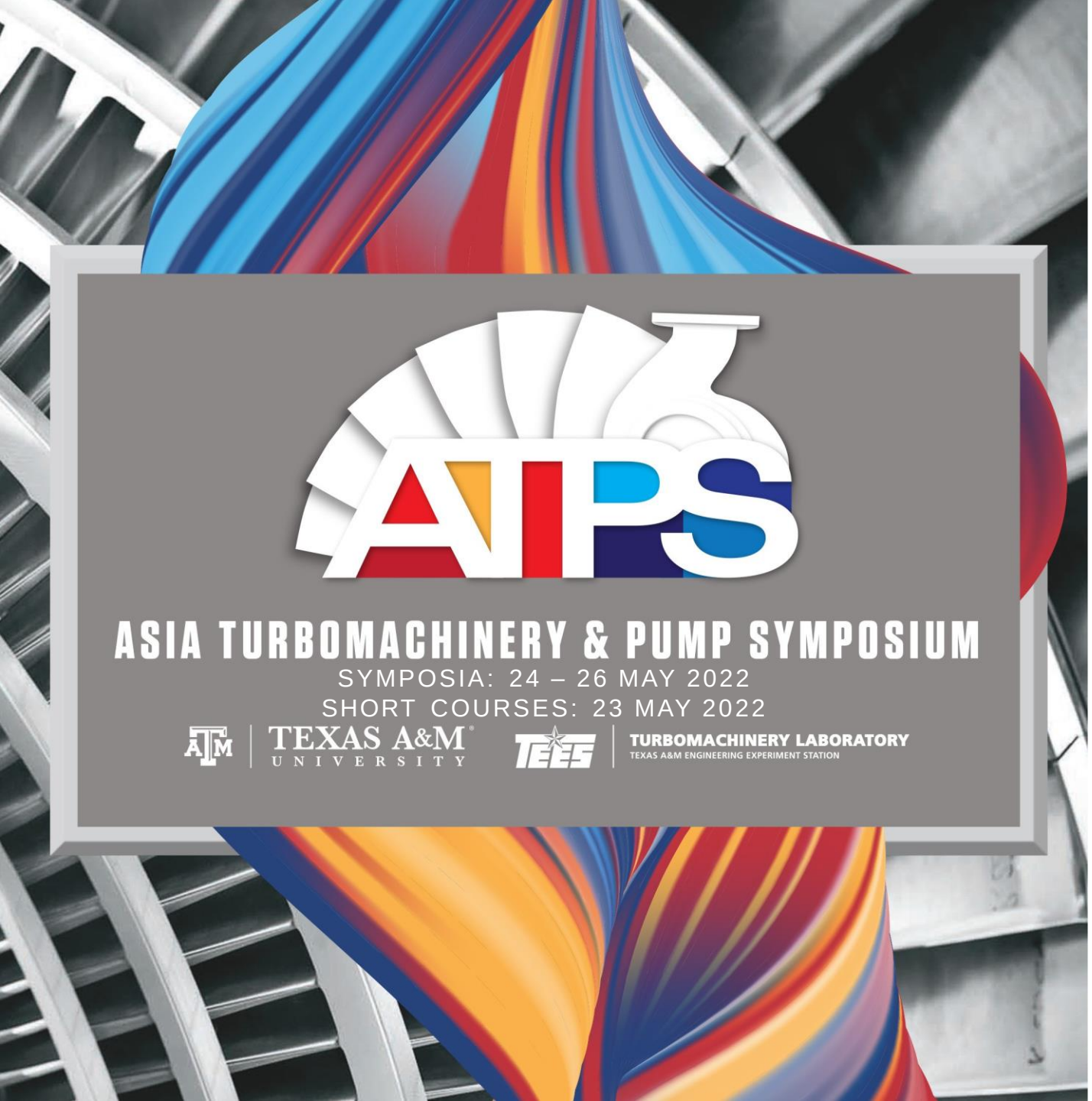

Unexpected Vibration on a Centrifugal Compressor Caused by Vibration Probe Support

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Author - Biography

Yves Bidaut

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Responsible for providing technical support in rotordynamics and stress analysis.

Function: development and analysis of components of centrifugal compressors for oil and gas application.

Before joining the site in Switzerland in 2003 was employed for 6 years in MAN Energy Solutions, Berlin where he was involved in the design, finite element analysis, rotordynamic analysis, testing and development of centrifugal compressors.
Received his diploma (Mechanical Engineering, 1995) from the University of Valenciennes (France).

Synopsis

- During the commissioning of a Main Air Compressor in an Air Separation Unit, the rotor showed increased radial vibrations at the Non-Drive End probe.
- The RCA revealed: The vibration resulted from the excitation of a natural frequency of the vibration probe support, triggered by the pressure fluctuation at the suction of the 11 blades-impeller.
- The probe support was redesigned to increase its stiffness in order to shift the natural frequency. After replacement of the support, no particular vibration appeared anymore.
- Generally: The vibration probe support requires careful attention, especially if the machine is standardized for a very large operation speed range.

Outline

1. **Background**
2. Description
3. Findings
4. Root Cause Analysis
5. Actions
6. Measurements after modification
7. Lessons learned, Conclusion

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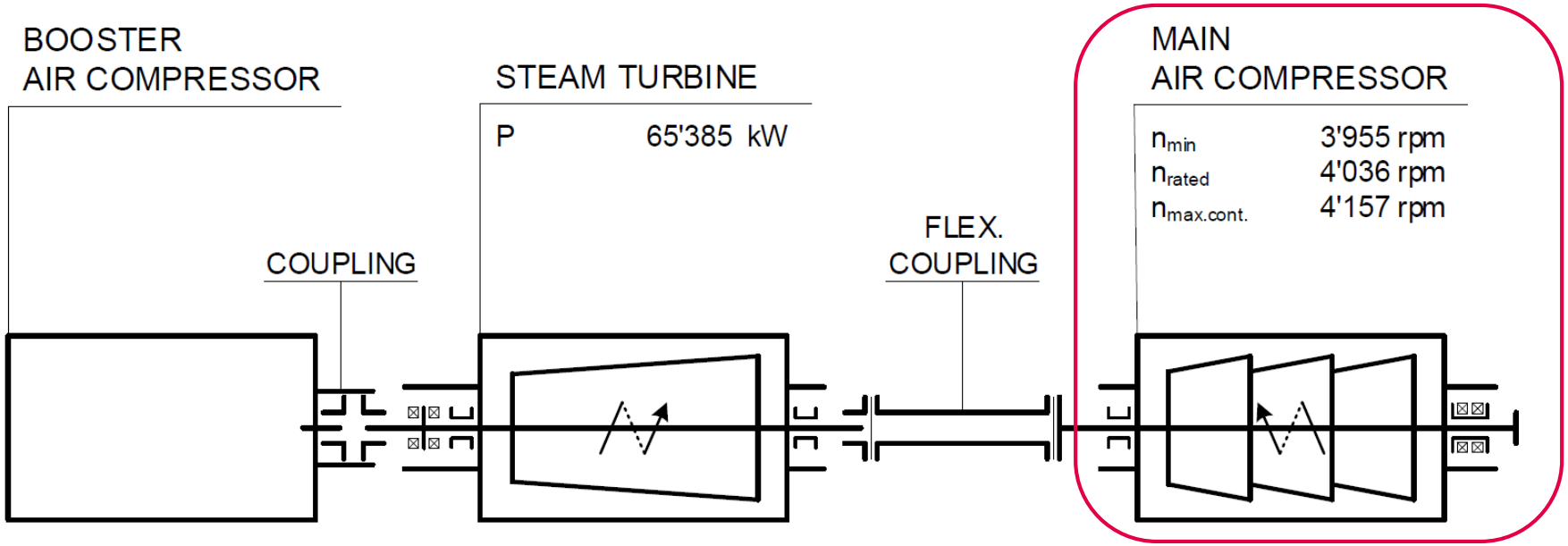
Background – Train Arrangement, Compressor



Main Air Compressor	
	3 stages, in-line
	Internal coolers between St. 1 - 2 and St. 2 - 3
	Tilting Pad Journal Bearing

Feature Main Air Compressor	SI Unit	
Suction Pressure	bara	0.9
Discharge Pressure	bara	5.6
Suction Temperature	°C	28
Discharge Temperature	°C	90
Mass Flow	kg/s	160
Gas (MW)	- (g/mol)	Air (29)

Description

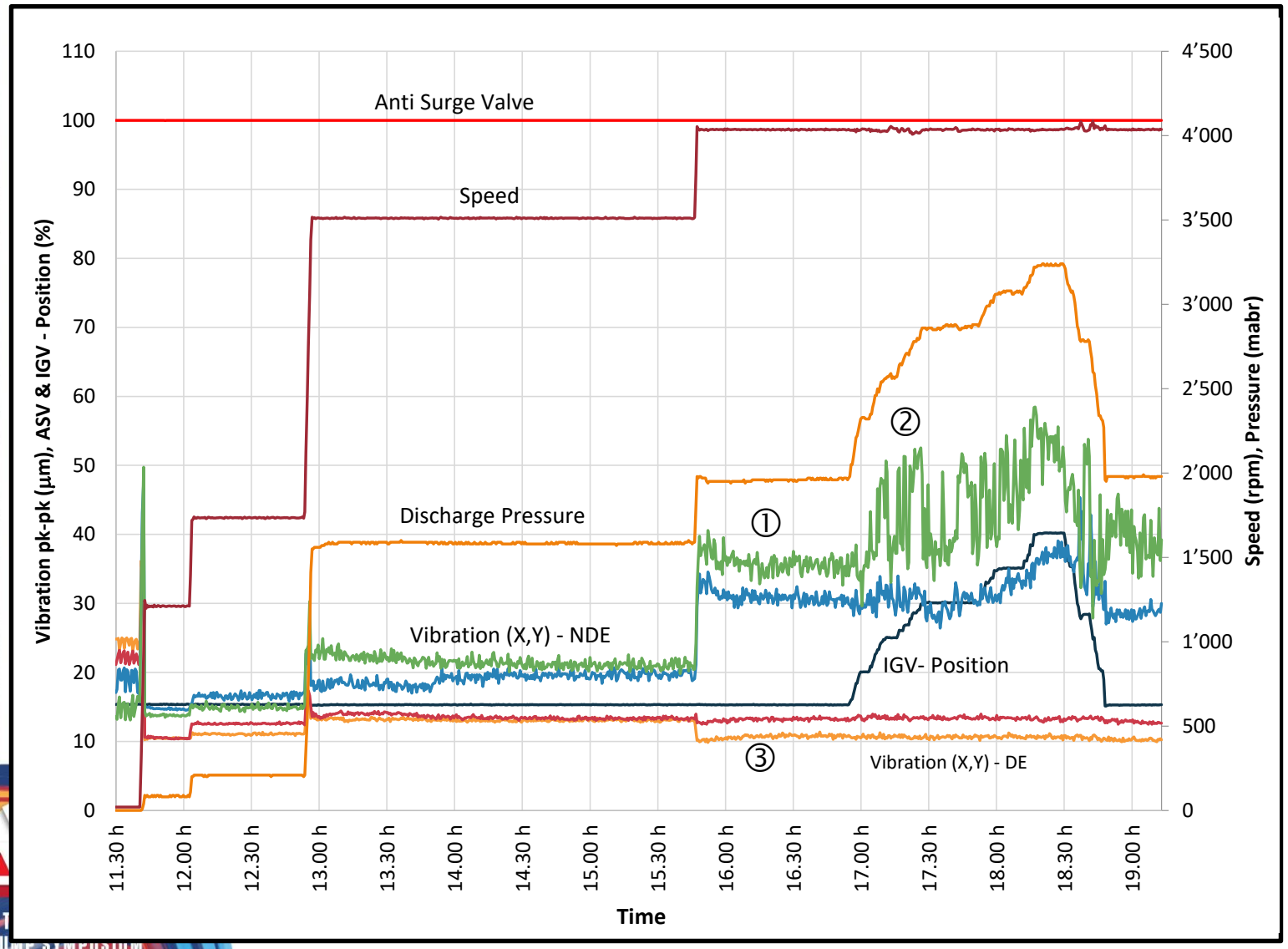
- Standard Compressor, designed for a wide speed range. Same machines (100% repeat) already in operation w/o any issue.

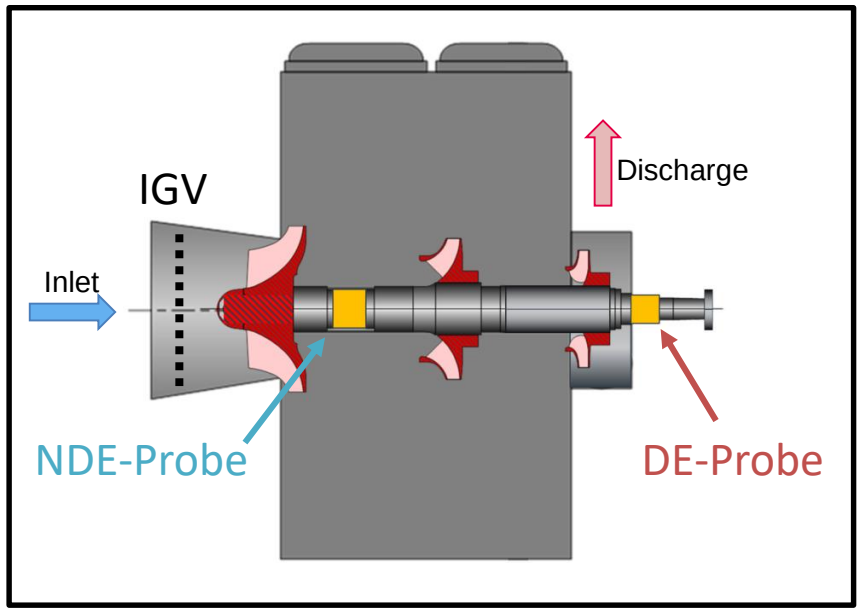
- Machine delivered on site w/o test

- During commissioning:
  increased radial vibrations appeared at Non-Drive End probe
  - ➢ Vibrations below trip limit
  - ➢ Vibrations increased with opening IGV
  - ➢ Because of unexpected vibrations

→ Origine of phenomenon investigated.

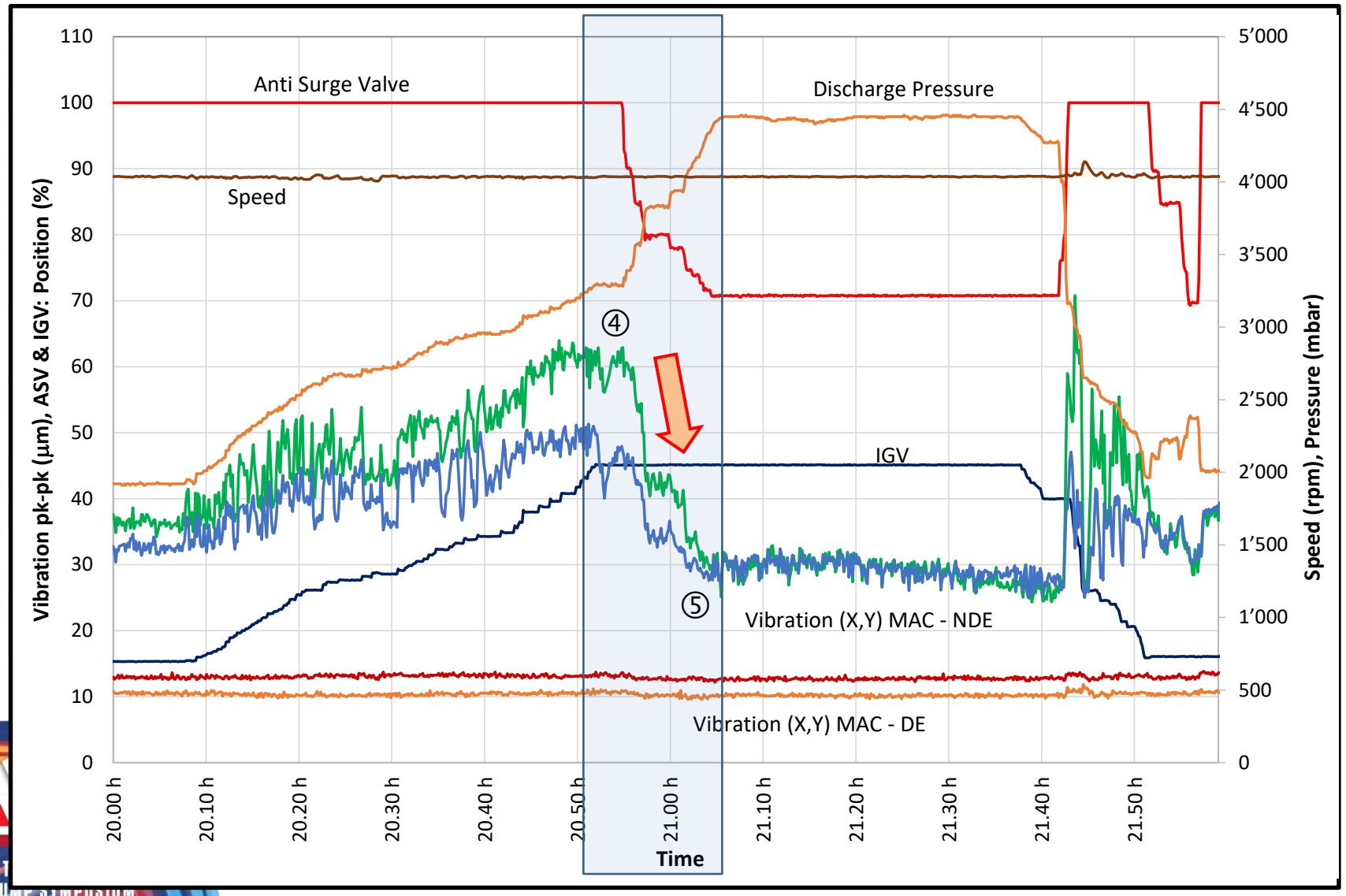
Findings – Lateral Vibrations (1/3)





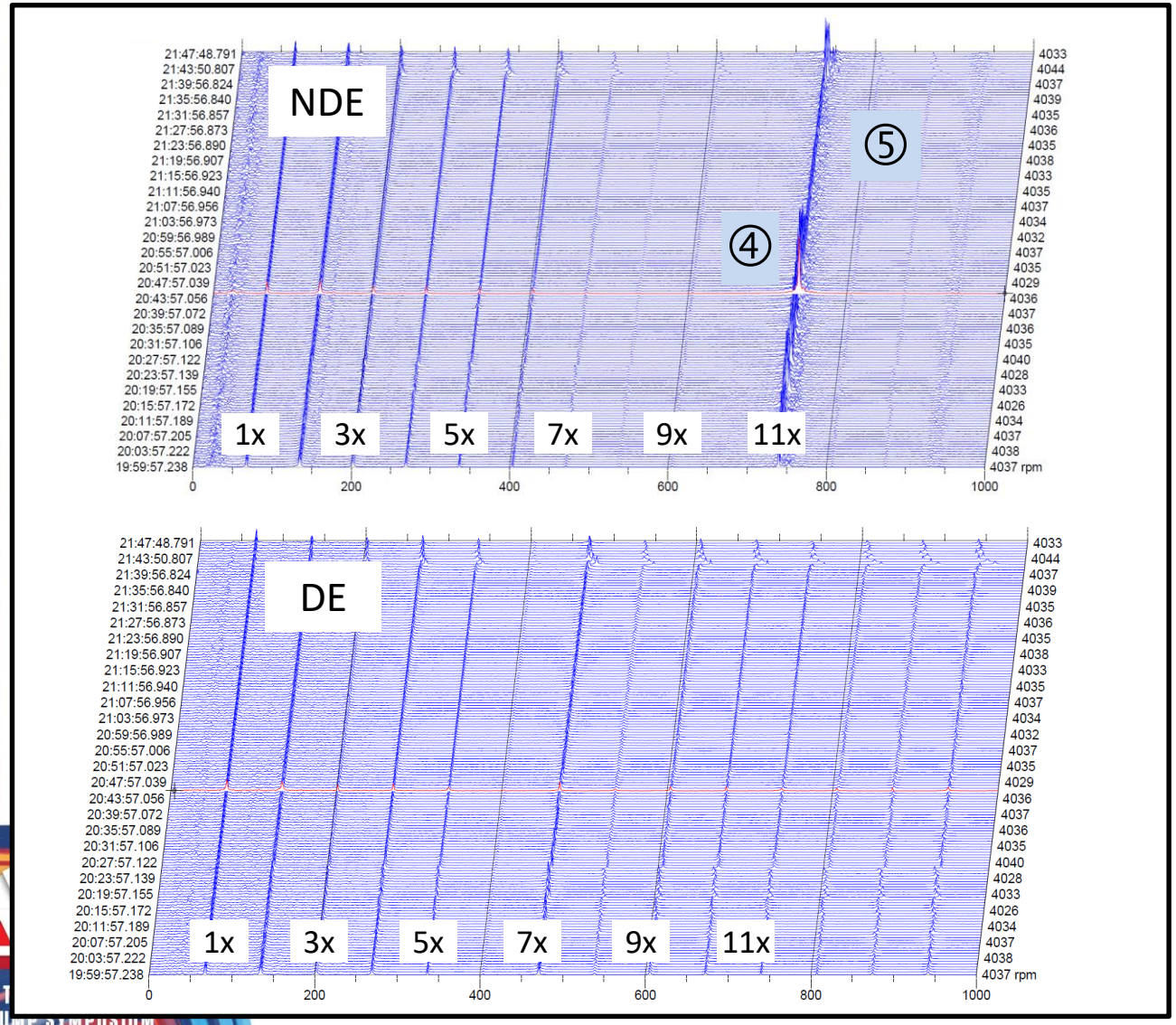
- Increased NDE-Vibration up to 60 µm with speed (①) then with load (②).
- Vibration below alarm (70 µm) and trip (93 µm)
- DE-Vibration still low (③)

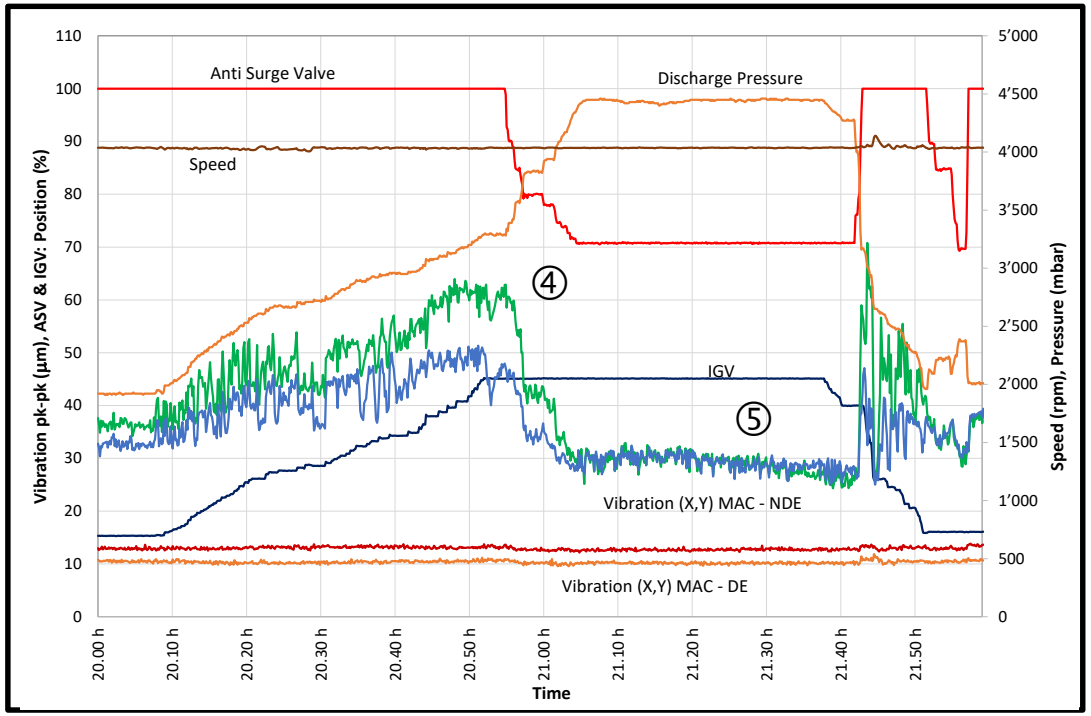
Findings – Lateral Vibrations (2/3)



- Sudden decrease of NDE-Vibration at both probes (④➔⑤) during increased discharge pressure @ constant IGV & speed
- All other vibration signals (DE-MAC, Steam Turbine, Axial Position) barely affected by operational conditions.

Findings – Lateral Vibrations (3/3) - Waterfall diagrams





- Vibrations: 11x super-synchronous
- Overall Vibration increase due to 11x

Root Cause Analysis – Further Investigations of Vibrations

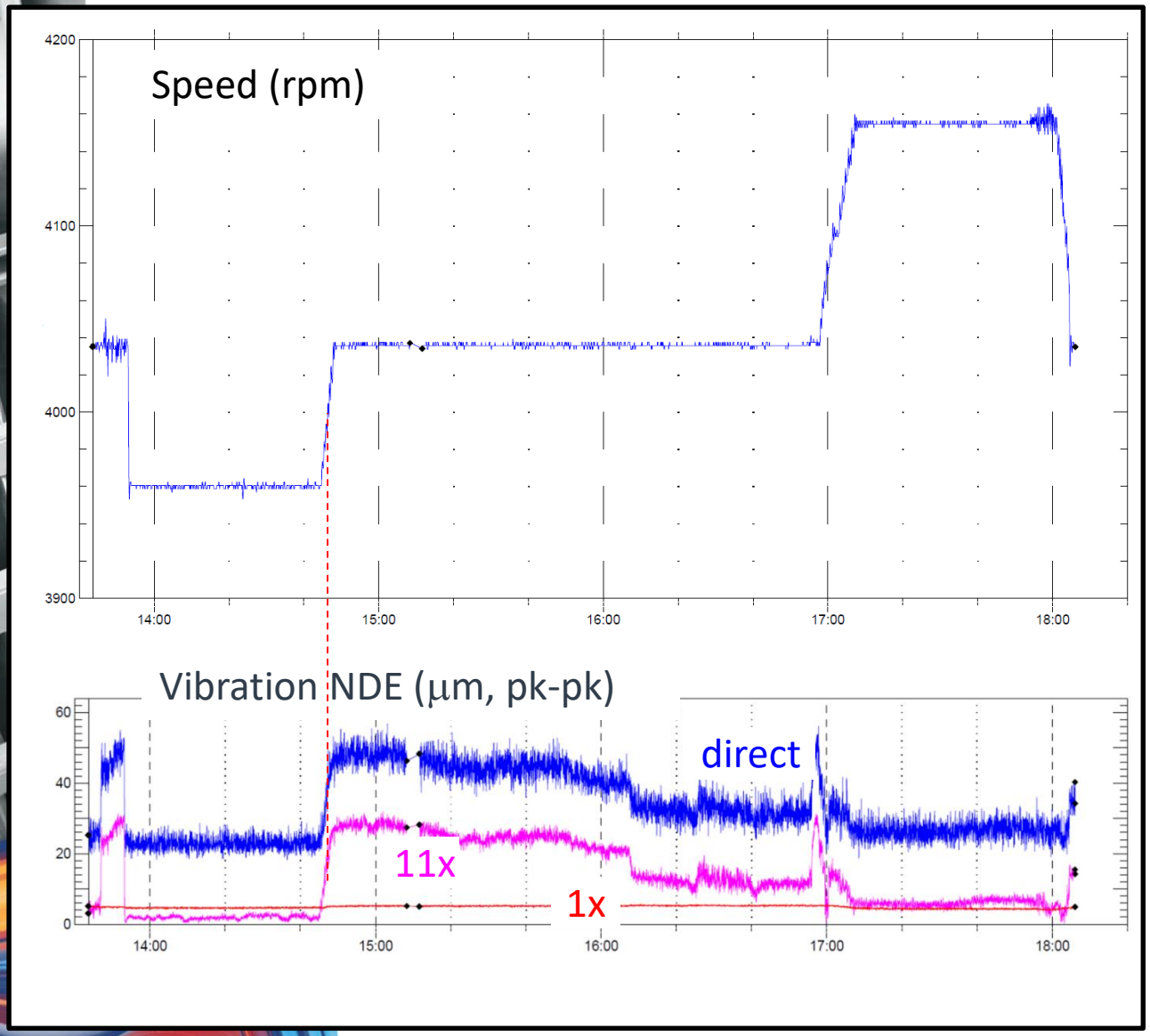
- Additional measurements performed at different operating conditions in order to characterize phenomenon.
- Test Procedure :

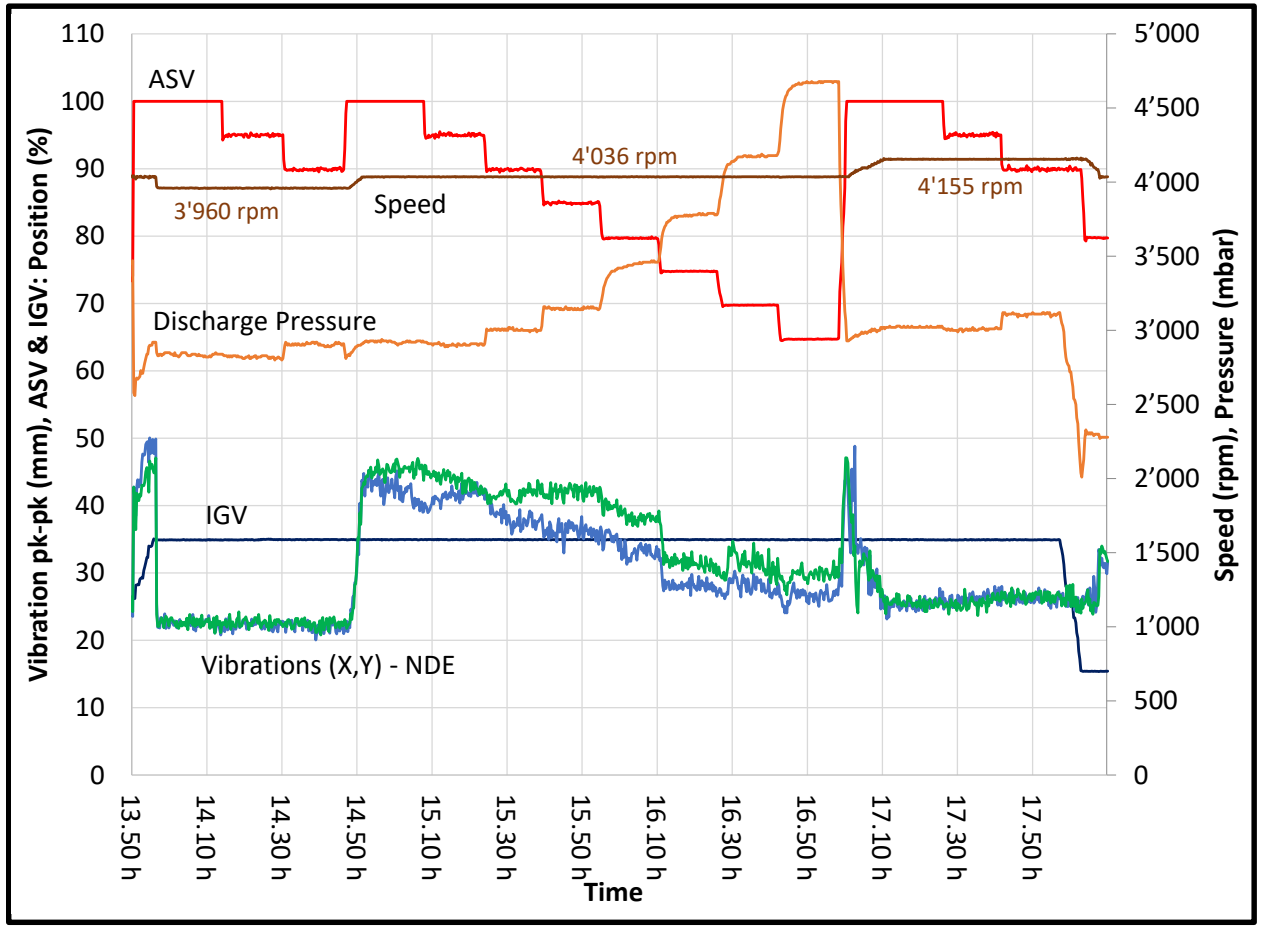
Test	IGV	Speed	Discharge Pressure	ASU
1	35%	3’960 rpm	≈ 2.9 bara	100% → 90%
		4’036 rpm	2.9 → 4.7 bara	100% → 65%
		4’155 rpm	≈ 3.1 bara	100% → 80%
2	45%	3’960 rpm	≈ 3.1 bara	100% → 90%
		4’036 rpm	3.2 → 3.7 bara	100% → 80%
		4’155 rpm	≈ 3.3 bara	100% → 90%
3	60%	3’960 rpm	≈ 3.3 bara	100% → 90%
		4’036 rpm	3.3 → 3.6 bara	100% → 85%
	50%	3’960 rpm	≈ 3.2 bara	100%
	60%	4’155 rpm	≈ 3.7 bara	100%
4	45%	3’960 → 4’155 rpm	3.2 - 3.4 bara	100%
5	45%	3’960 → 4’155 rpm	3.2 → 3.4 bara	75%

IGV: 0% : closed – 100% : open

RCA – Further Investigations – Test 1

Test	IGV	Speed	Discharge Pressure	ASU
1	35%	3'960 rpm	≈ 2.9 bara	100% → 90%
		4'036 rpm	2.9 → 4.7 bara	100% → 65%
		4'155 rpm	≈ 3.1 bara	100% → 80%



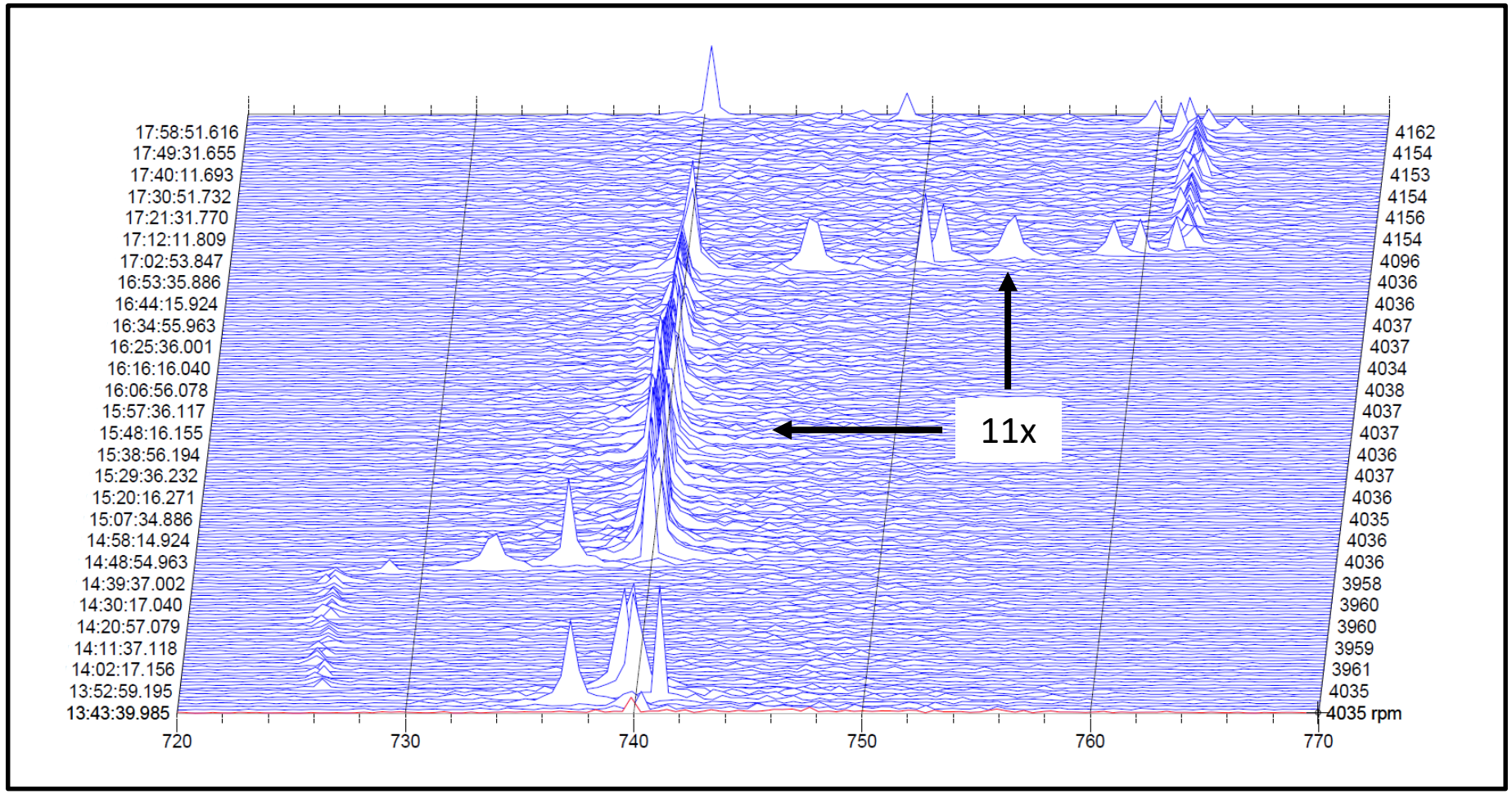


Vibrations NDE:

- Sudden increase @ ≈ 4'000 rpm
- Then slight decrease with increased pressure
- More sensitive to speed than to pressure

RCA – Further Investigations – Test 1

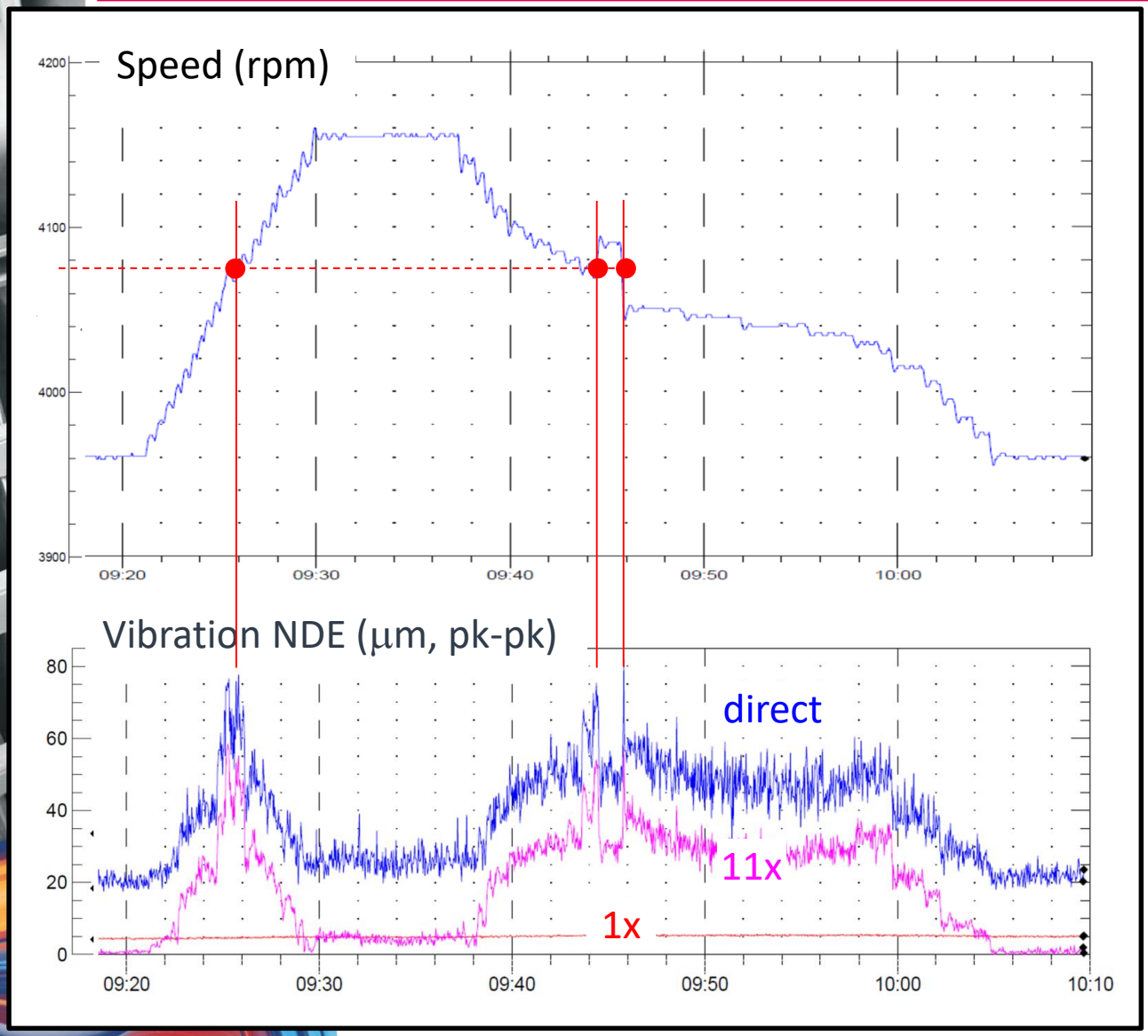
Test	IGV	Speed	Discharge Pressure	ASU
1	35%	3'960 rpm	≈ 2.9 bara	100% → 90%
		4'036 rpm	2.9 → 4.7 bara	100% → 65%
		4'155 rpm	≈ 3.1 bara	100% → 80%

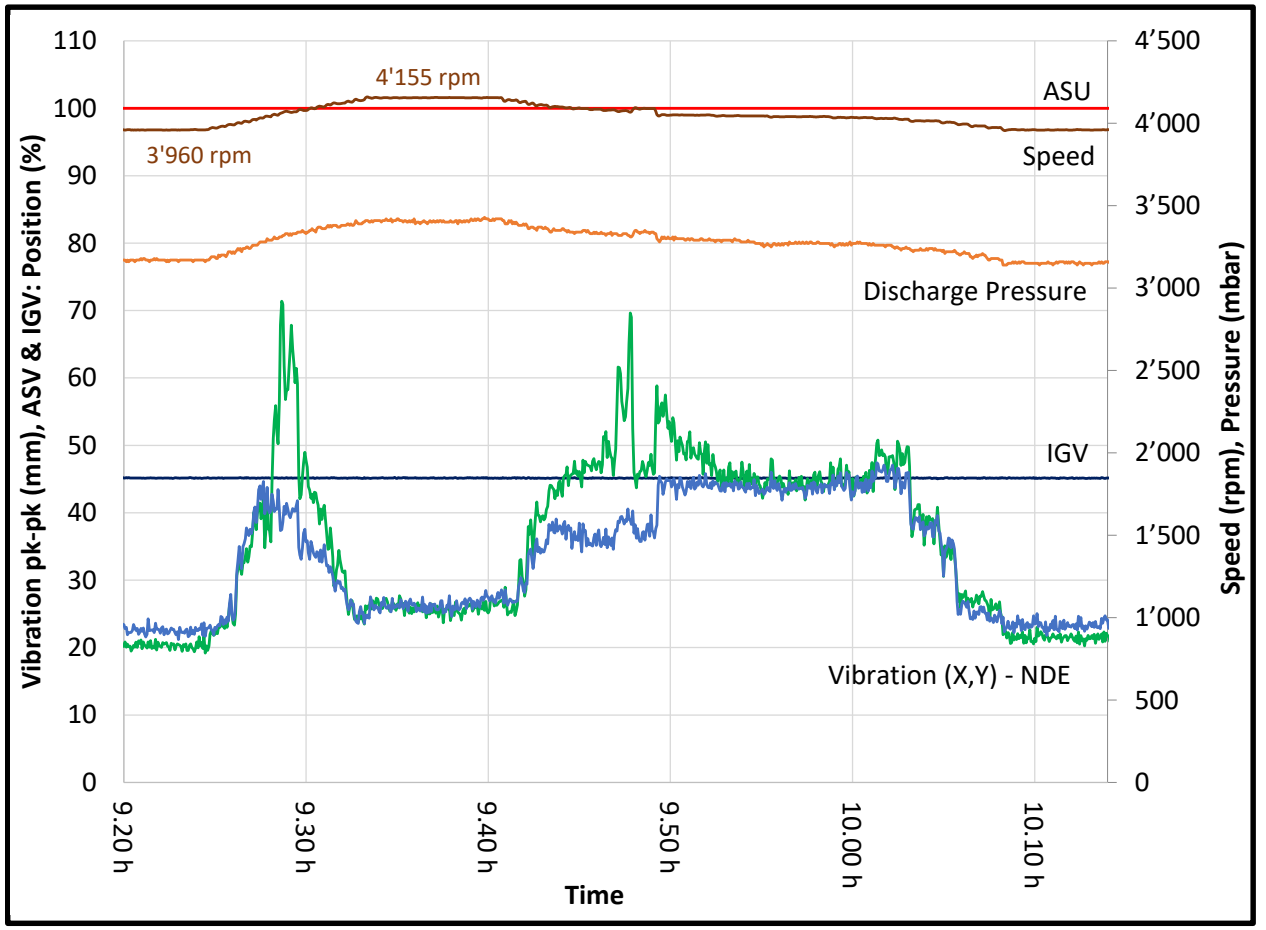


- Origin of high vibrations: 11x super-synchronous
- 11x synchronous always present, independly of operating condition

RCA – Further Investigations – Test 4

Test	IGV	Speed	Discharge Pressure	ASU
4	45%	3'960 → 4'155 rpm	3.2 - 3.4 bara	100%



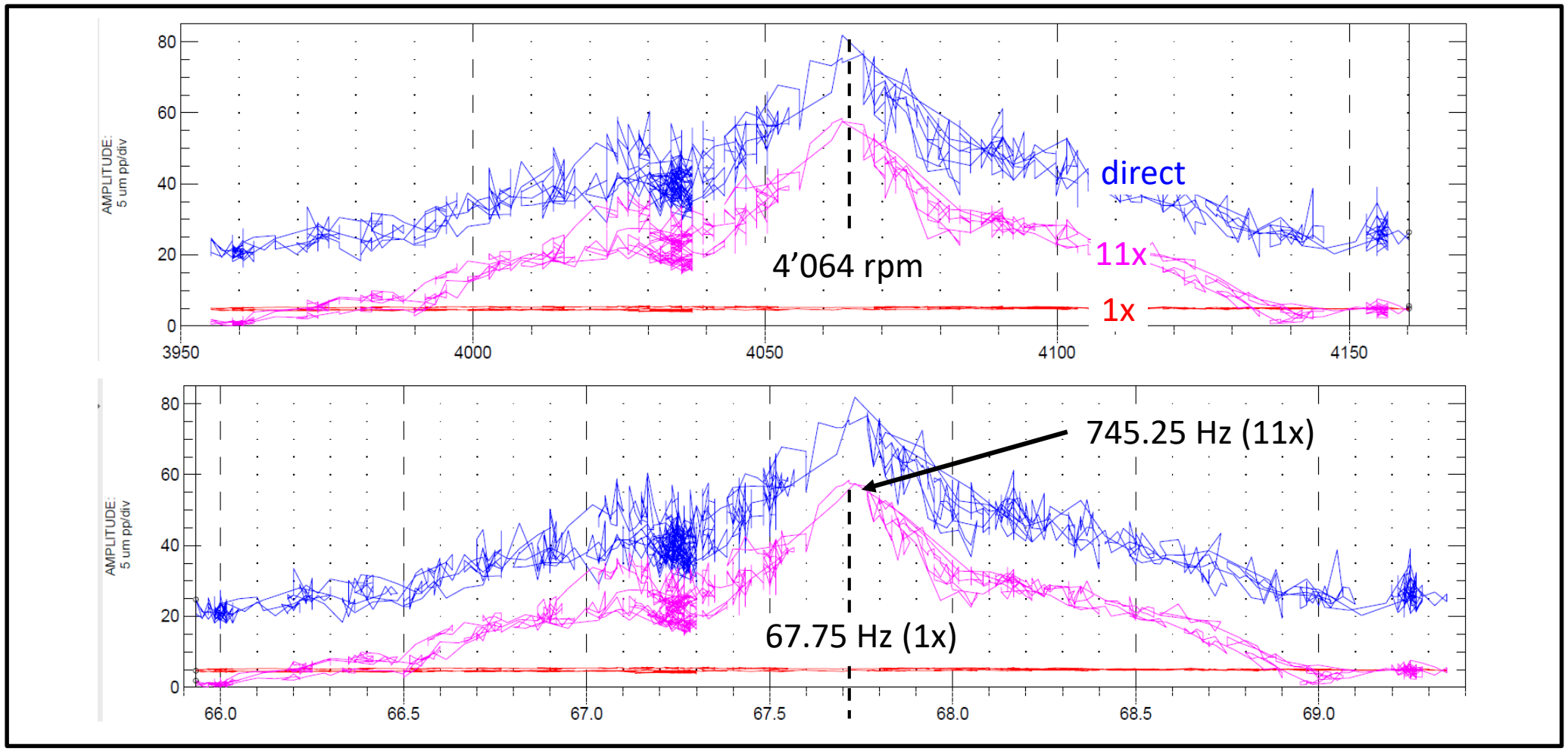


Vibrations NDE:

- Clear dependence on speed
- Max amplitude (80 µm) reached @ ≈ 4'070 rpm

RCA – Further Investigations – Test 4

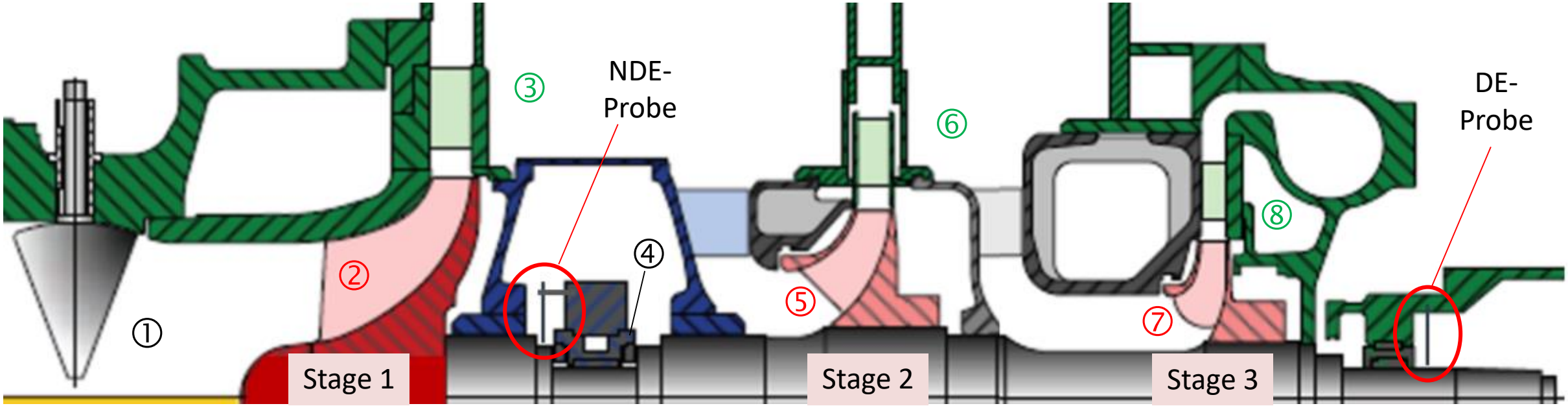
Test	IGV	Speed	Discharge Pressure	ASU
4	45%	3'960 → 4'155 rpm	3.2 - 3.4 bara	100%



- Clear resonance @ 4'064 rpm and 11x harmonic
- Resonance frequency: 745 Hz

RCA – Origin of 11x - Excitation

- Listing of blade numbers of rotor and stator parts



	Name	# blades
①	IGV	≠ 11
②	Impeller 1	≠ 11
③	Diffuser 1	>>11
④	AxBearing Pads	≠ 11

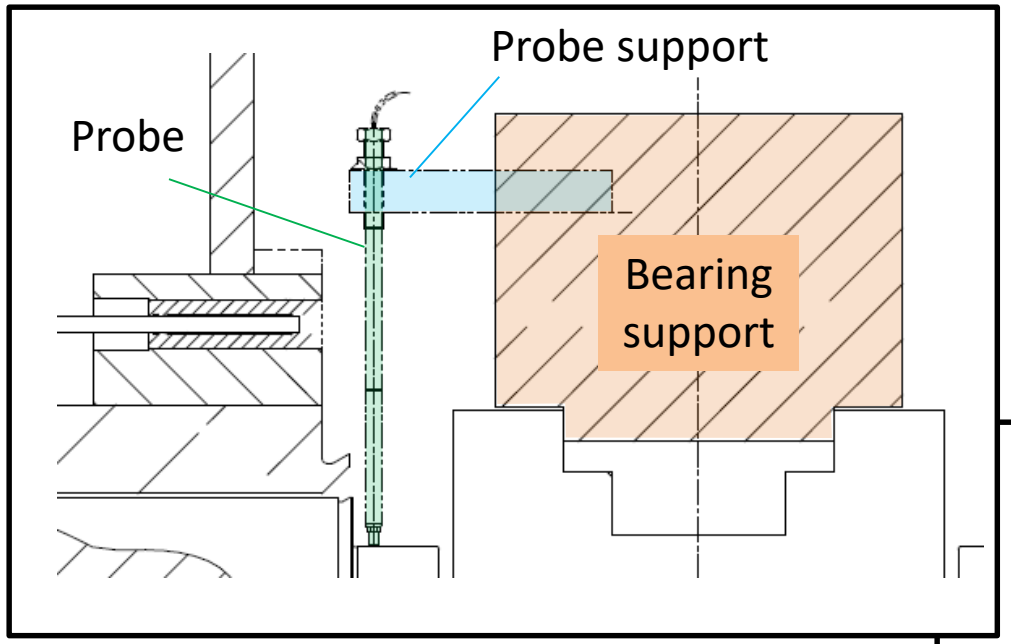
	Name	# blades
⑤	**Impeller 2**	**11+11**
⑥	Diffuser 2	>>11
⑦	Impeller 3	≠ 11
⑧	Diffuser 3	>>11

(11 main + 11 splitter blades)

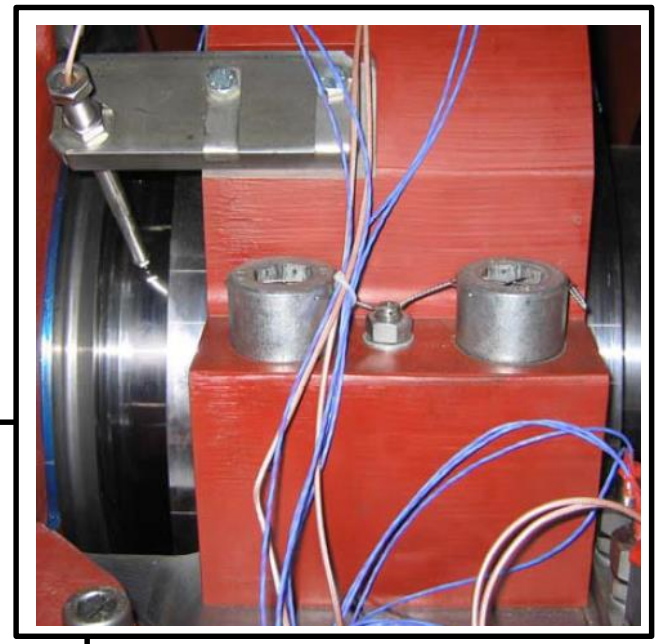
→ Excitation from non-uniform flow at inlet of impeller 2

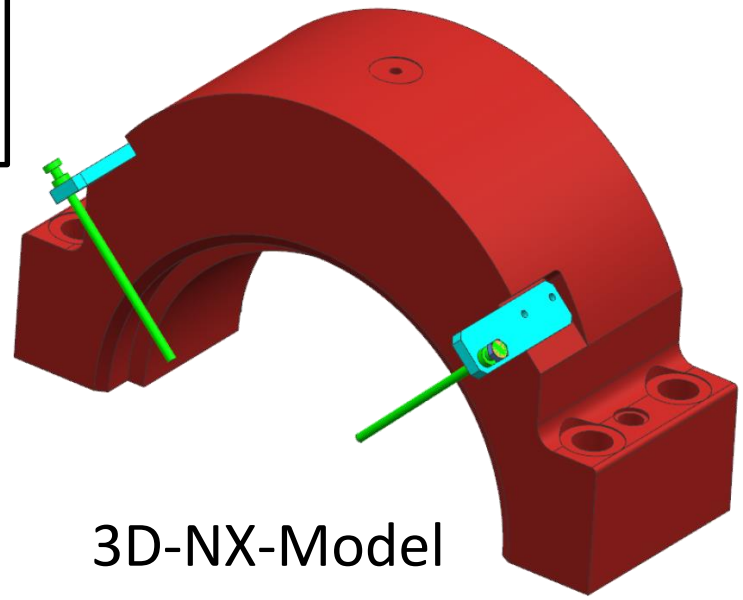
RCA – Modal Analysis of Probe Support

- Model of assembled parts



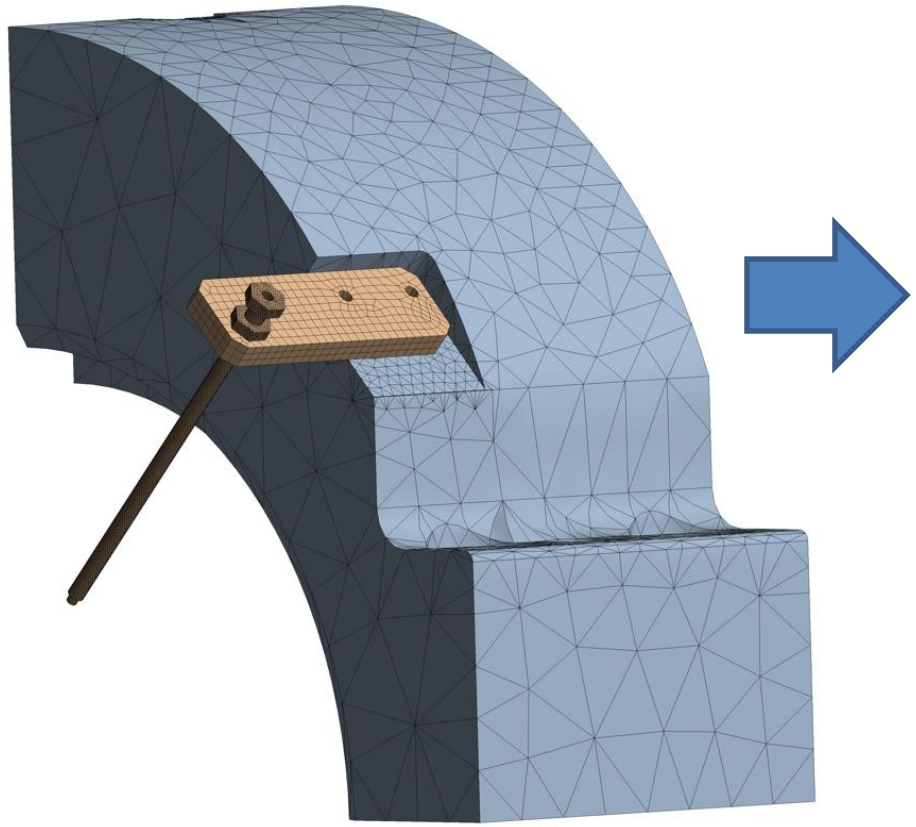
Cross Section



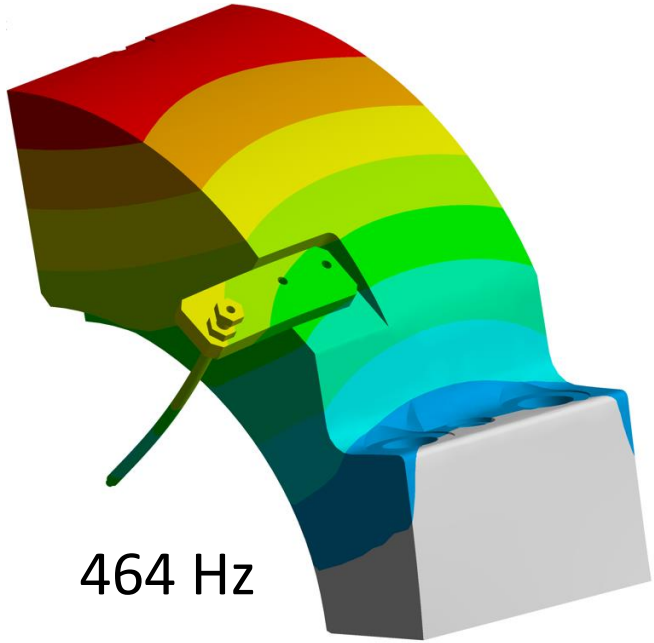


3D-NX-Model

RCA – Modal Analysis of Probe Support – FEA-Results

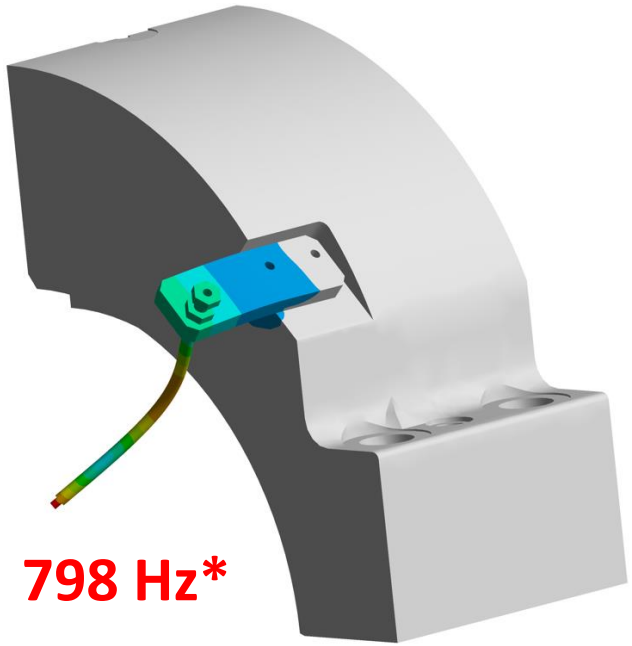


Meshed Half-Model



464 Hz

Bearing Support



798 Hz*

Probe Support

** 798 Hz: Probe considered as hollow tube.*
703 Hz: Probe considered as "full" tube
→ Expected natural frequency: between 703 Hz and 798 Hz

Eigenmodes

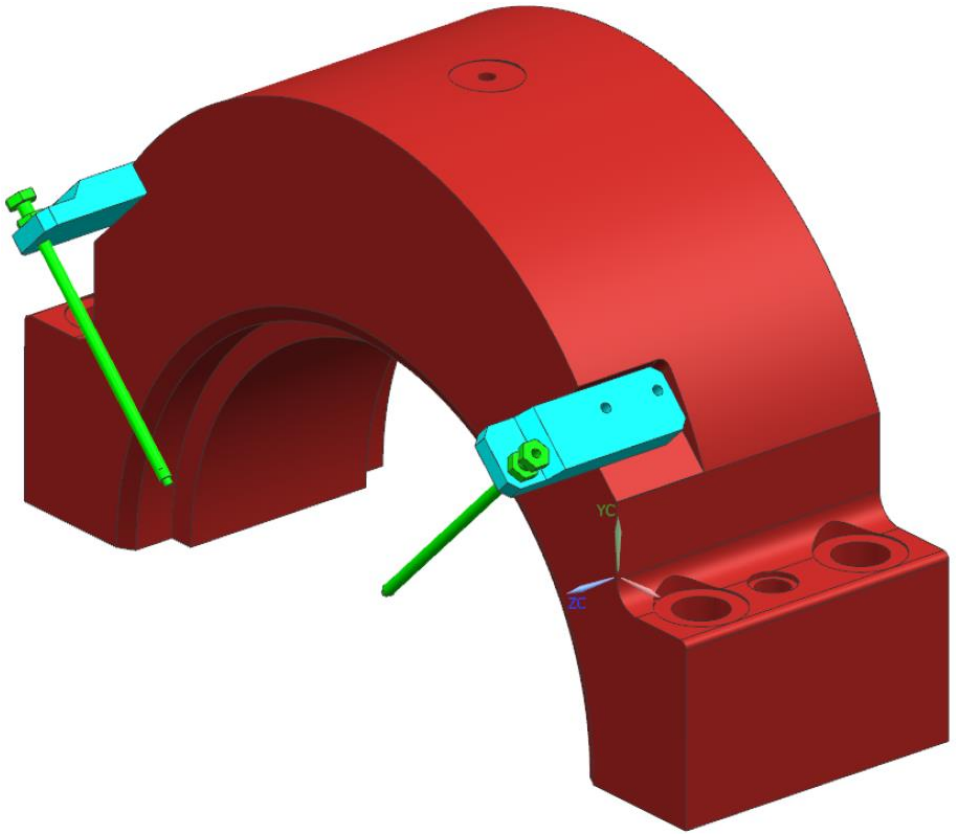
→ Excitation of the natural frequency of probe support @ approx. 750 Hz

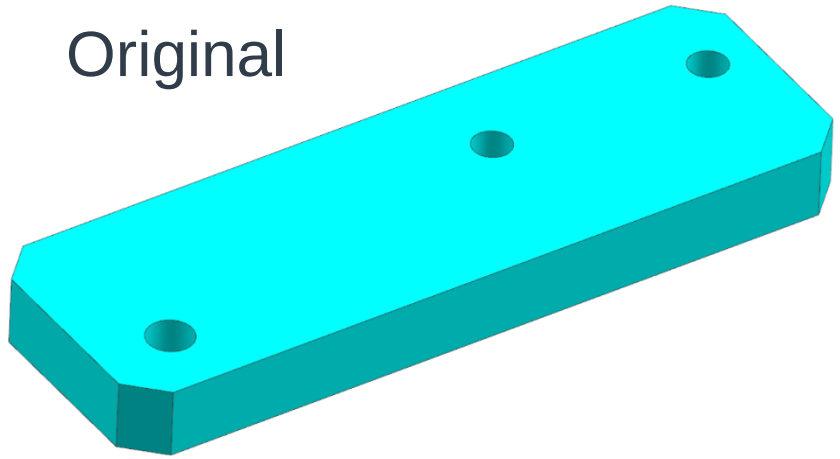
RCA – Summary and Countermeasures

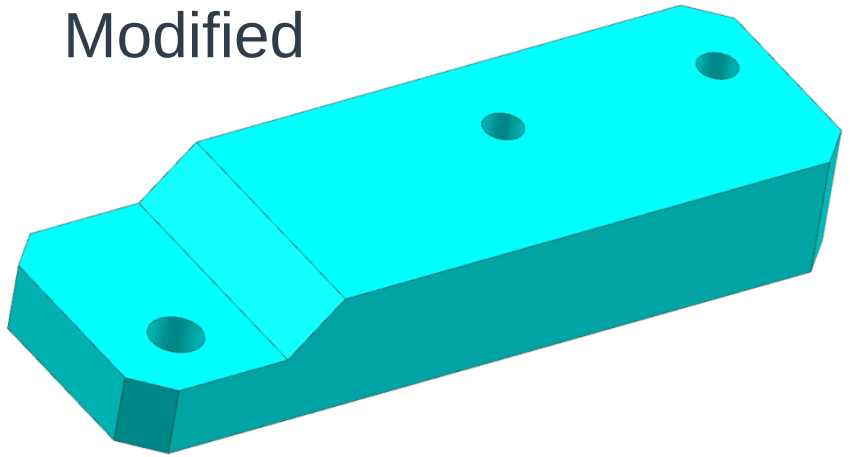
- Findings
  - Bearing, Casing and Probes were correctly mounted
  - Vibrations correlated with 11 times super-synchronous :
    Number of impeller's blades near NDE-bearing
  - Higher vibration appeared at only one particular speed → resonance
- RCA
  - Increased vibration results from the excitation of natural frequency of probe support, triggered by pressure fluctuation at the suction of the 11 blades-impeller (forced vibration)
- Countermeasure
  - Design of support revised → Increased stiffness to shift natural frequencies

Countermeasure : Modified Probe Support

3D-Model with revised probe support

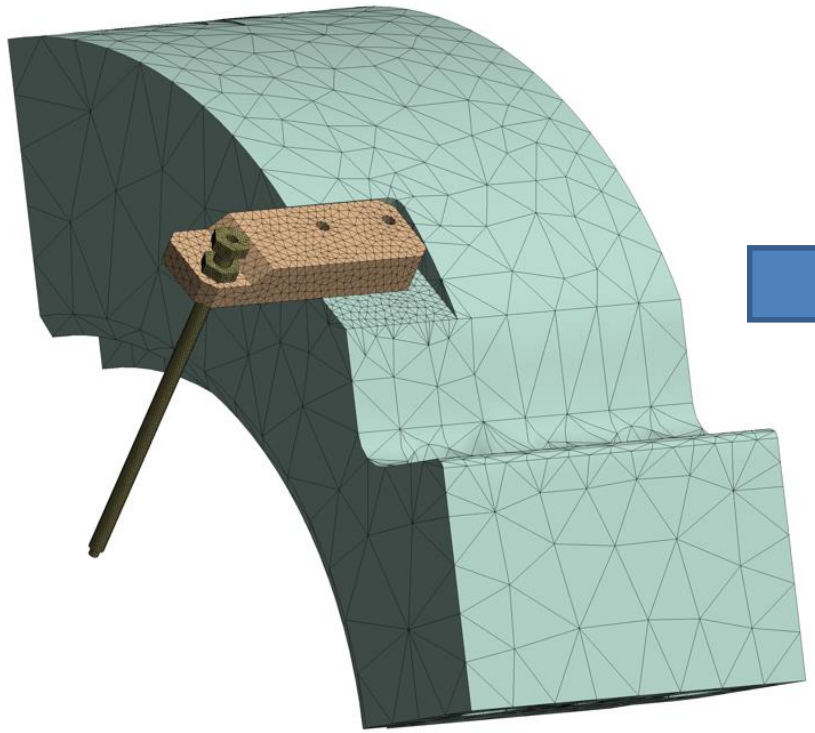




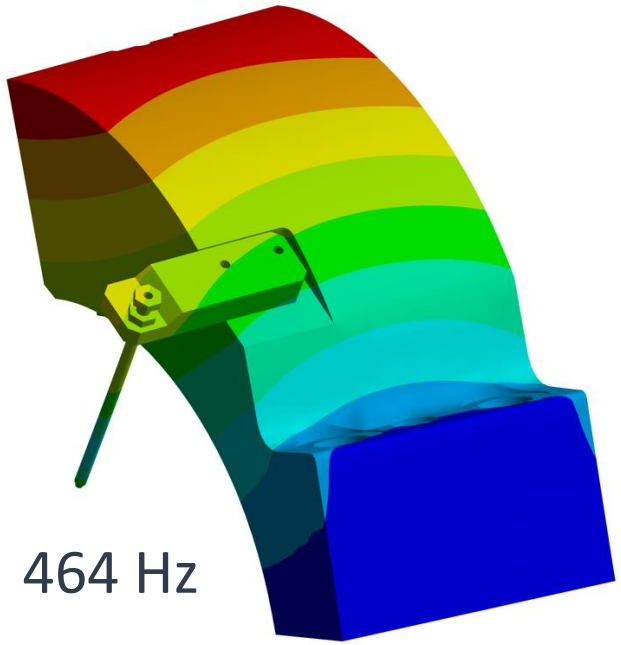


Countermeasure : Modified Probe Support

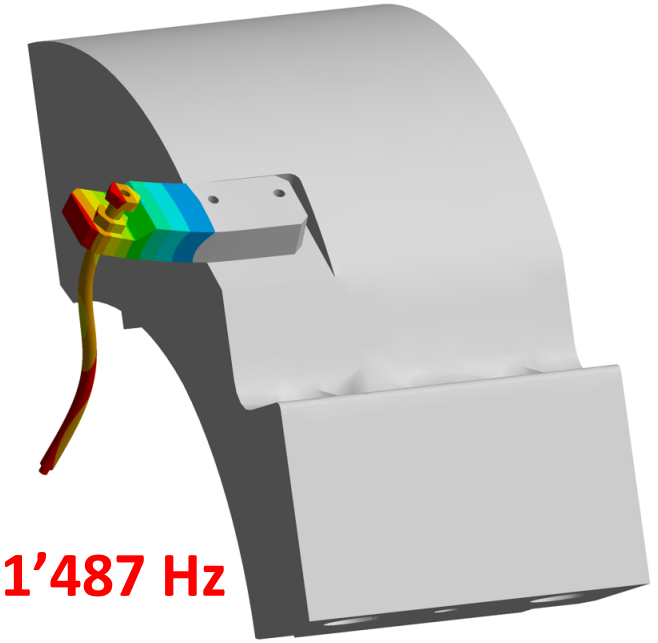
- FEA - Results



Meshed Half-Model



Bearing Support

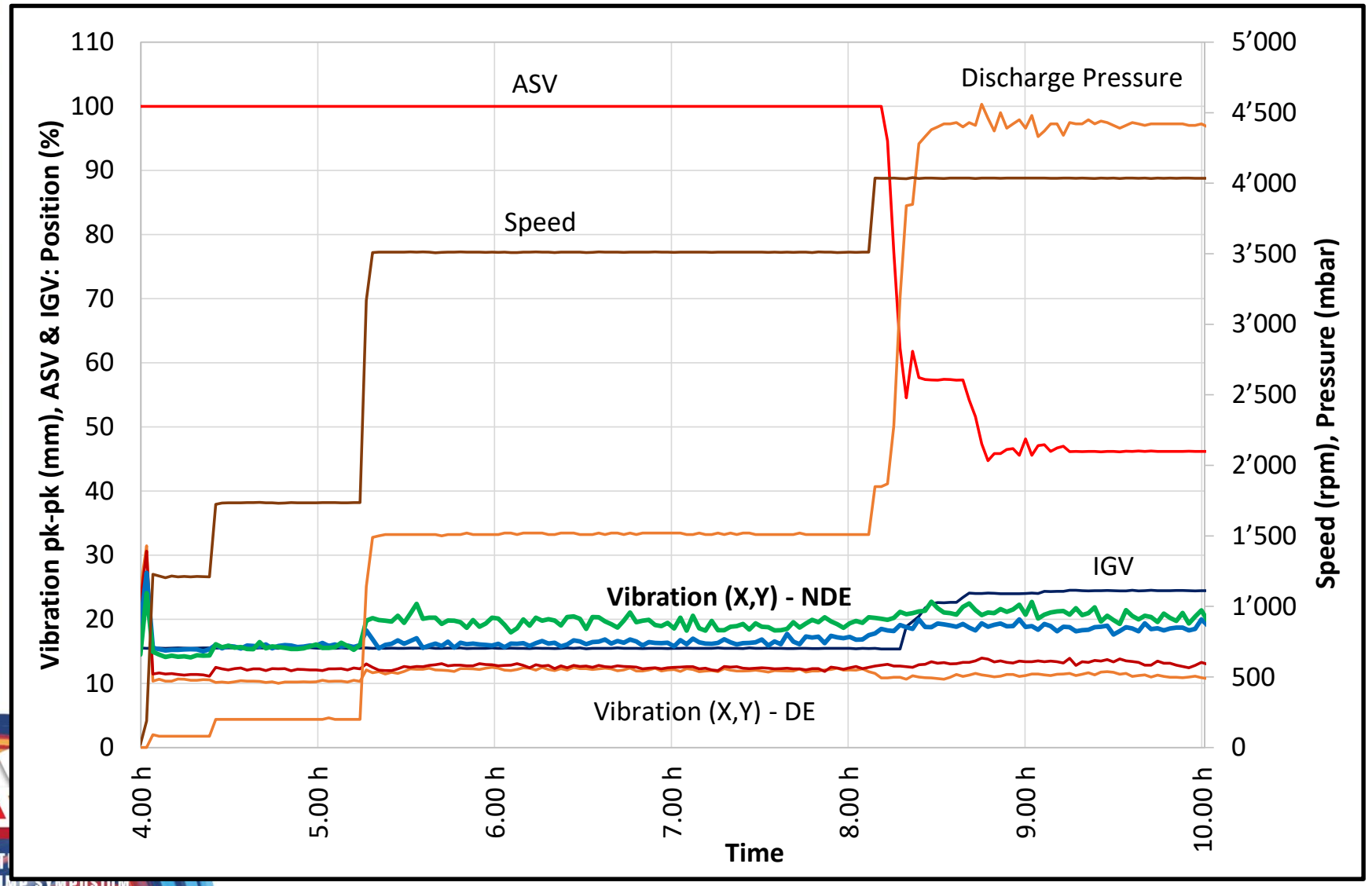


Probe Support

Eigenmodes

→ Natural frequency of probe support increases up to 1’487 Hz

Measurements after Modification



- All vibrations low and stable

Lessons learnt / Summary

- The support of vibration probes requires careful attention (especially if machines are standardized for very large operating speed range)

- If necessary, a simple FE Analysis should be performed to determine the natural frequencies of the support and for optimization of the design.

Case Study – Support Probe

Thank you !
Questions ?

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