ACC Vibration

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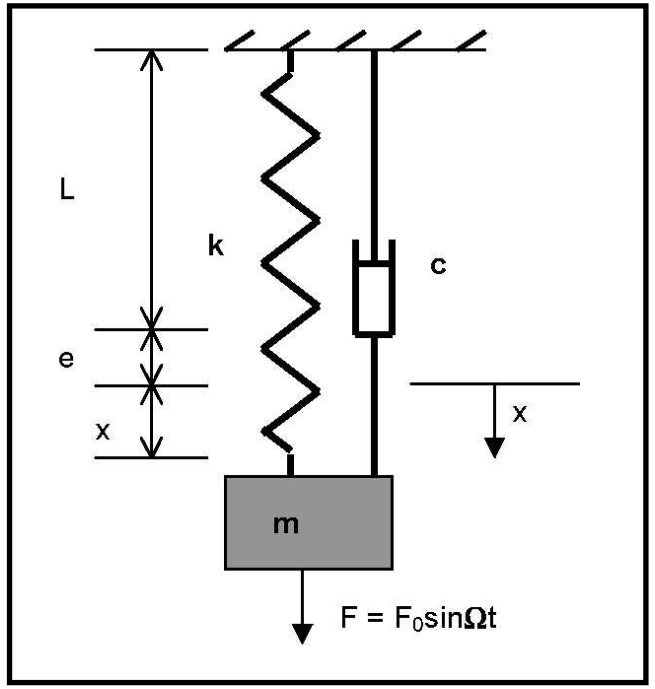
OUTLINE

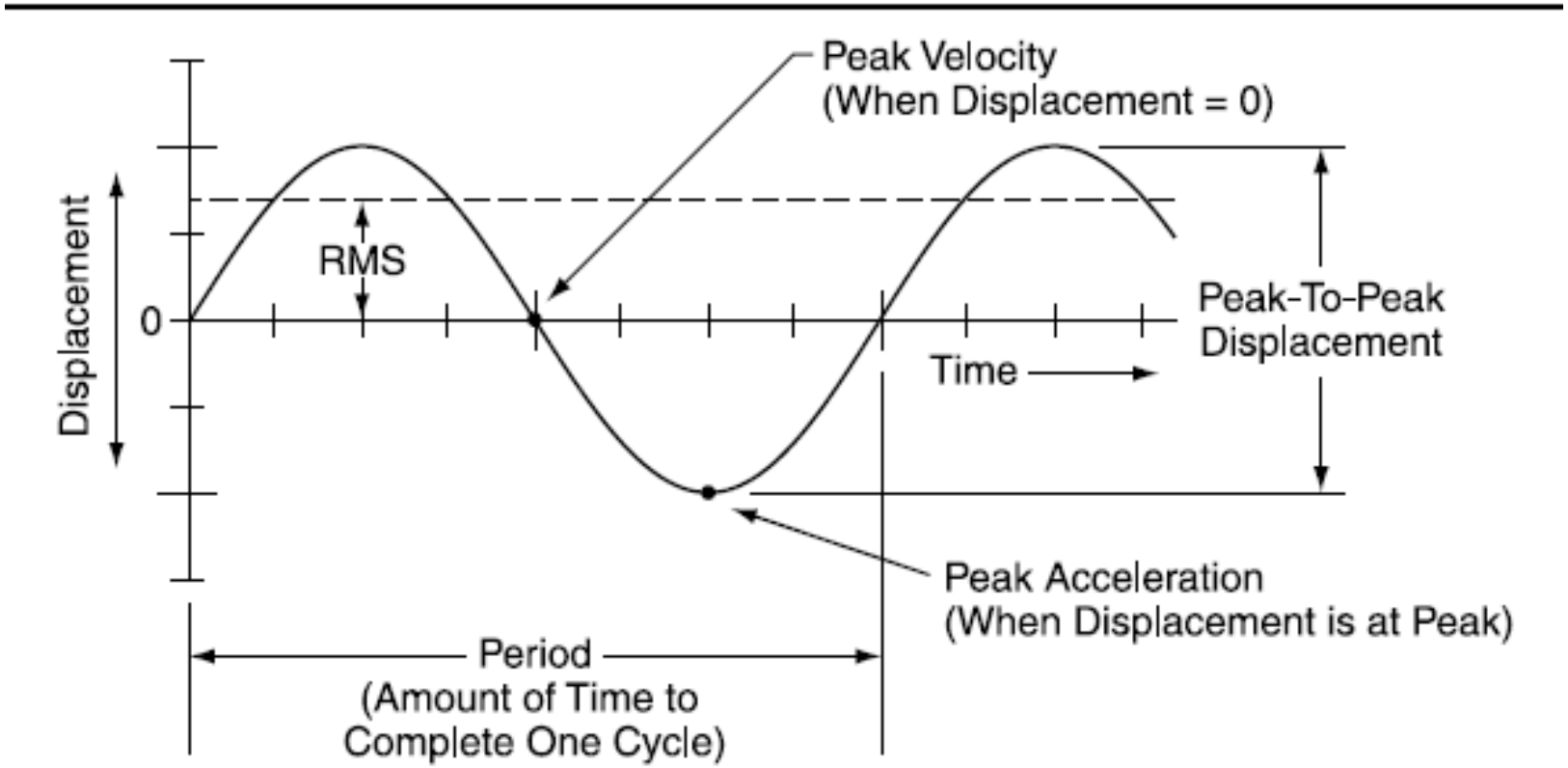
- Vibration Basics
- Existing Vibration Standards
- Case Study – Dominion VCHEC
  - Retrofit project summary
  - Preliminary vibration assessment
  - Post-retrofit vibration measurements
  - Mitigation solutions
  - Final results
- Lessons Learned
- Next Steps

Vibration Basics

- Forced Mechanical Vibration
- Measured using vibrometer, FFT analyzer and/or accelerometers (g's)
- Integrated to velocity (mm/s or in/s)

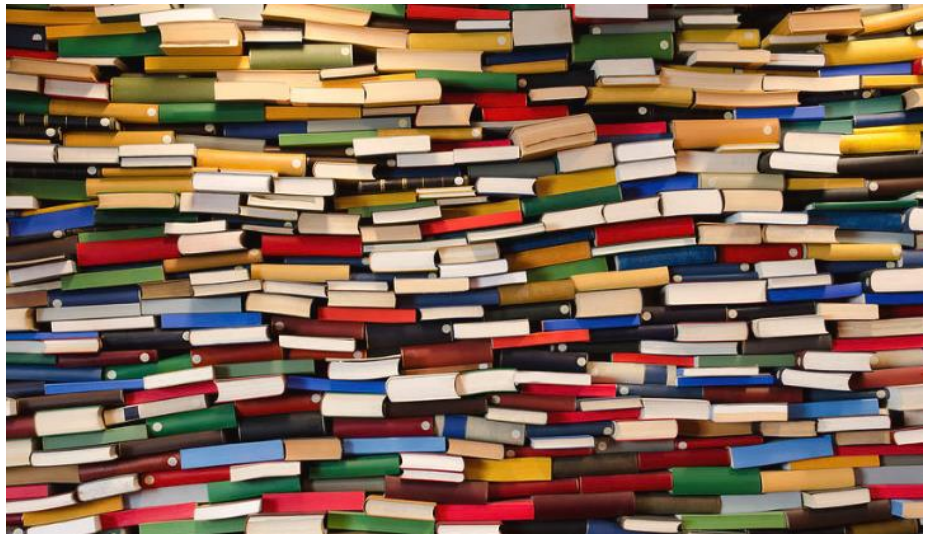


Vibration Basics



Vibration Standards

- ANSI/AMCA Standard 204-05 *Balance Quality and Vibration Levels for Fans (ISO 14694)*
- *ISO 10816 – Mechanical Vibration of Industrial Machines*
- *CTI – Standard for Vibration Limits in Water Cooling Towers*



ANSI/AMCA Standard 204-05

Table 5 — Seismic vibration limits for tests conducted *in situ*

Condition	Fan-application category	Rigidly mounted mm/s		Flexibly mounted mm/s	
		Peak	r.m.s.	Peak	r.m.s.
Start-up	BV-1	14,0	10	15,2	11,2
	BV-2	7,6	5,6	12,7	9,0
	BV-3	6,4	4,5	8,8	6,3
	BV-4	4,1	2,8	6,4	4,5
	BV-5	2,5	1,8	4,1	2,8
Alarm	BV-1	15,2	10,6	19,1	14,0
	BV-2	12,7	9,0	19,1	14,0
	BV-3	10,2	7,1	16,5	11,8
	BV-4	6,4	4,5	10,2	7,1
	BV-5	5,7	4,0	7,6	5,6
Shutdown	BV-1	Note 1	Note 1	Note 1	Note 1
	BV-2	Note 1	Note 1	Note 1	Note 1
	BV-3	12,7	9,0	17,8	12,5
	BV-4	10,2	7,1	15,2	11,2
	BV-5	7,6	5,6	10,2	7,1

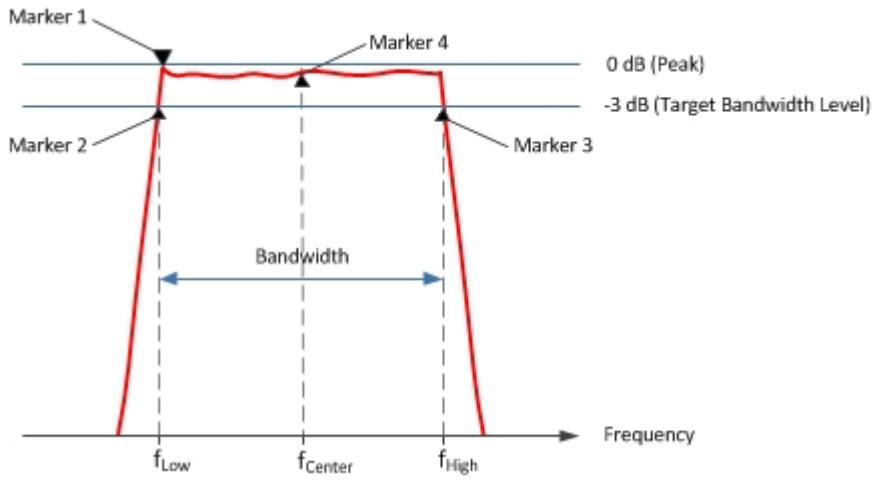
NOTE 1 Shutdown levels for fans in fan-application grades BV-1 and BV-2 should be established based on historical data.

NOTE 2 The r.m.s. values given in this Table are preferred. They are rounded to a R20 series as specified in ISO 10816-1. Peak values are widely used in North America. Being made up of a number of sinusoidal wave forms, these do not necessarily have an exact mathematical relationship with the r.m.s. values. They may also depend to some extent on the instrument used.

- In-situ
- BV-3 for large ACCs
- Flexibly Mounted
- 16.5 mm/s (0.65 in/s) peak
- 11.8 mm/s (0.46 in/s) r.m.s

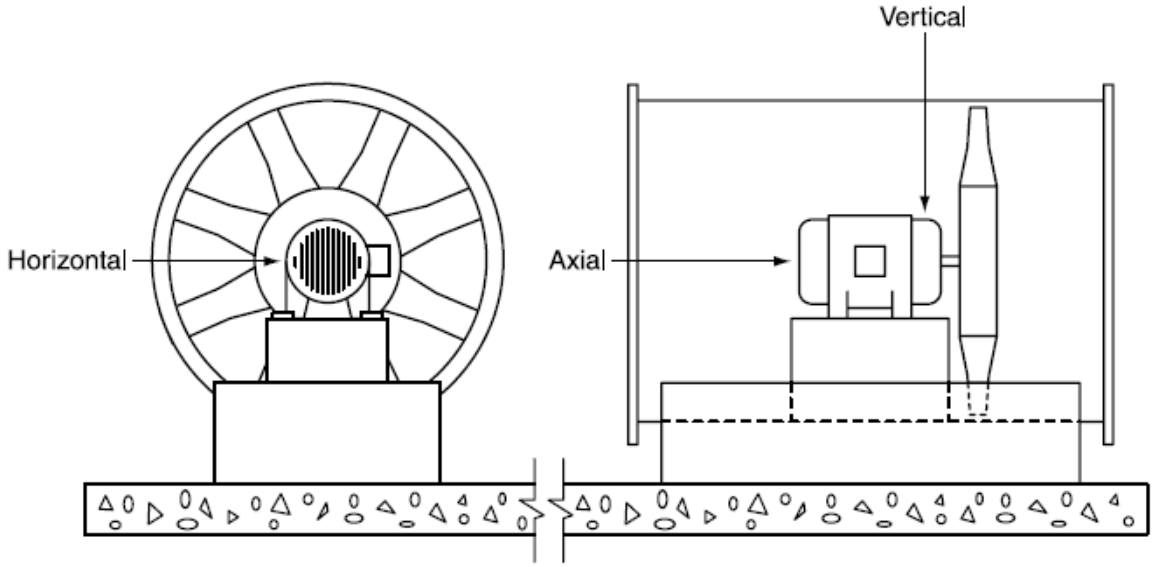
Vibration Standards – Missing Components

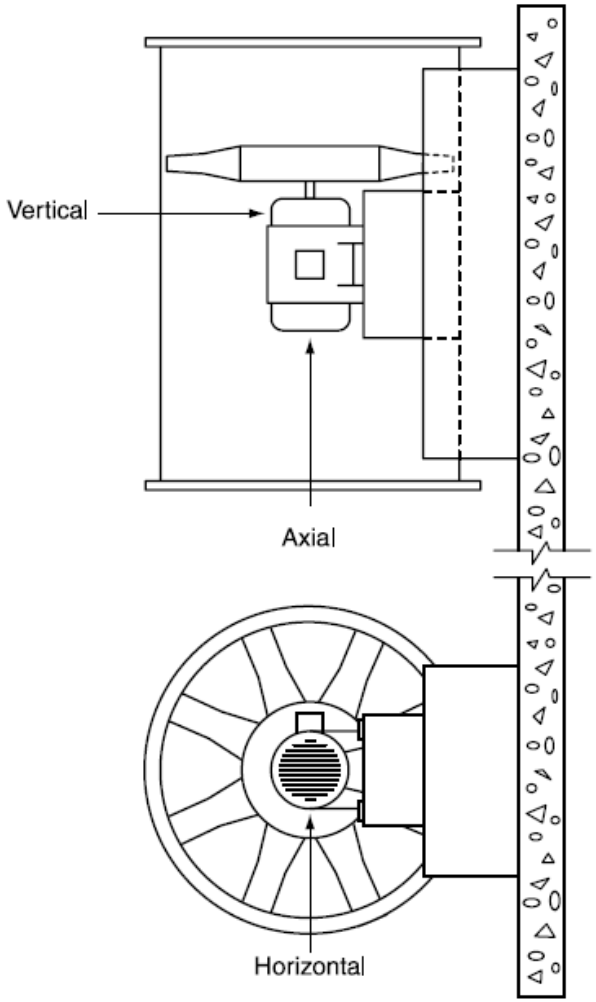
- Temporal Element
  - How long to measure?
  - Is any exceedance unacceptable?
  - Averaging allowed?
- Bandwidth filtering (f_{min} – f_{max}) ?
- Direction?



Vibration Standards – Missing Components

- Measurement Locations
  - Motor bearings?
  - Gearbox?
  - Fan itself?





Case Study - VCHEC

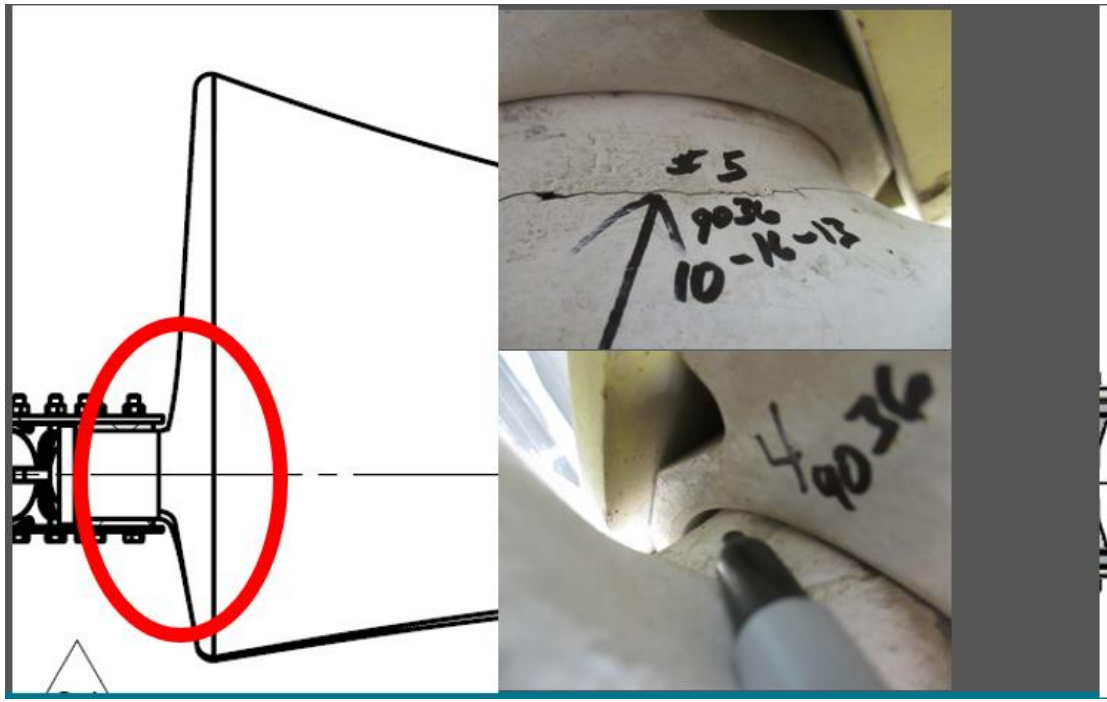
- Virginia City Hybrid Energy Center (VCHEC)
- Dominion owned and operated
- Duel fuel – coal waste and biomass
- Two (2) 30-cell ACCs with 7-blade Tecsis FRP blades

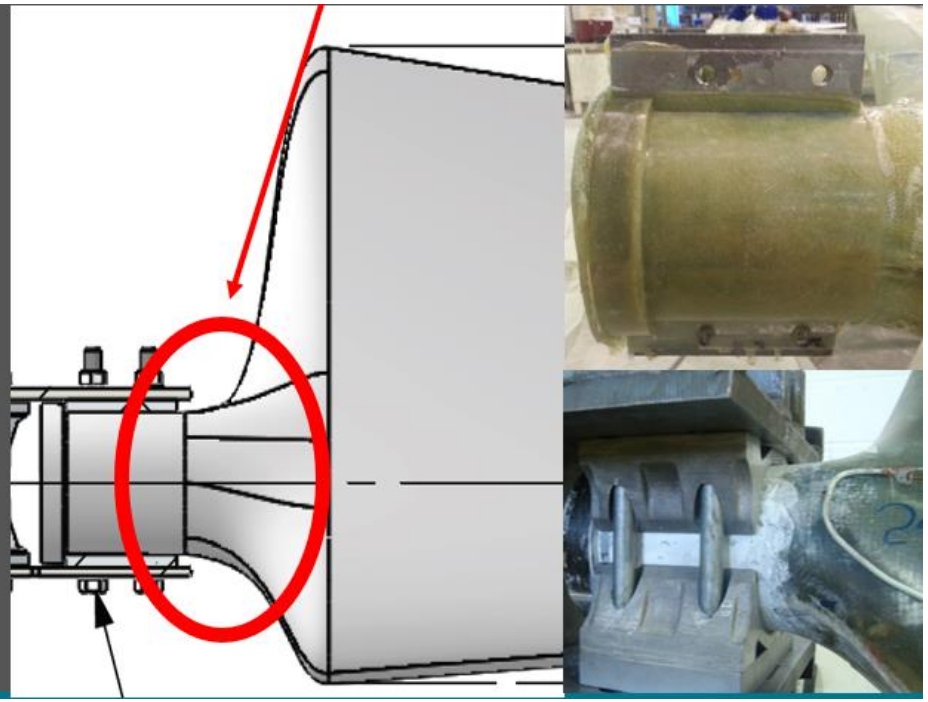
Case Study – Blade Cracking

- Blades showing signs of cracking
- Widespread cracks noticed starting in 2016

Case Study - Remedy

- Tecsis
- FanTR





Case Study – Fan Comparison

Fan	Tecsis	FanTR
Motor Speed (rpm)	1780	1780
Fan Speed (rpm)	86	86
Number of Blades	7	9
Blade Pass Frequency (Hz)	10	13
Mass (lbs)	2,965	2,789

Case Study – Bump Test

- With fans off, excite structure to determine natural frequency(ies)
- Three directions
  - Vertical (jumping)
  - Perpendicular (mallet)
  - Parallel (oops)

Direction	Vertical	Perp.	Parallel
Nat. Freq (Hz)	5.0	5.8	

Case Study – Fan Trial

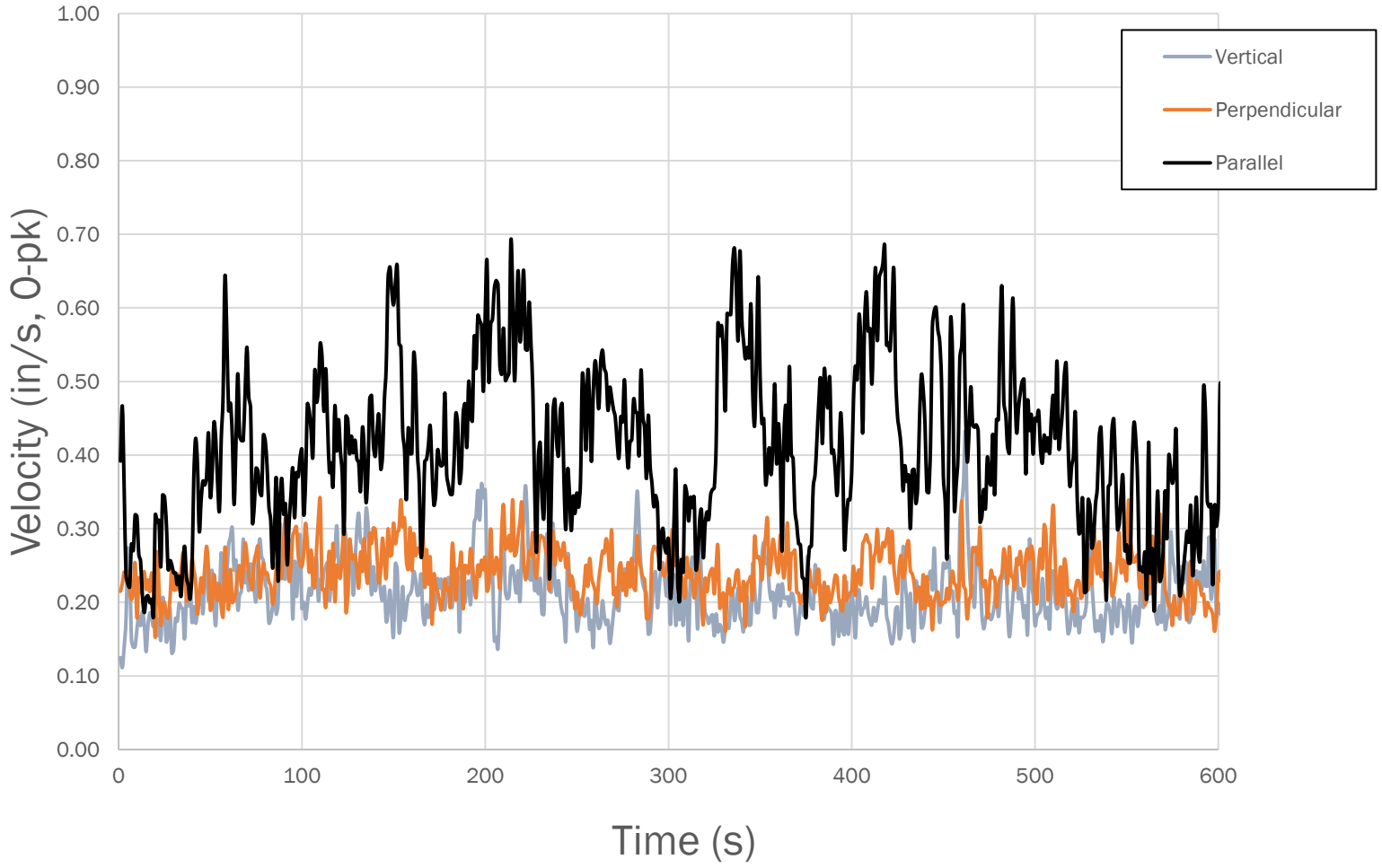
- Installed two (2) FanTR 9-blade fans in 2018
- Measured vibration monthly for 10-second duration.
- Vibration levels within acceptable limits
- Remaining 28 fans installed in 2020

Case Study – Vibration Results

- Triaxial accelerometer on motor outboard
- Pass < 0.65 in/s, 0-pk
- **10min duration**

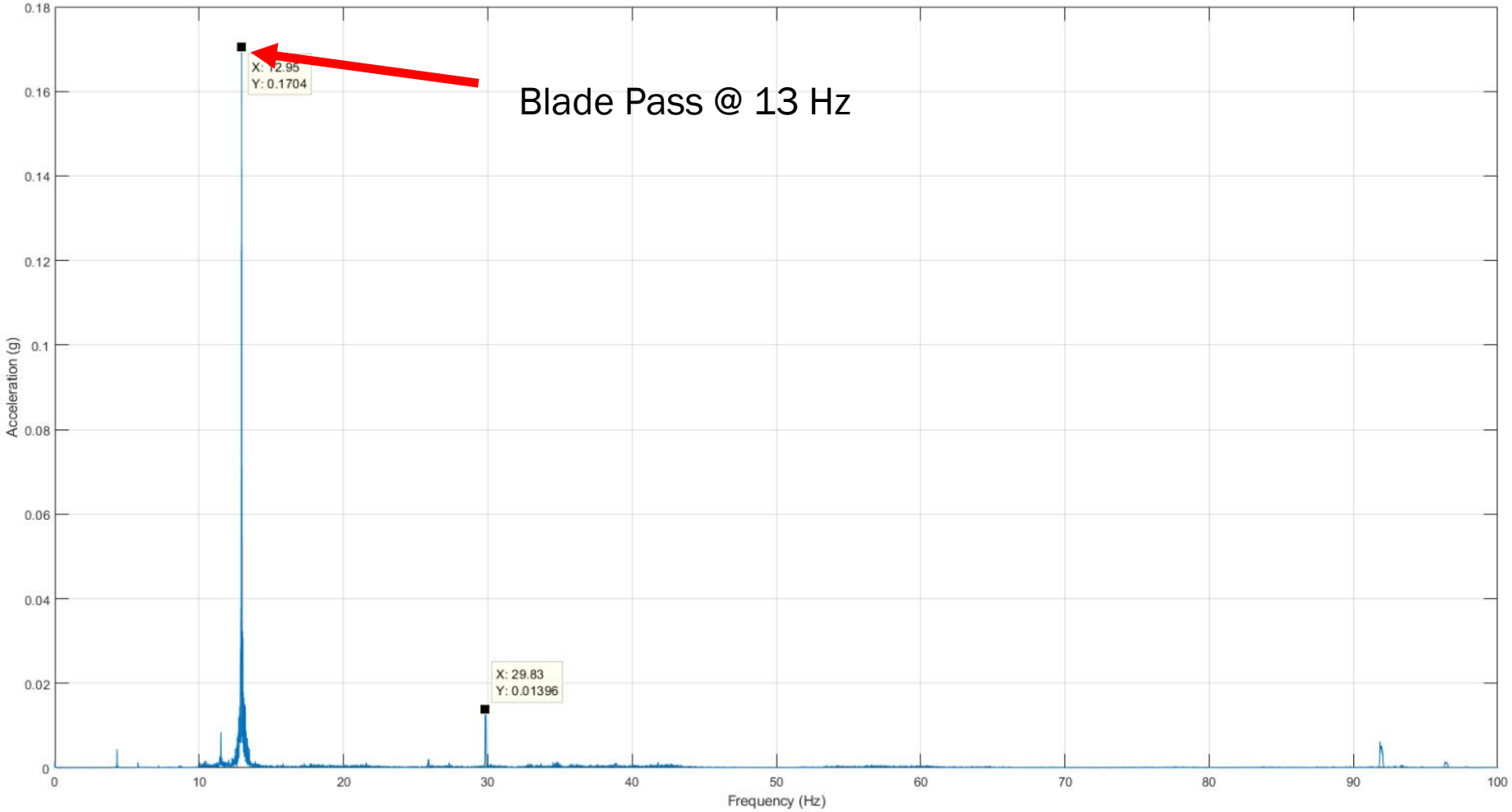
Street	Fan Module					
	A	B	C	D	E	F
1	Fail	Fail	Pass	Pass	Fail	Fail
2	Pass	Fail	Pass	Pass	Fail	Pass
3	Pass	Fail	Fail	Pass	Fail	Pass
4	Fail	Fail	Pass	Fail	Fail	Pass
5	Pass	Fail	Pass	Pass	Fail	Pass

Case Study – Vibration Results (cont.)

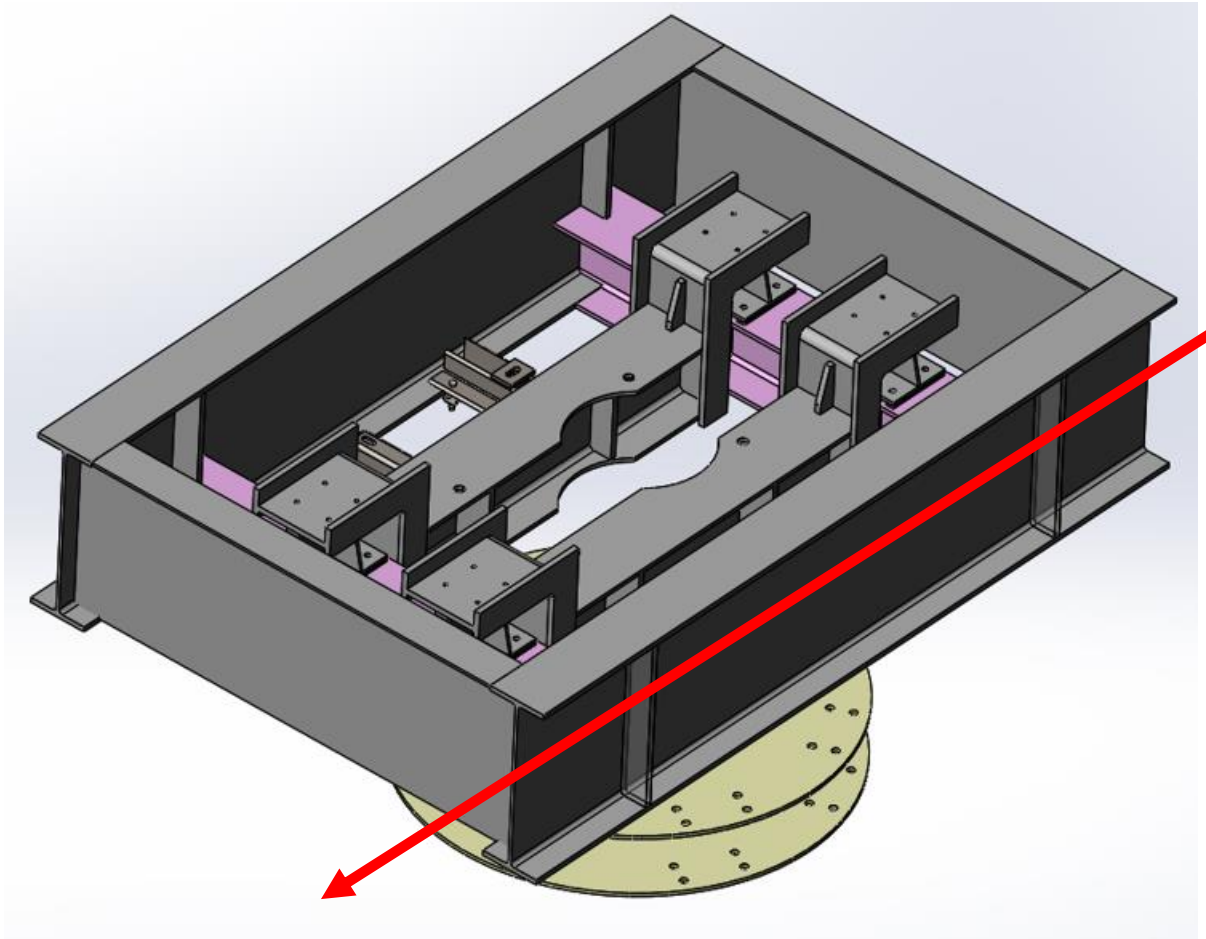


- Module 5E (typ) of B and E modules
- All 30 fans on HI

Case Study – FFT (parallel direction)

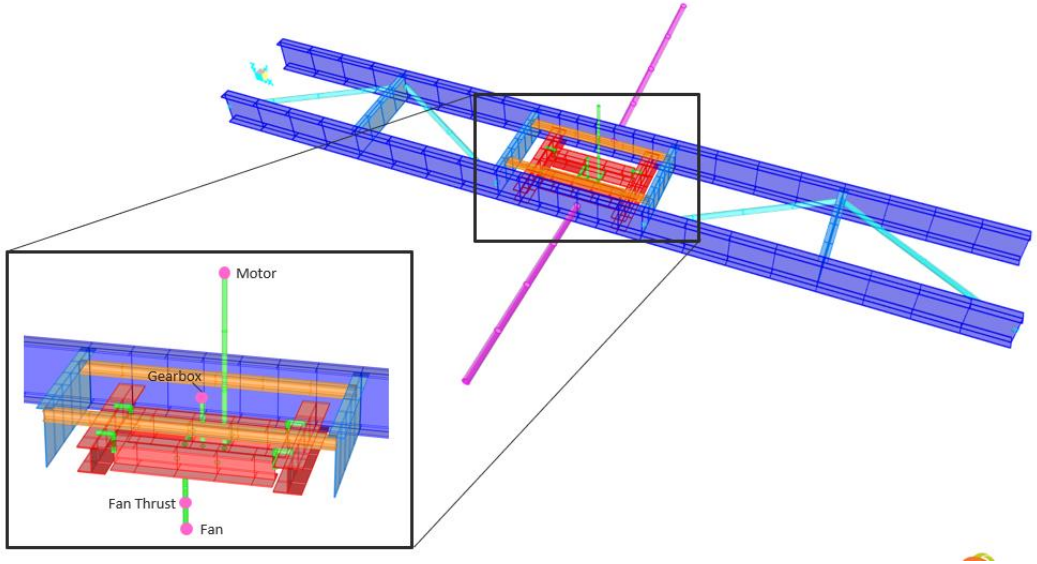


Case Study – Gearbox Mounting



Parallel Direction

Case Study – FEM



FEM Analysis confirmed primary vibration mode at 13 Hz in parallel direction on 2 speed motor modules

Case Study – Analysis Summary

- Highest vibration occurred on Modules B and E (2-speed motors) due to 800 lbs difference
- Vibration occurred primarily in direction parallel to bridge
- Dominant vibration frequency occurs at blade pass frequency (13 Hz)
- Beating phenomenon occurs over minutes as fans rotate at slightly different speeds
- High vibration from 2-speed modules transmitted to adjacent single speed modules

Case Study - Confirmation

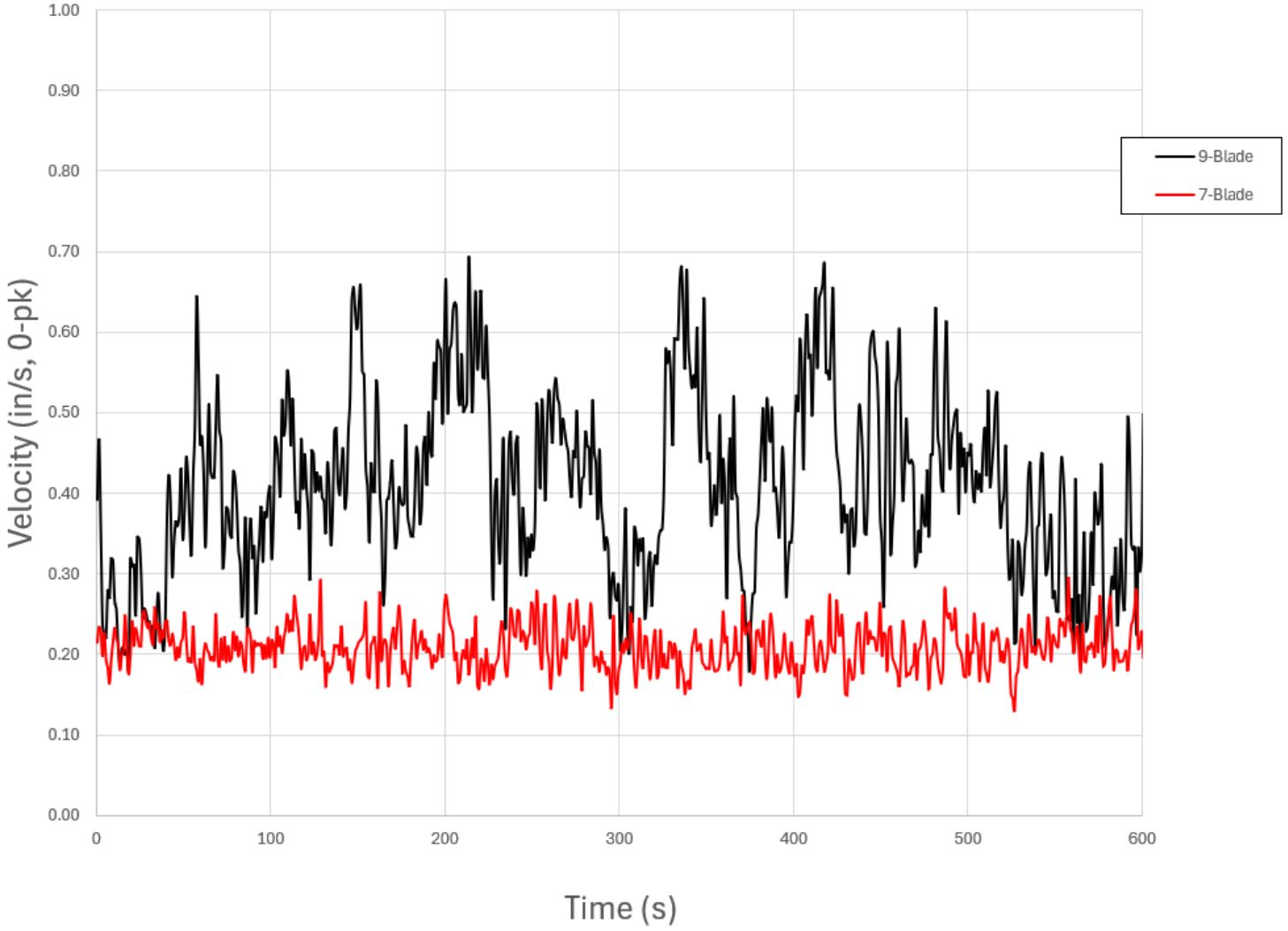
- Performed bump test in parallel direction on both single and 2-speed fan modules
- 2-speed motor fan module natural frequency coincides with operational blade pass frequency

Module	5D (single speed)	5E (2-speed)
Nat. Freq, parallel direction (Hz)	19	12.5

Case Study – Potential Mitigation

- Replace vibration pads
- Vary/mix blade pitch within each cell
- Support (attach) motor to bridge structure
- Lower the entire assembly and raise fan up the output shaft
- Add tuned mass damper to motor feet
- Implement phase locking mechanism
- Change number of fan blades

Case Study – Results (Parallel Direction)



Lessons Learned

- Vibration is tricky! Seemingly minor modifications/changes can have big impact on vibration
- Consider natural and operating frequencies in multiple directions, locations and modules
- Be aware of potential for multiple fan interactions – long-term measurements

Questions/Next Steps

- Are existing industry guidelines on fan vibration appropriate for ACCs?
  - What is normal and what is excessive vibration?
  - What is appropriate measurement duration? RMS or Peak?
  - Averaging? Filtering?
  - Is an ACC specific standard warranted?
- Should A-frame and induced draft ACCs be subjected to same vibration criteria?
- Is there ongoing research to model ACC fan vibration impacts without having to model entire ACC structure?