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Torsional vibration problem with recirculation gas blower due to variable frequency drive

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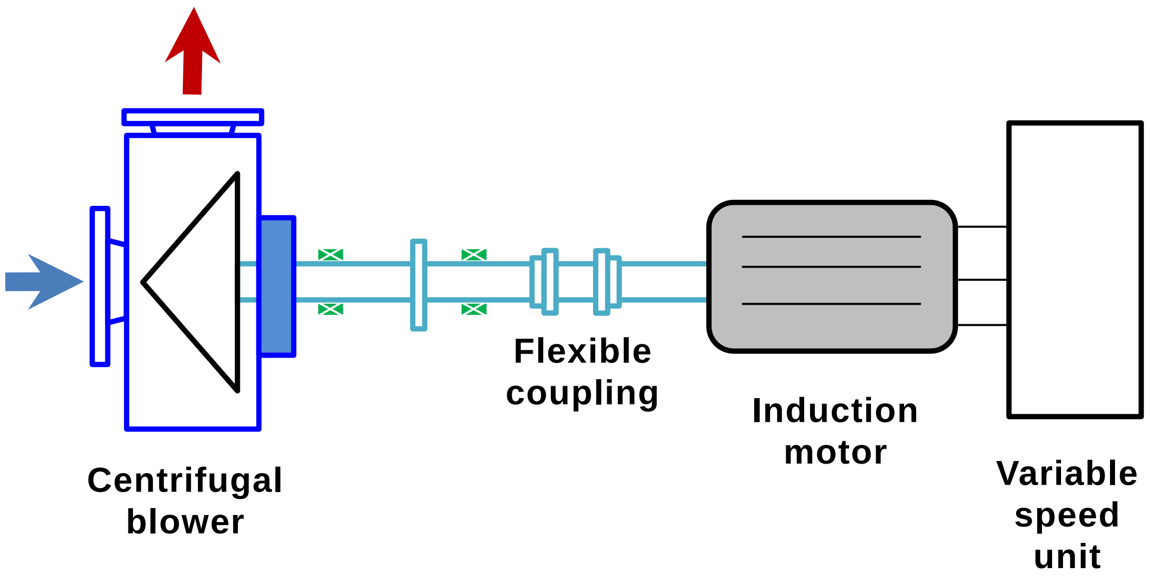
Abstract

- The centrifugal blower is equipped with variable-frequency-drive (VFD). Many times the unit has experienced coupling failures after installing a new VFD. It was found damage at about a 45 degree caused by high torsional load
- Supported by API 684 and the similar case studies presented [2], the VFD has been suspected of having a torsional response on the system.
- The results in measured torque showed that in operation with closed-loop control of VFD, Direct Torque Control Mode, the oscillating torque increased dramatically.
- Proper tuning of speed controller parameters reduces the torque by a factor of five and without closed-loop control, scalar mode, greatly reduced torsional excitation.
- As a result, it was decided to configure VFD to operate in scalar control mode where the torque is far below the coupling manufacturer's torque limit.

Machine train

Centrifugal blower + Coupling + Induction Motor + Variable speed unit



Operating speed 900 to 1200 rpm

- 4-pole motor with rated power 330kW
- 6-pulse voltage source inverter using scalar mode control at the beginning
- Diaphragm coupling type was properly sized for the application, speed and load
- Two failures of coupling experienced after replacing new variable speed unit using Direct-torque-Control (DTC) mode
  - First failure after 14 days of operation
  - Second failure after 60 days of operation

Problem statement

Metallurgical study indicated torsional fatigue cracking at about a 45-degree angle between diaphragm and center tube

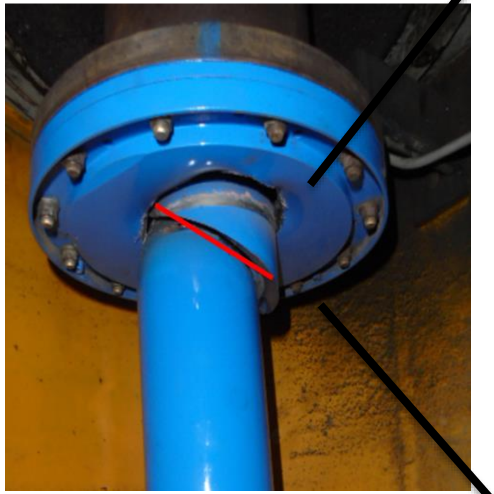


Figure 1: *Crack about 45-degree*

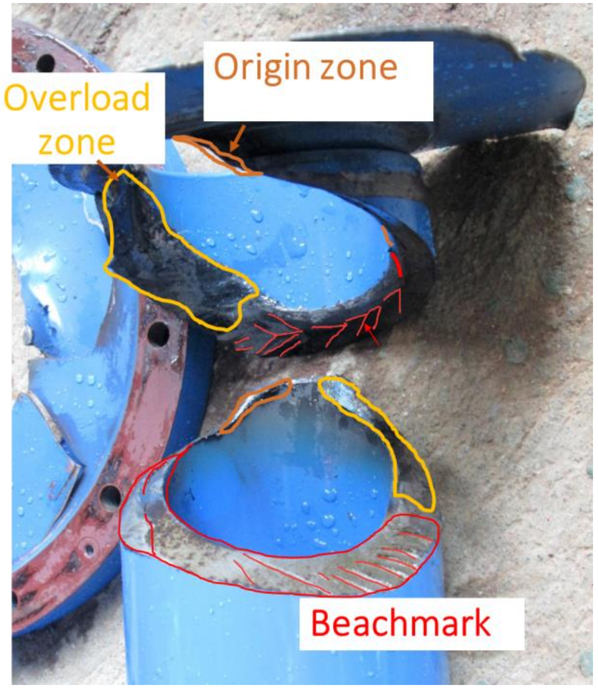


Figure 2: *A fatigue zone, with progression area of Beachmark*

The strain gauges with telemetry installed at a coupling spacer was used to identify the torsion load on the coupling

Overview of processing data

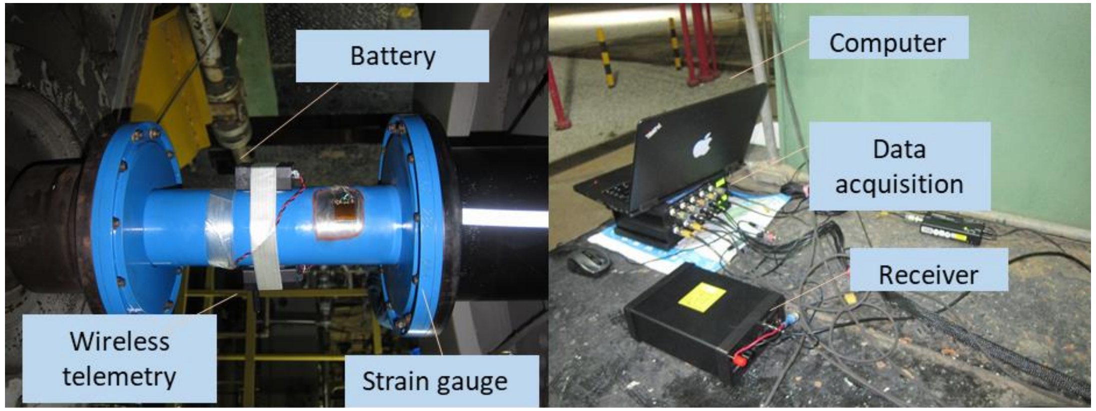


Figure 3 :*The process of measuring oscillating torque*

Various tests were performed by sweeping the motor speed from 0-1500 rpm and comparing that with VFD characteristics

Analysis method

Simplified diagram of VFD control mode

Direct Torque Control

Speed controller gain (Kp)

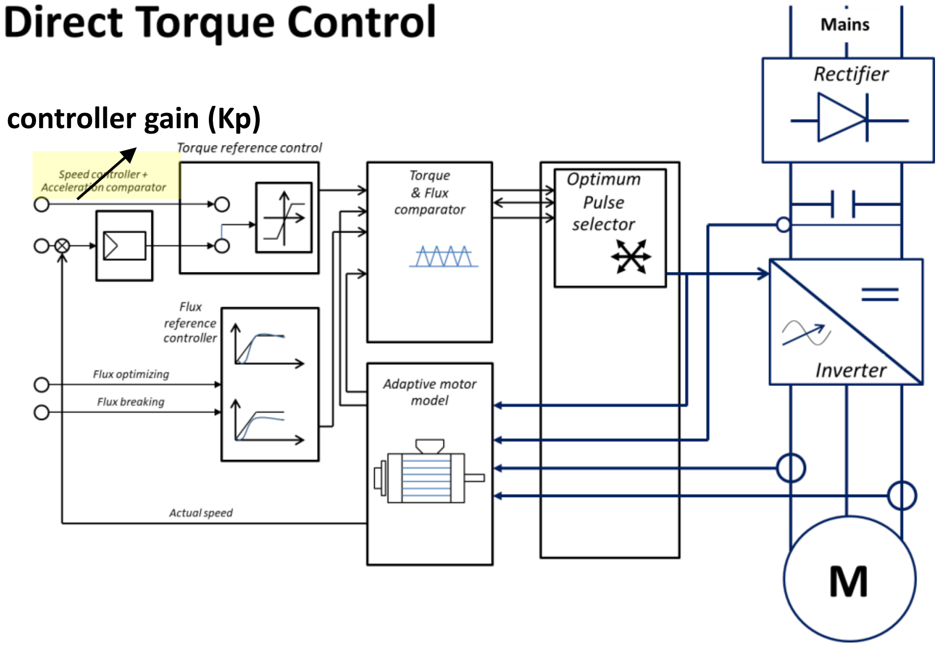


Figure:4 Closed-loop control

Scope of work

- Tuning speed controller gain from Kp=11.2 to Kp=2
- Sweeping speed 0 -1480 rpm for each
- Compare the torque trend to Scalar control mode

Scalar Control

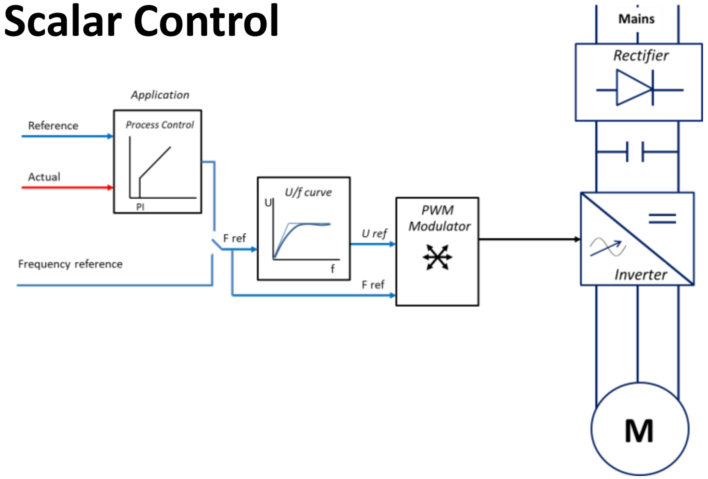


Figure 5: Open-loop control

Wang ,et al. (2012), believed the closed-loop control created significant torsional excitation, suggesting open-loop control was preferred for low dynamic response

Analysis method

Predicted torsional model and mode shape

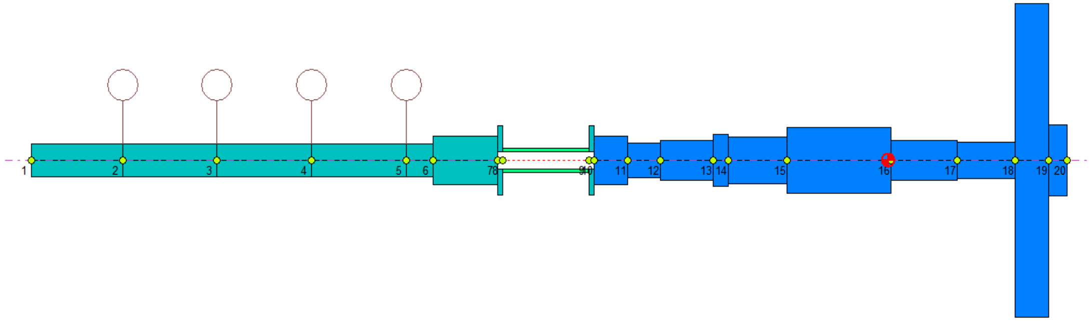


Figure 6: Lumped-Mass modeling of system
(Courtesy of DyRoBes)

1st TNF = 35.23Hz

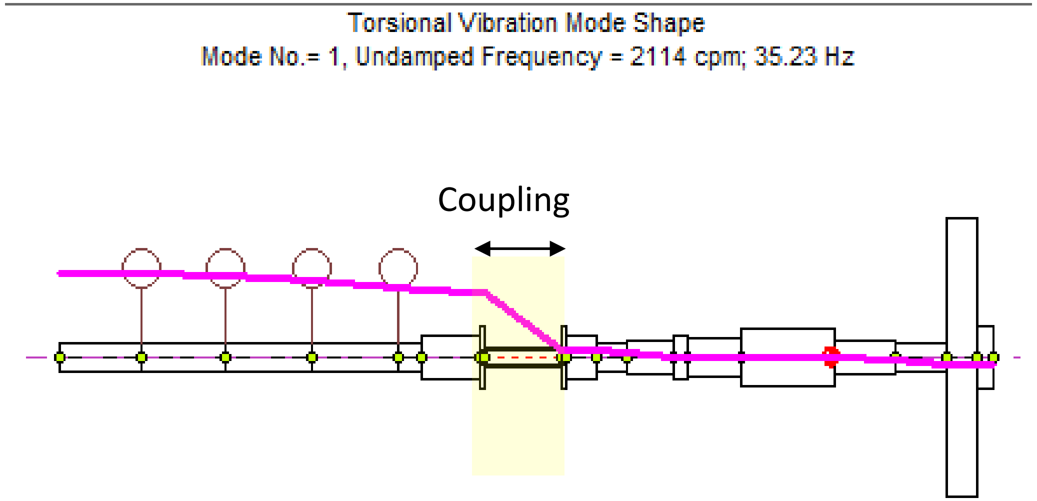


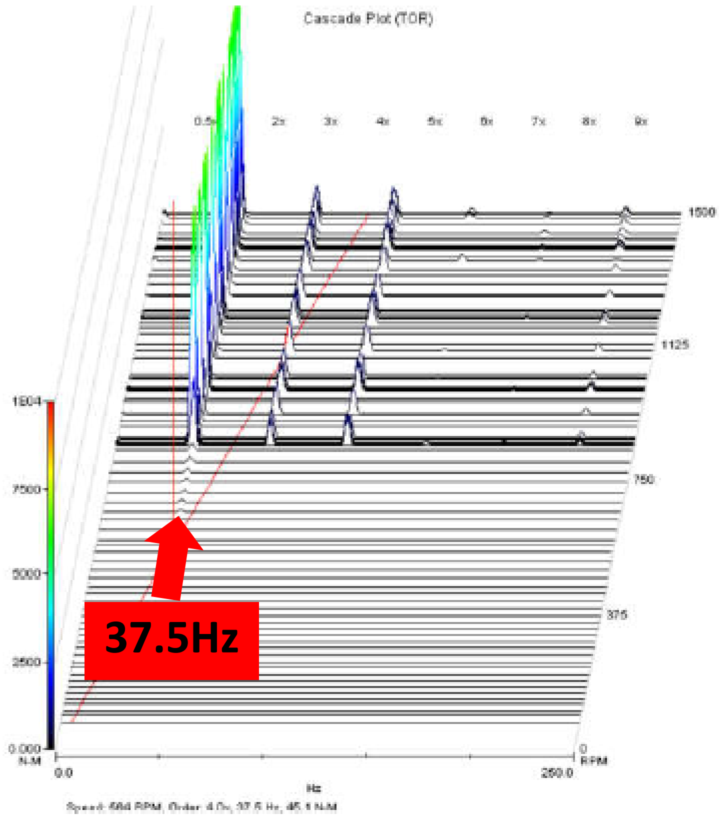
Figure 7: 1st torsional natural mode shape
(Courtesy of DyRoBes)

Based on 1st TNF, its mode shape revealed high stress on the coupling

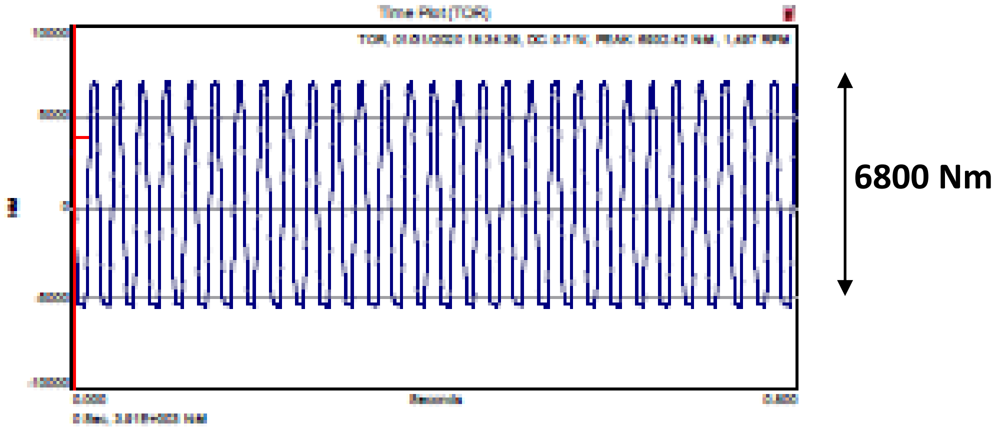
The first predicted torsional natural frequency is 35.23Hz . Primary torsional modes are those influenced by the coupling torsional stiffness

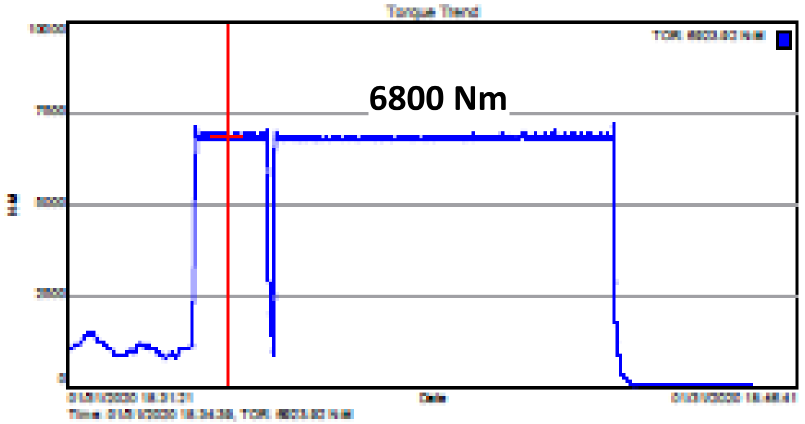
Analysis method

Plot of measured oscillating torque response



Operating in Direct-Torque-Control mode (DTC)





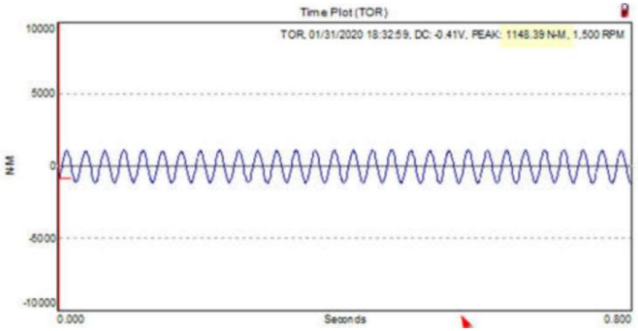
The overall trend with averaging amplitude about 6800 Nm (0-Pk)

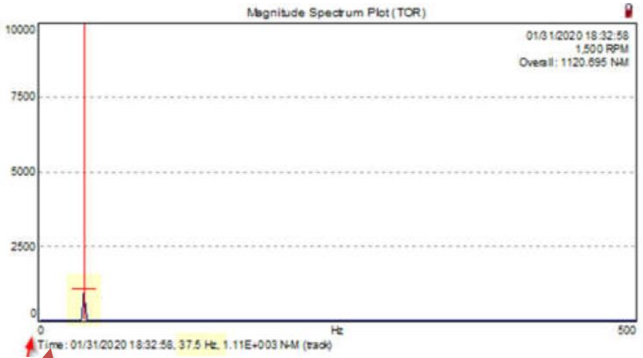
The oscillating torque in the trend plot showed the magnitude was 6800 Nm(0-Pk) at a locked-in frequency of 37.5Hz, close to the predicted 1st TNF

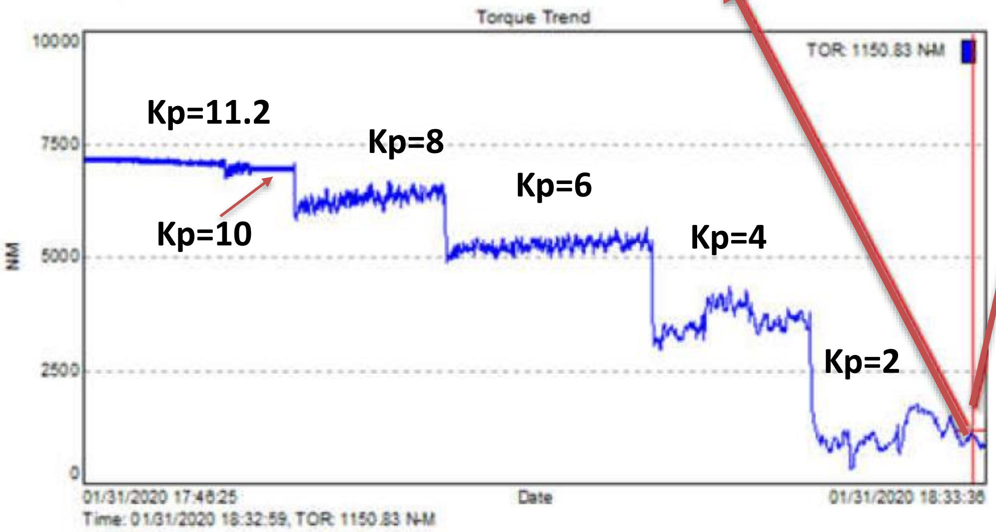
Analysis method

Plot of measured oscillating torque response

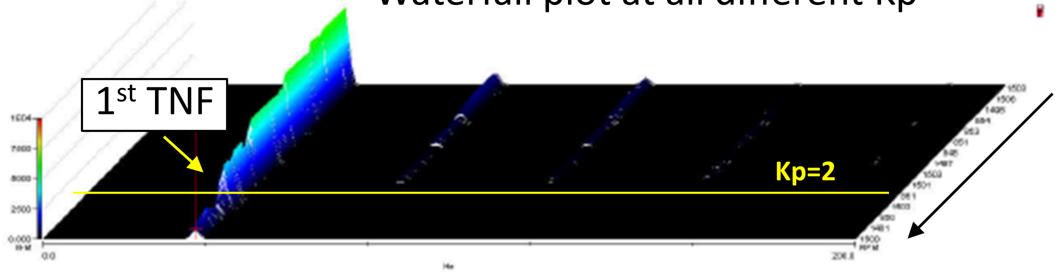
Operating in DTC mode and varying speed controller gain Kp from 11.2 to 2







Waterfall plot at all different Kp



The 1st TNF was continuously excited but reduces as gain control lowered

The oscillating torque in trend plot showed the magnitude was decreased to as low as 1500Nm when Kp equaled 2 with the presence of 1st TNF peak

Analysis method

1st torsional natural frequency (TNF) predicted vs measured in Campbell plots

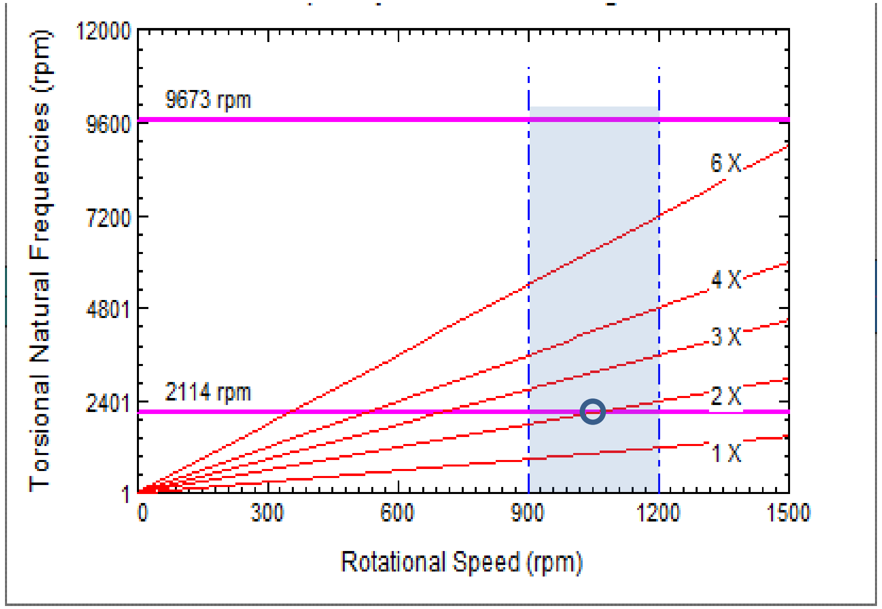


Figure 8: Predicted frequency interference diagram (Courtesy of DyRoBes)

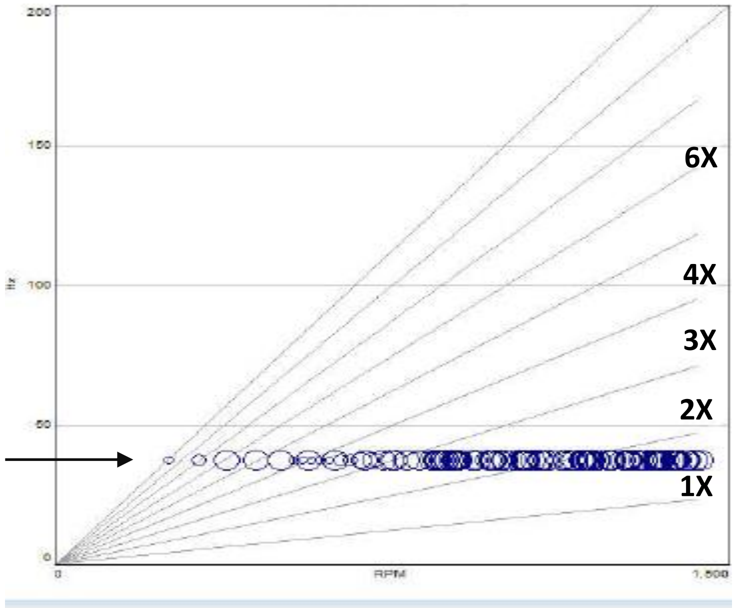


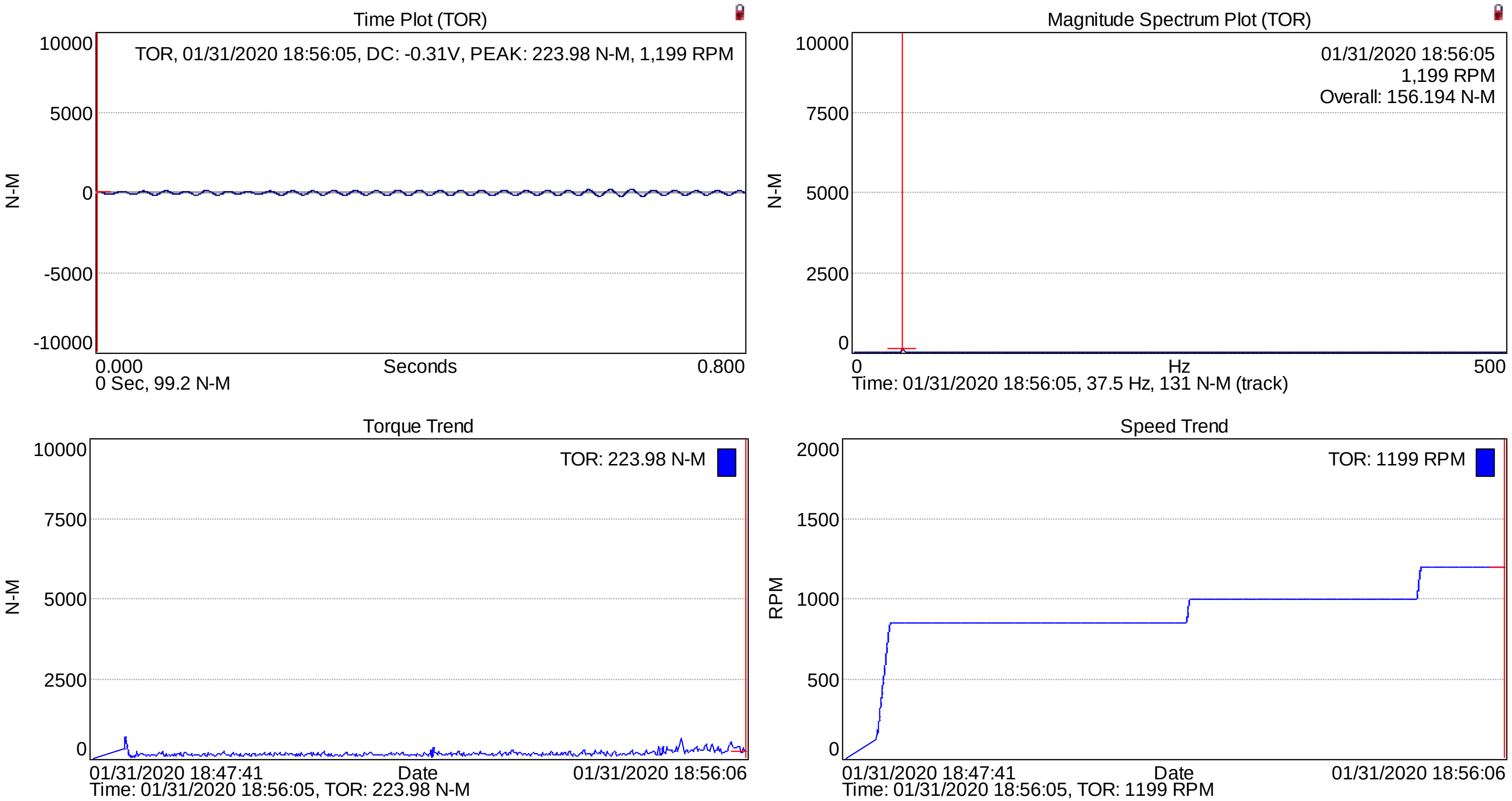
Figure 9: Field measurement using strain gauges

The VFD unit must be properly tuned during commissioning to minimize torsional excitation, although the system was operating well away from the design 1st TNF

Analysis method

Plot of measured oscillating torque response

Operating in the Scalar mode

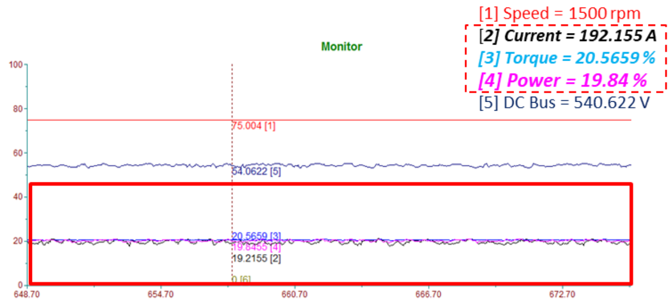
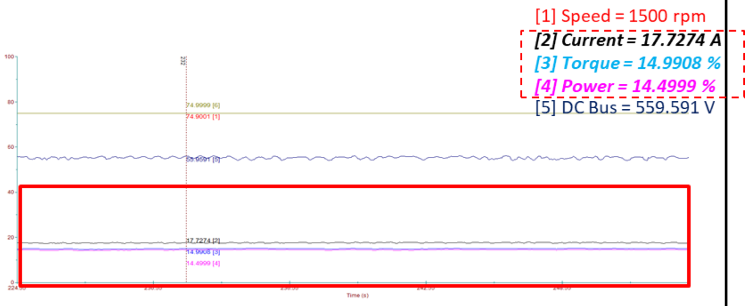
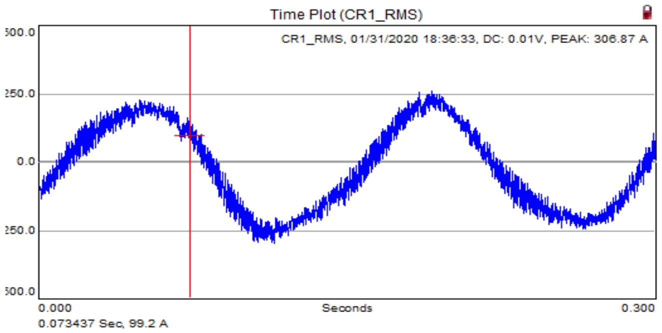
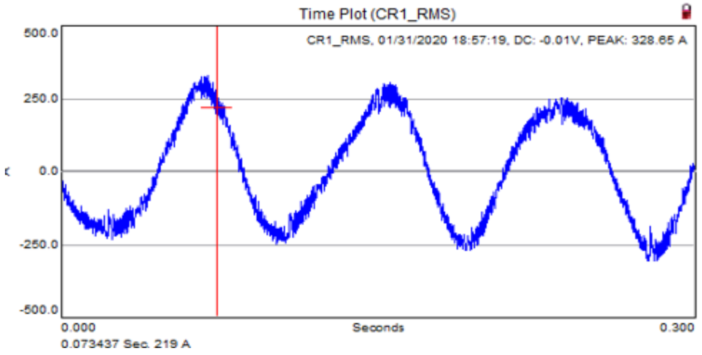


The oscillating torque trend plot showed the magnitude was below 500 Nm when sweeping speed to 1200rpm without the presence of 1st TNF

Analysis method

Electrical parameters analysis

1500 rpm

Methodology	Direct torque control	Scalar control
VFD parameter recorded in panel		
	Power, current and torque values are fluctuating more in DTC mode	
Motor current analysis (current probe installed)		
	Higher distortion current seen in DTC mode compared to scalar mode	

In DTC mode the current, power and torque values fluctuated more than in scalar control mode as it tried to achieve precise motor speeds

Results

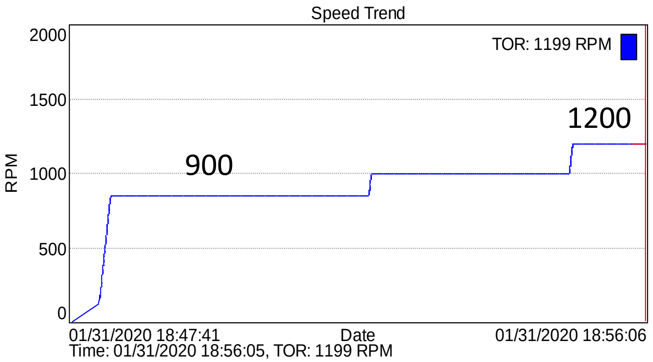
The implemented VFD operation as a scalar control mode

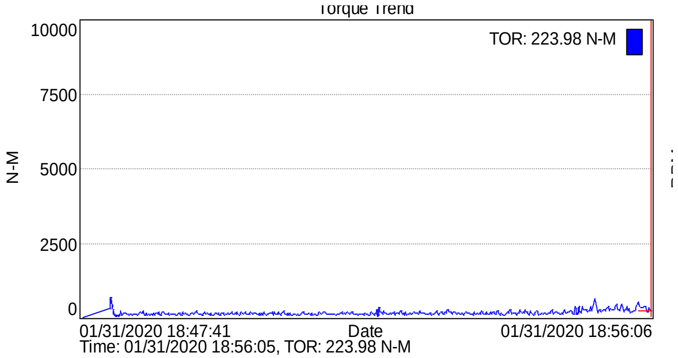
Compared the actual torque value

	VFD control mode	Oscillating torque (Strain-gauge measured)
BEFORE	DTC, Kp=11.2	~6800Nm
AFTER	Scalar mode	<500Nm

Capability of coupling *(Rated continuous torque)* **6700 Nm**

Trend plots of sweeping speed and oscillating torque





When operating in scalar mode, the actual torque value (less than 500 Nm) is far below the manufacturer's torque limit of 6700 Nm, compared to DTC mode where the torque exceeded the manufacturer recommendation

Conclusion and recommendation

- VFD motors in high inertia systems (i.e. fans) with flexible couplings that have very low damping must be verified by field torsional measurement.
- Torsional measurement is valuable for verification of low excitation levels which is unpredictable in the design stage and highly recommended for a reliable Turbomachinery system.
- There are other Pros and Cons in different VFD control modes, such as: response time, precise speed control and harmonics in the power system etc.
- Scalar control can be used with low dynamic response, over 100 ms. The blower typically does not require high response (<1-2ms).

Reference

- API 684, 1996, "Tutorial on the API Standard Paragraphs Covering Rotor Dynamics and Balancing: An Introduction to Lateral Critical and Train Torsional Analysis and Rotor Balancing ," First Edition, American Petroleum Institute, Washington, D.C.
- Wang, Q., Feese T. D., and Pettinato B.C., 2012, "Proceedings of the Forty-First Turbomachinery Symposium, Turbomachinery Laboratory, Texas A&M University, College Station, Texas, pp.21-23.