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TEXAS A&M UNIVERSITY | TEES TURBOMACHINERY LABORATORY
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Self excited torsional vibration
in Single Shaft Combined Cycle Turbine-Generator train

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a Baker Hughes business

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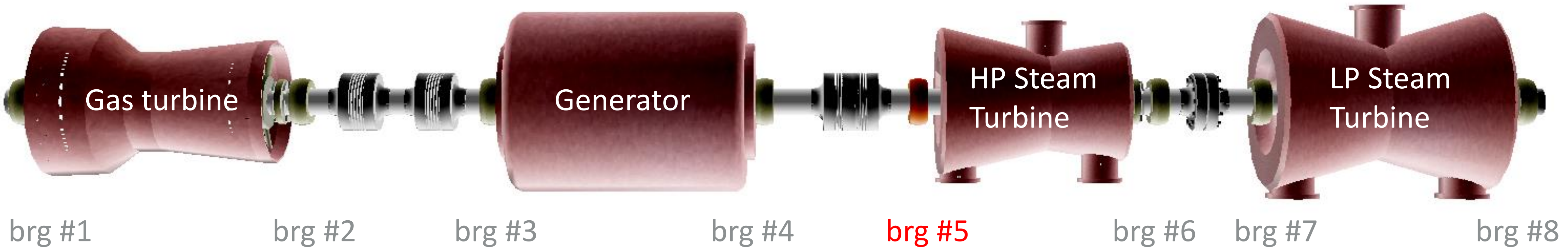
Abstract

This case history describes the investigation of the source of unstable behavior of a newly commissioned single-shaft, combined cycle, power generator unit. The source was found to be nonlinear operation of the flexible coupling between the generator and steam turbine, causing self-excited parametric torsional oscillations, transferred into radial vibration, detectable in monitoring system.

The machine diagram

- Single shaft combined cycle, new, under commissioning.



The problem

- High vibration levels at brg #5, during full speed no load condition of the gas turbine.
- Coupling between generator and the steam turbine is flexible (diaphragm) type.

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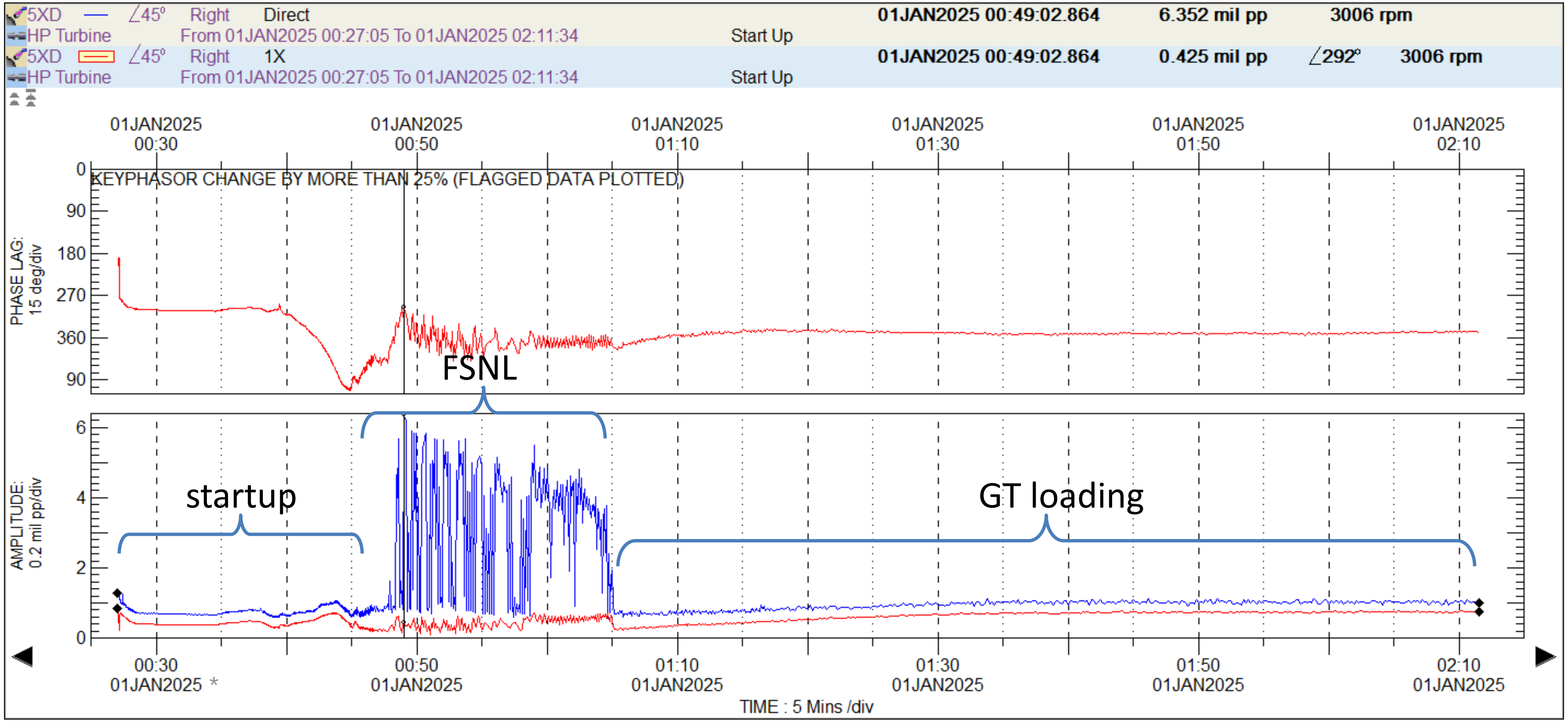
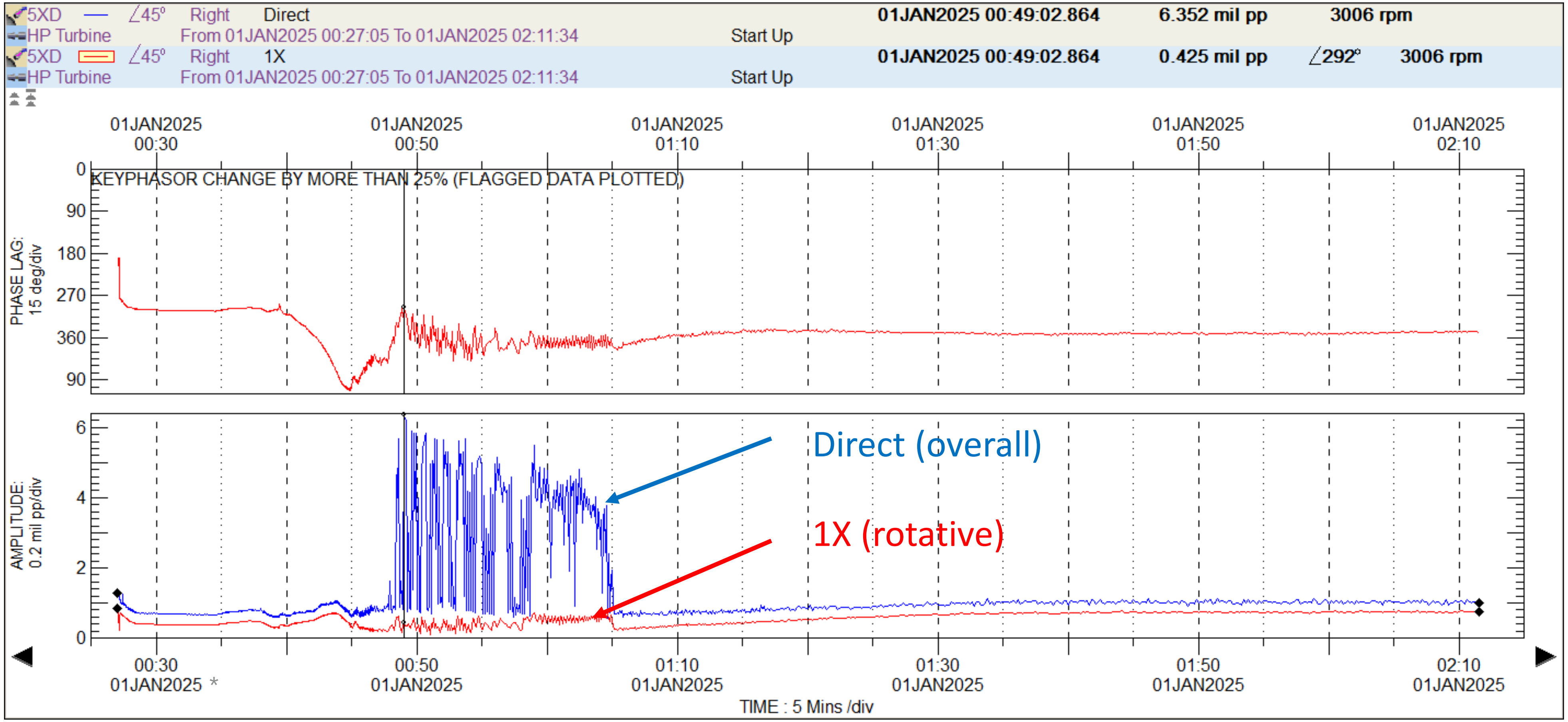


*Note: Date and time changed to anonymize the unit.

The problem

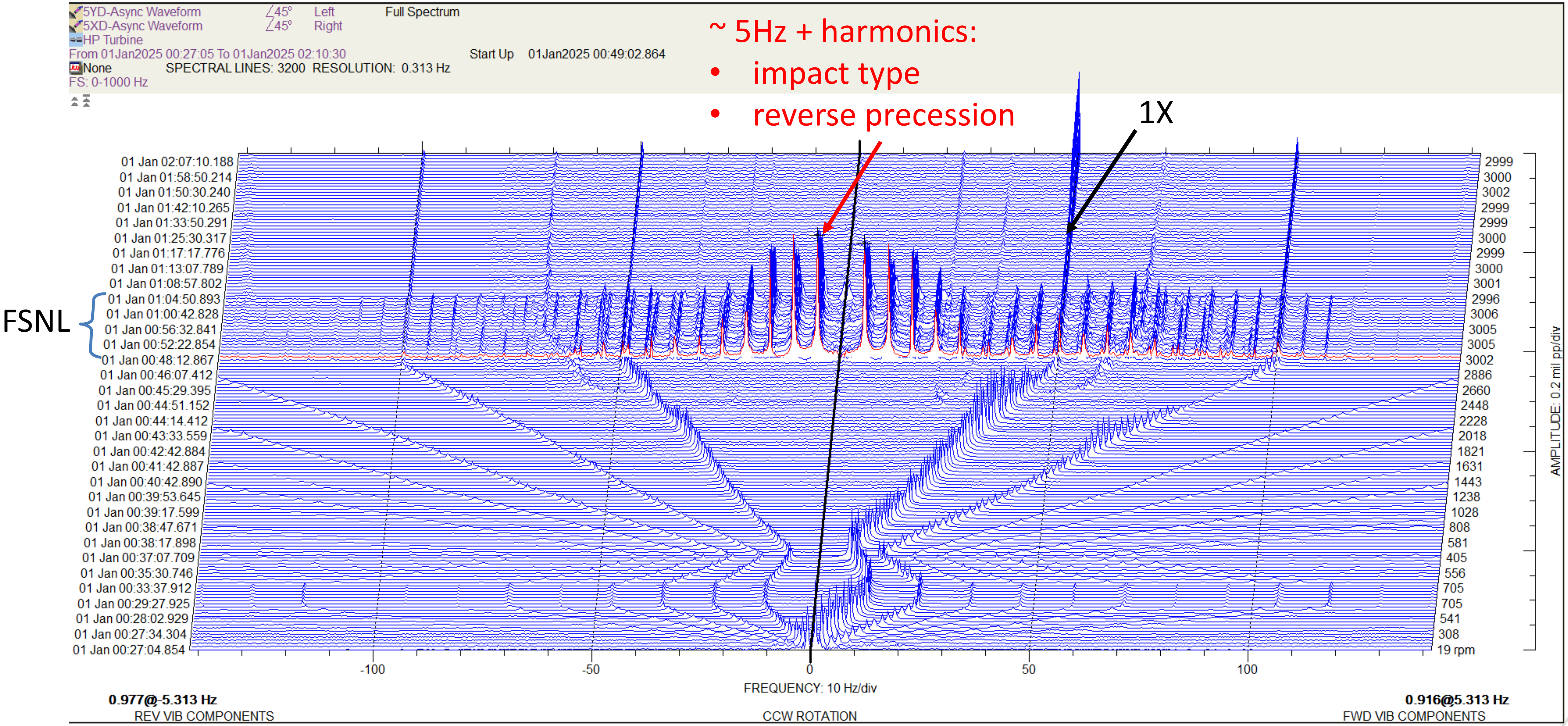
- High Not 1X vibration levels at brg #5, when gas turbine at FSNL conditions.



*Note: Date and time changed to anonymize the unit.

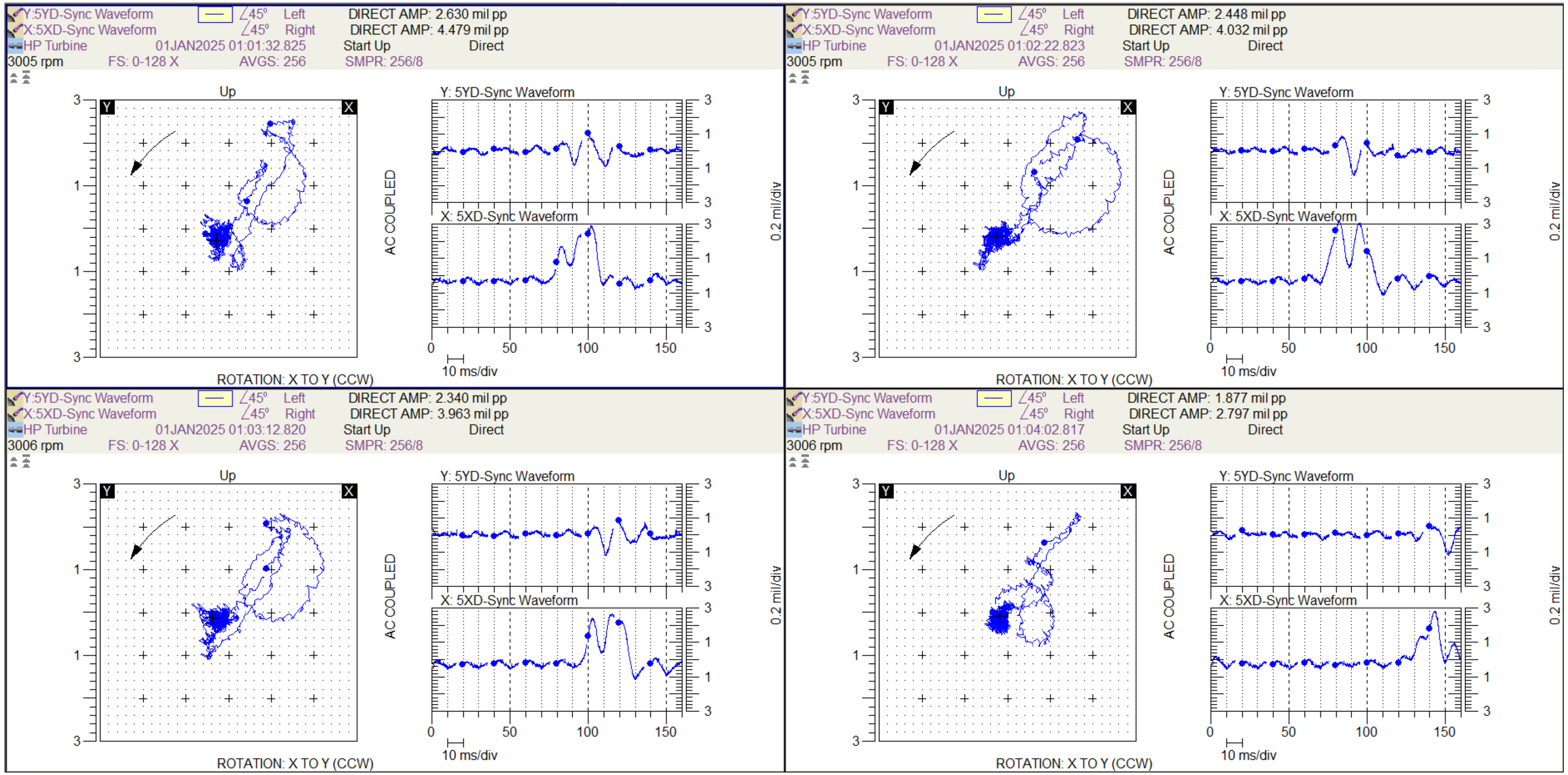
Frequency domain

Shaft relative vibration, full spectrum waterfall



Time domain

Sample orbit + timebase plots

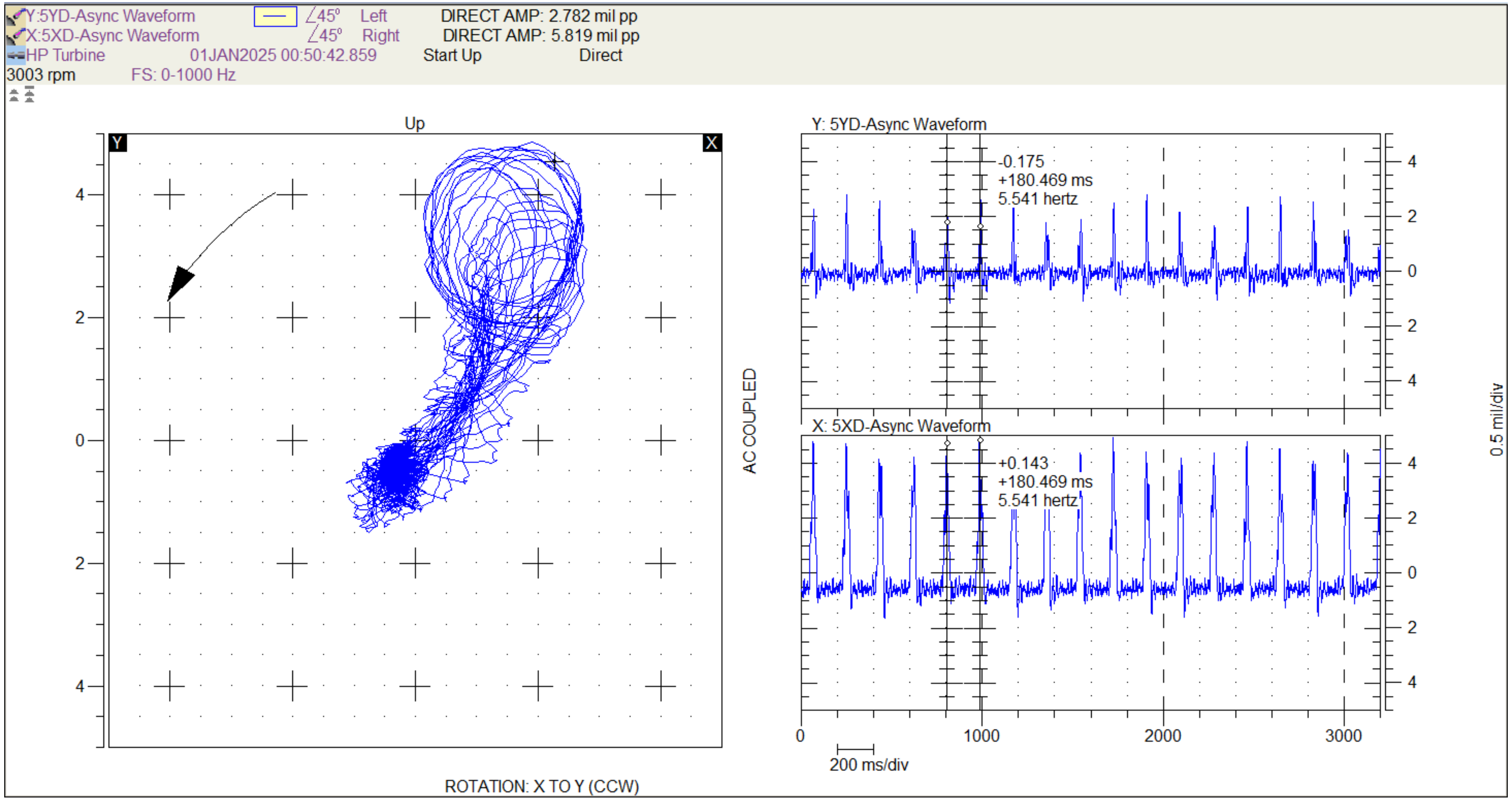


- Impact type events
- Moving shaft from stable trajectory
- Consistent direction
- Seems repeatable…

We need a longer observation period to see repeatability.

Time domain

Orbit and timebase plot from asynchronous waveforms.

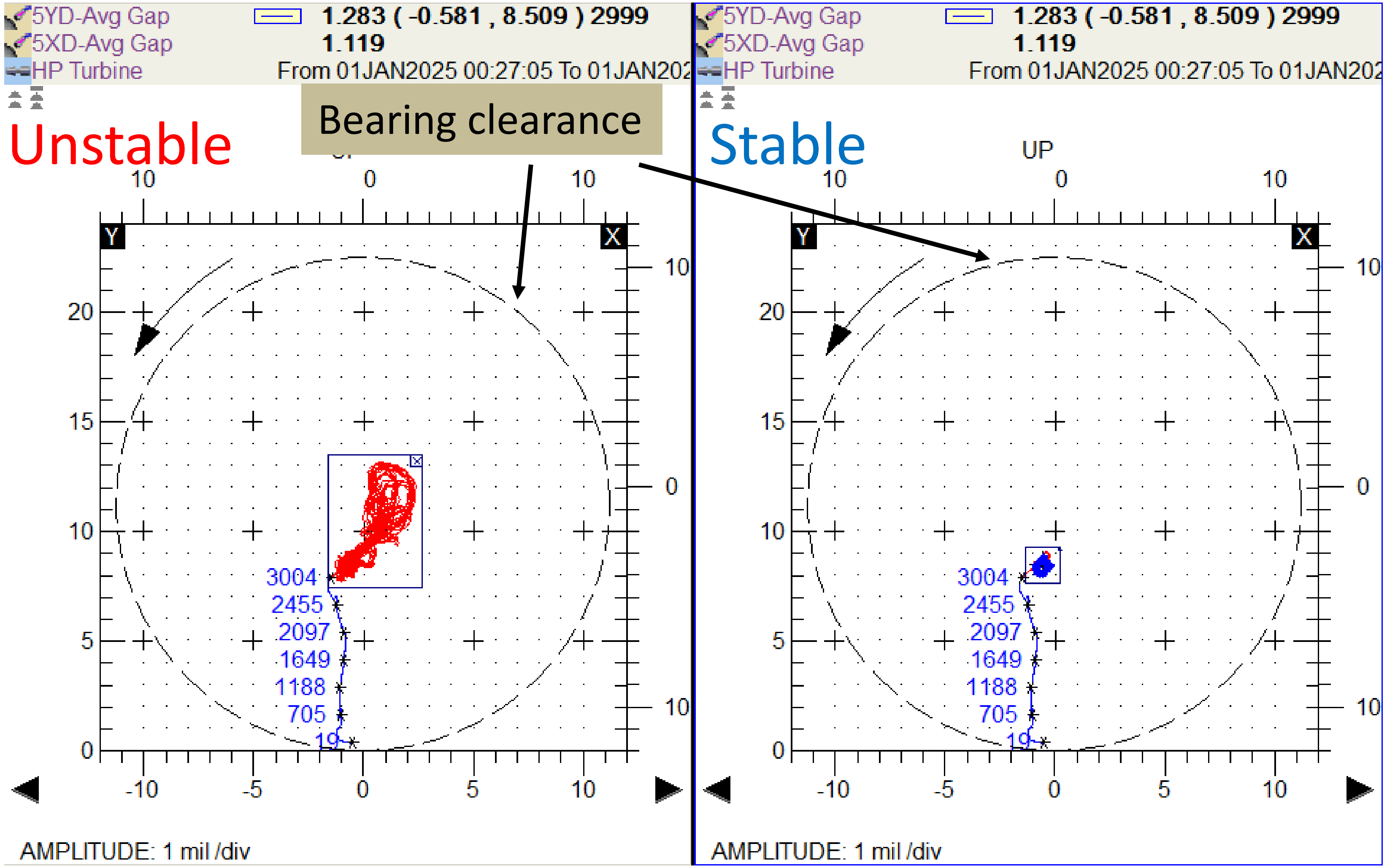


- Impacts are repeating with frequency **5.54 Hz**
- No known excitation at this frequency

- Can it be a system resonance?
- Can it be a radial rub?

Vibration excursion

Shaft centerline plot with orbit overlay



- SCL position is normal and far from the clearance boundary
- There is no difference in position for stable/unstable operation
- Vibration excursions are not interfering with clearance limits.

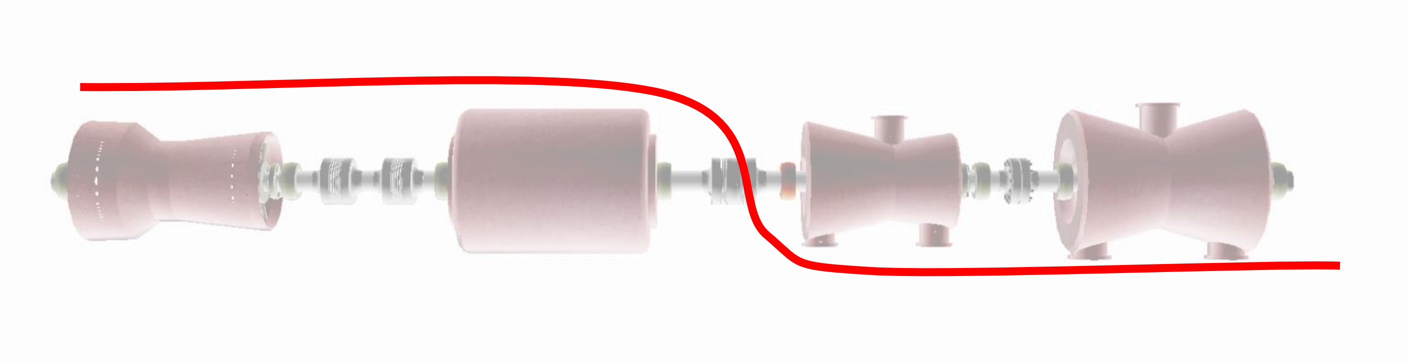
It does not look a like radial rub...

- The 5.54 Hz is far too low frequency for a lateral mode of this type of unit.

Can it be torsional mode?

Torsional mode

- OEM rotordynamic calculations confirm 1st torsional mode at 5.54Hz
- The nodal point for the mode is located at generator – steam turbine coupling



What is the vibration conversion mechanism between torsional and lateral mode?

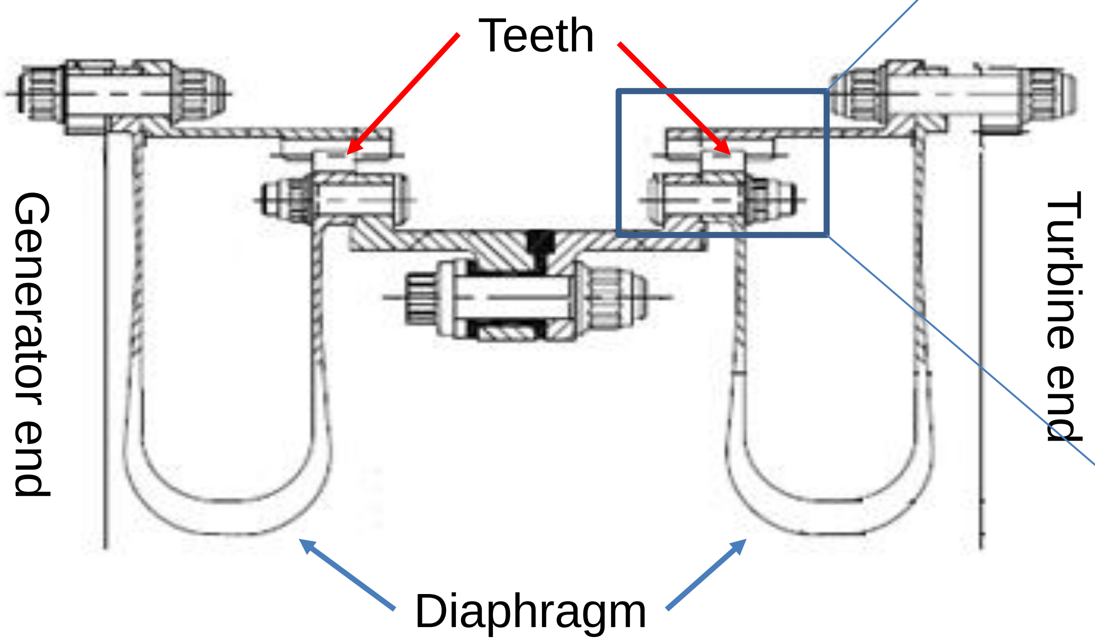
Known typical reasons:

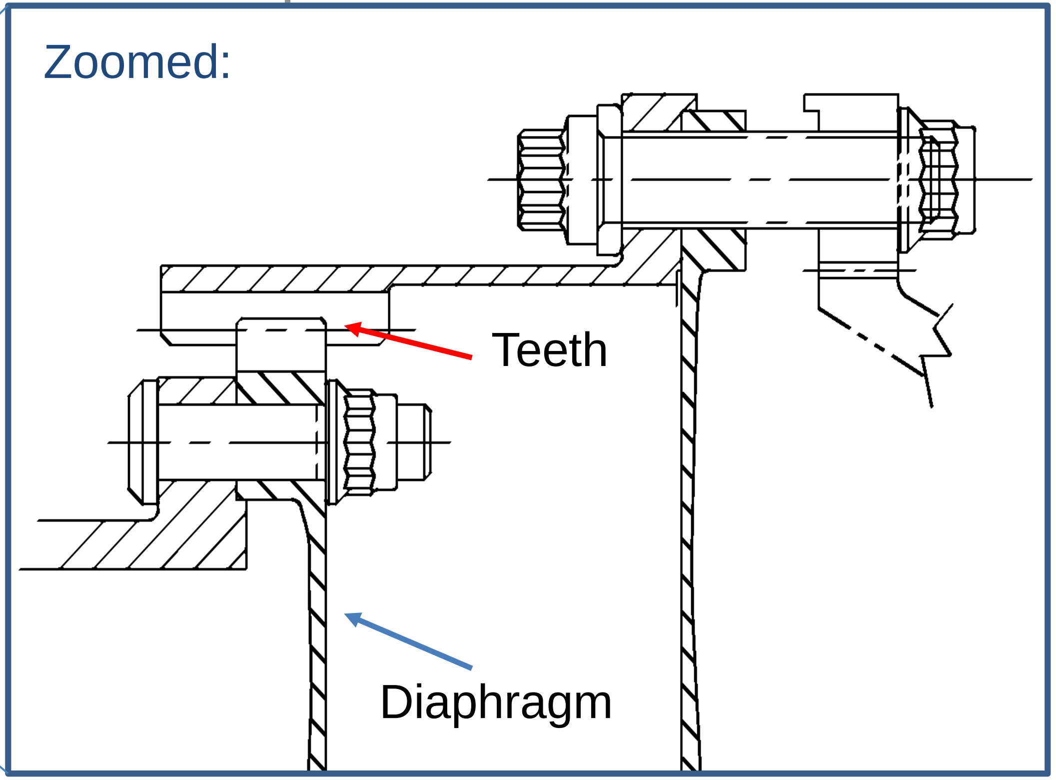
- Gearbox teeth action (Does not seem relevant, does it?)
- Coupling damage causing asymmetry/deformation and nonlinearities
- …

Vibration conversion mechanism

- Coupling diaphragm has the teeth to enable safe shutdown in case of damage. They are not designed to be in contact, in normal operation.

Flexible diaphragm coupling

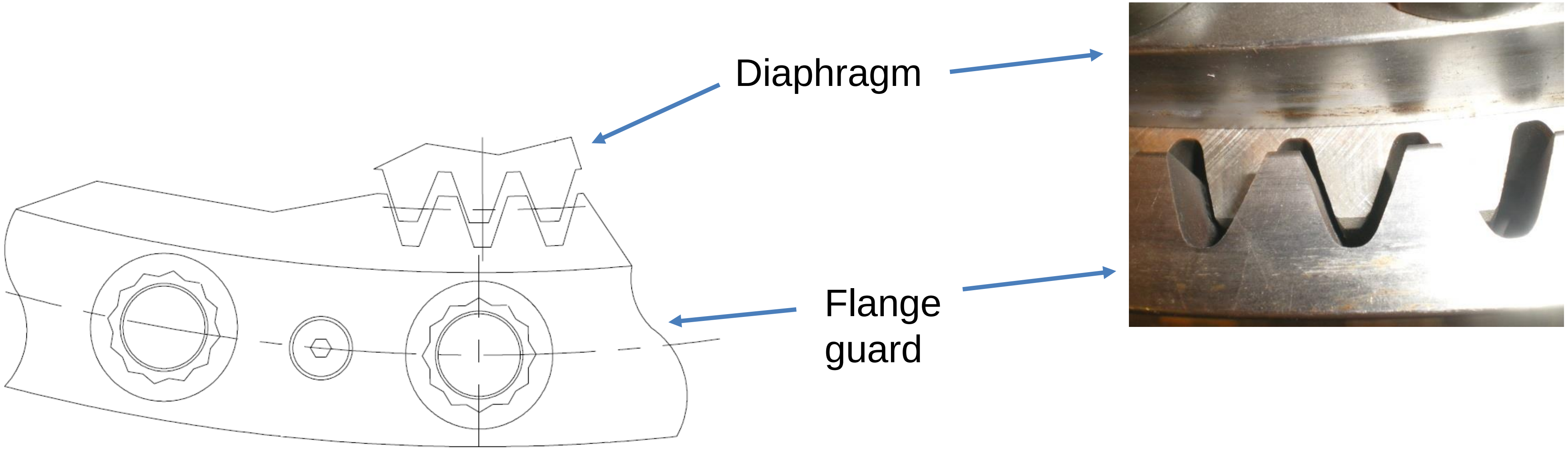




Vibration conversion mechanism

- Coupling diaphragm has the teeth to enable safe shutdown in case of damage. They are not designed to be in contact, in normal operation.
- Apparently, they <u>are</u> in contact - when torsional oscillations are too big, for any reason.

But what excites torsional vibration?



Vibration classification*

- **Free vibration**

  Free vibration is initiated by a disturbance to the system. Once started, the vibration occurs at the system natural frequency and dies away at a rate determined by damping or other frictional losses.

- **Forced vibration**

  Forced vibration is produced by a continuous, periodic forcing of the system. If the amplitude of the force is constant, the amplitude of vibration will also be constant.

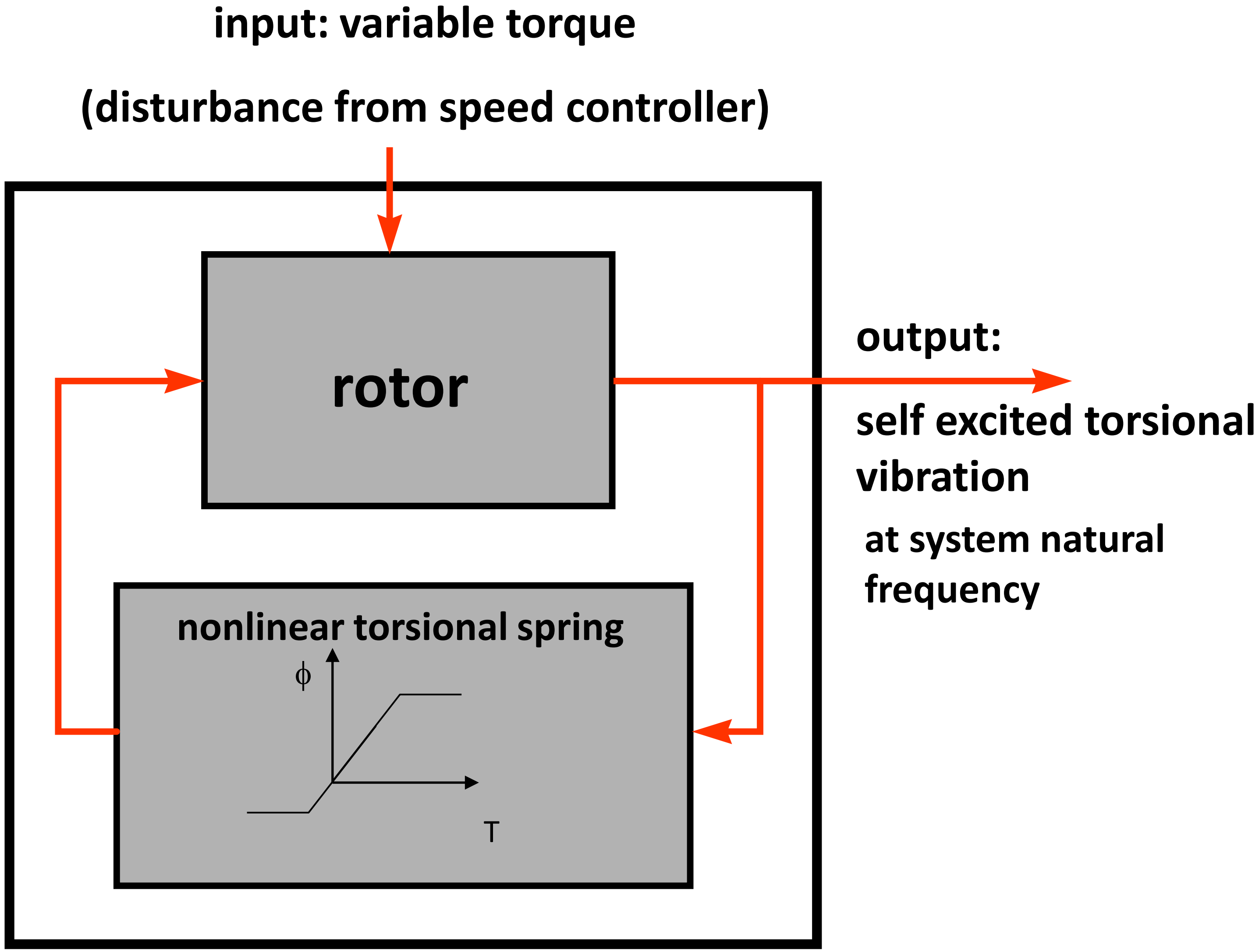
- **Self-excited vibration**

  Self-excited vibration occurs when a system has a method of converting a non-vibrating energy source to vibration energy. The self-excited vibration takes place at a natural frequency of the system.

Observed vibration cycle is not decaying. Also, no forcing at 5.54 Hz frequency was found. So, it can be self-excited. And the phenomenon does take place at the natural frequency of the system.

*Fundamentals of Rotating Machinery Diagnostics; Bently D.E., Hatch, C.T., Grissom B.

The problem description



The solution
(general case for nonlinear oscillator):

- Increase stiffness
- Increase damping
- Remove nonlinearity
- Remove forcing
- Reduce level of perturbations
- …

Viable practical solutions

What to do?	How can it help?	Concerns:
Increase coupling stiffness.	Linear spring for bigger range of amplitude.	Coupling redesign.
Change the position of teeth to symmetric.	Linear spring for bigger range of amplitude, on low loads.	Reduces stability margin for high loads.
Add damping.	Reduce amplitude to stay in linear region.	Coupling redesign, complicated system, reduced reliability.
Remove nonlinearity.	Removes the instability.	Coupling redesign, consequences for the train characteristics.
Remove forcing.	No energy – no vibration.	Impractical, machine has to work (i.e. transfer energy).
Reduce the level of perturbations.	If we can run the machine without changes in torque for low loads and stay within linear range of the coupling…	Maybe… What are the perturbation levels?

Discussion: why problem ceases with loading?

- More torque applied loads the teeth firmly on one side.

Not in this case, the coupling is designed to work without teeth contact.

- More torque applied puts the tooth in more centric position between adjacent teeth, preventing contact.

Sounds reasonable, however not the reason in this case - at the moment of stabilization the static torque on coupling is not increased because steam turbine is not loaded.

- Synchronization of generator to the grid stabilizes the speed of generator due to electric forces.

This can be valid stabilization factor, although for the negligible active load it would be most likely insufficient.

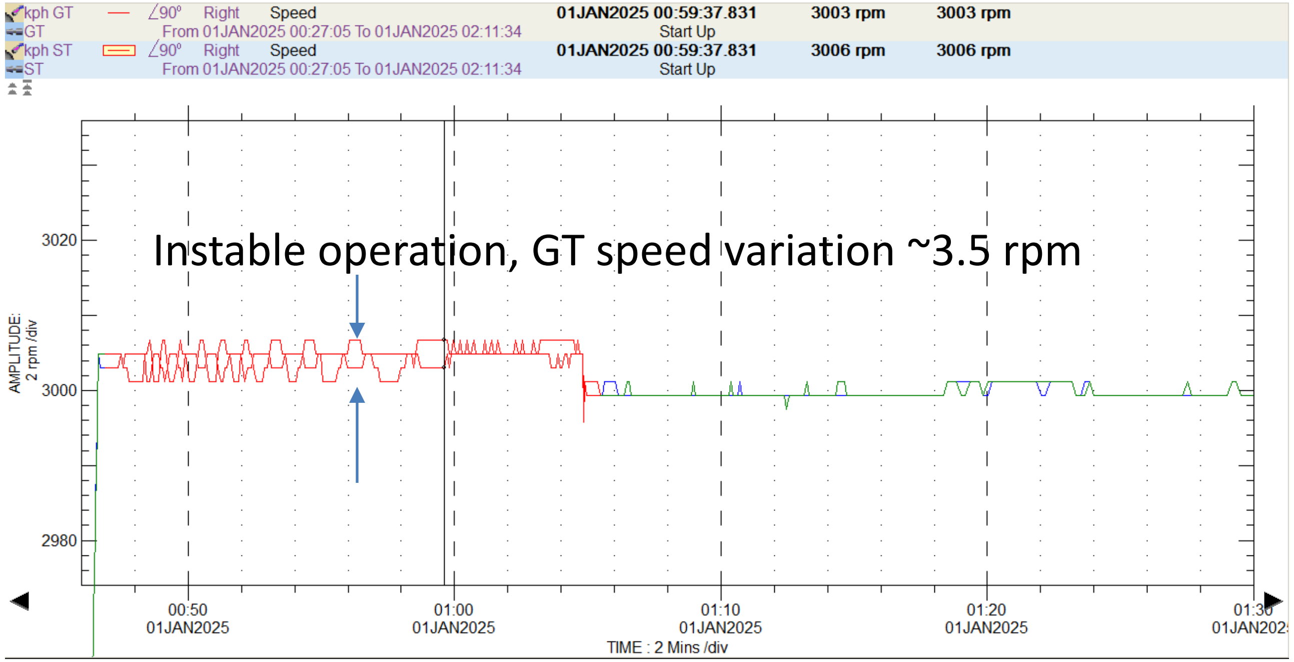
- When total demand of fuel is low, even relatively small adjustments of amount of fuel have significant impact on rotating speed. The signal to noise ratio is worst for low load condition. The NOx reduction algorithm signal can be considered as the noise disturbing the operation of the speed controller.

This was considered the most likely reason and initiated control system data analysis..

Identification of the source

Monitoring data analysis:
For the low loads, perturbations as low as Δ=3.5 rpm were sufficient to drive instability.

OEM analyzed operation of the GT controller.
The identified source was NO_X emission control algorithm. Fine tuning of it ensured stable operation. (Δ < 1.5 rpm).



This solved the problem.

Lessons learned

For diagnostician there were few new elements in this case:

- Self excited-vibrations due to nonlinearity of the dynamic stiffness are common for radial vibration but in this case it was the torsional vibrations that went unstable.
- The safety feature of the flexible coupling created both a non-linearity and a conversion mechanism, so radial vibration problem emerged. Torsional vibrations in single shaft trains are in most cases undetected until developed failure.
- When torsional problems occurred on other machines, the symptoms were primarily at high torque load conditions. Due to the coupling design, the problem manifested during “no-load” conditions.
- For most cases of torsional excitations of such units, it is coming from the variable load of the generator. In this case, it was the NOx reduction algorithm that had to plead guilty.

Q&A session

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