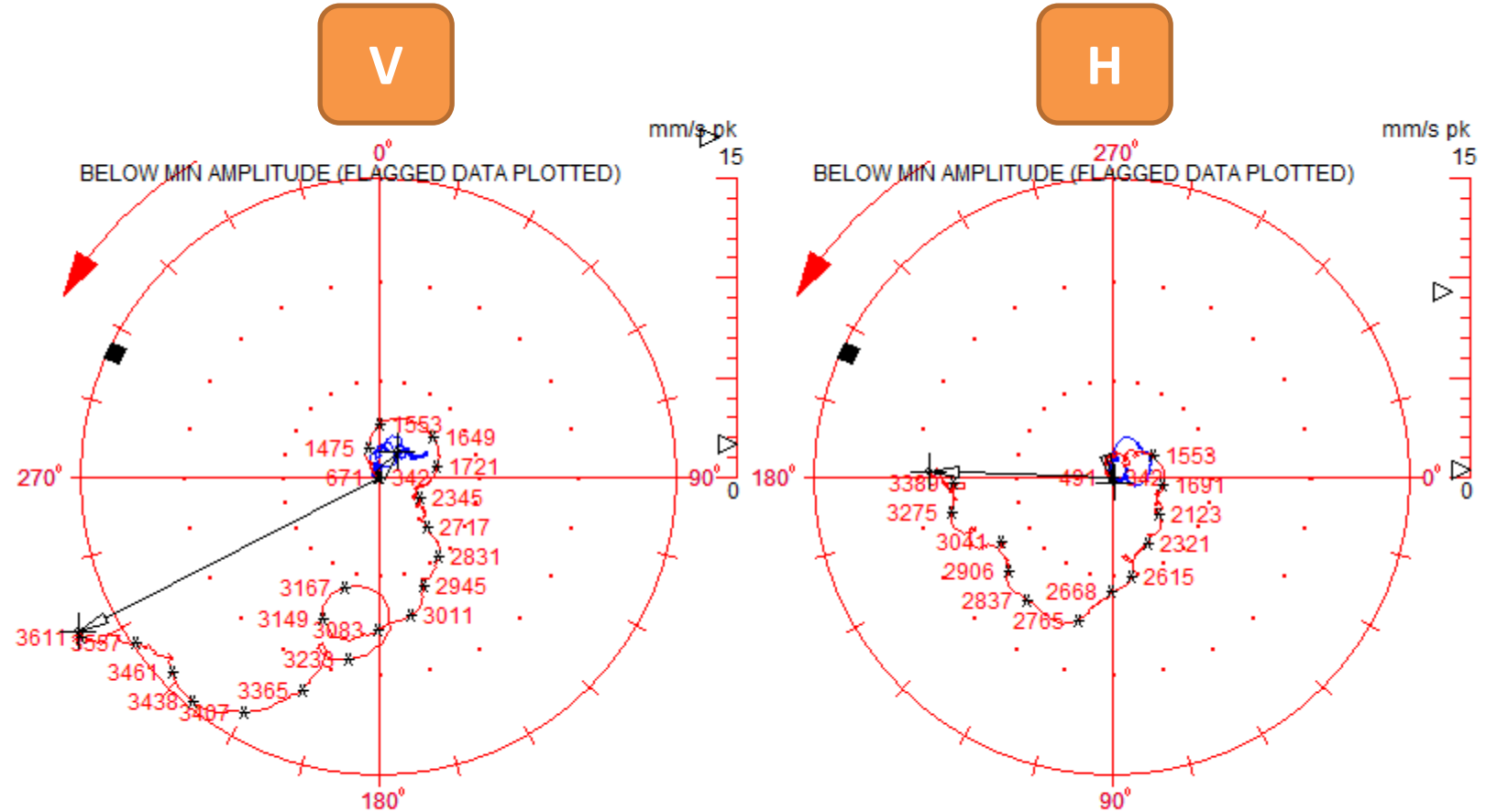
CCW ROTATION



# Post Analysis

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

Gen NDE V	1.577 mm/s pk	∠37°	3615 rpm	14N	Gen NDE H	0.272 mm/s pk	∠70°	3615 rpm	14N
Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00				Generator	From 14NOV2020 15:30:00 To 14NOV2020 16:38:00			
Gen NDE V	16.98 mm/s pk	∠243°	3615 rpm	30C	Gen NDE H	9.233 mm/s pk	∠182°	3615 rpm	30C
Generator	From 30OCT2020 16:53:47 To 30OCT2020 17:05:19				Generator	From 30OCT2020 16:53:47 To 30OCT2020 17:05:19			



15 mm/s pk FULL SCALE

CCW ROTATION 15 mm/s pk FULL SCALE

CCW ROTATION



# 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.

