Dynamic response of large ACC fan systems

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Enexio

Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

On-site measurements: Shaft loads
- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics
- Adams model
- System response
- System design

Outline

1. **Background**
2. **On-site measurements: Blade loading**
   - Full-scale measurements
   - Wind effects
   - Vibration frequencies
   - Excitation reconstruction algorithm
3. **Laboratory measurements: Analysis of vibration sources**
   - Fan bridge
   - Platform height
4. **On-site measurements: Shaft loads**
   - Site setup
   - Start/Stop
   - Bending moment
5. **Simulation of fan system dynamics**
   - Adams model
   - System response
   - System design

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

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Background

Background

On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height

On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment

Simulation of fan system dynamics
Adams model
System response
System design

Background

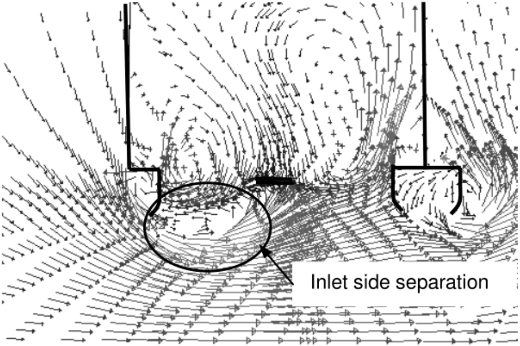
Test Case A air-cooled condenser (ACC) fans

At the Test Case A coal-fired power stations, steam is condensed in an air-cooled condenser (ACC) by forcing ambient air through inclined heat exchangers with an array (288) of large Ø9 m, 270 kW axial flow fans situated at a height of 50 m.

Background

Fan blade loading

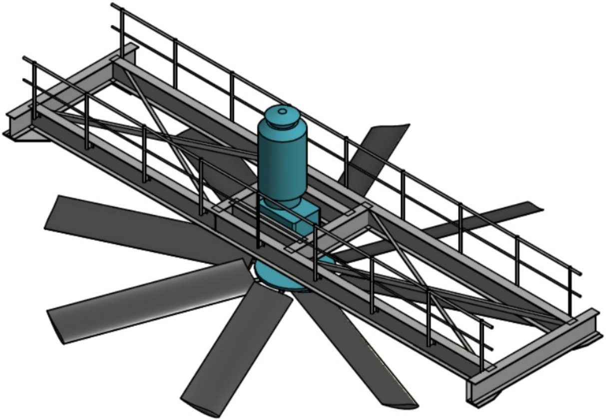
- Each fan is suspended from a fan bridge.
- Distorted inlet air flow conditions due to winds and other fans[1]as well as the downstream flow obstruction (bridge) cause varying aerodynamic loads.



[1] Van der Spuy, S.J., Von Backström, T.W. and Kröger, D.G. (2009). An evaluation of simplified methods to model the peromance of axial flow fan arrays. R & D Journal of the South African Institution of Mechanical Engineering, vol. 26, pp. 12–20.

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

On-site measurements: Blade loading



Dynamic Response

Background

On-site measurements: Blade loading

Full-scale measurements

Wind effects

Vibration frequencies

Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

Fan bridge

Platform height

On-site measurements: Shaft loads

Site setup

Start/Stop

Bending moment

Simulation of fan system dynamics

Adams model

System response

System design

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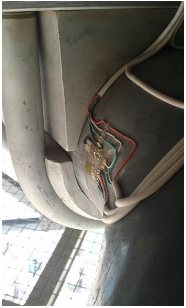
Full-scale measurements[2]

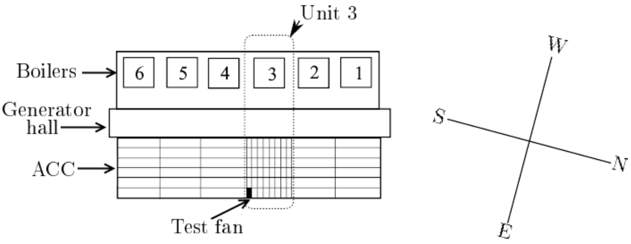


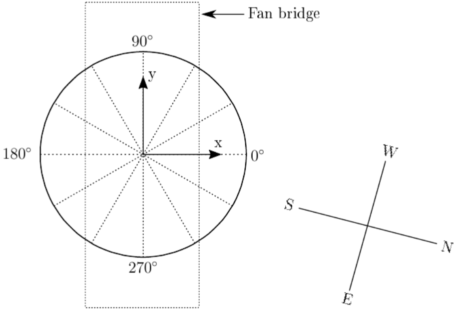
[2] Muiyser, J., Els, D.N.J., Van der Spuy, S.J. and Zapke. A. (2014). Measurement of air flow and blade loading at a large-scale cooling system fan. R & D Journal of the South African Institution of Mechanical Engineering, vol 30, pp 30–38

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

Full-scale measurements

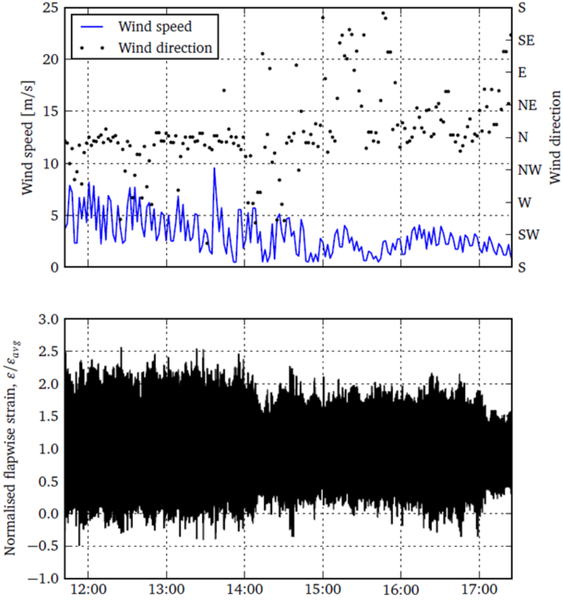
Site setup Test Case A





Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

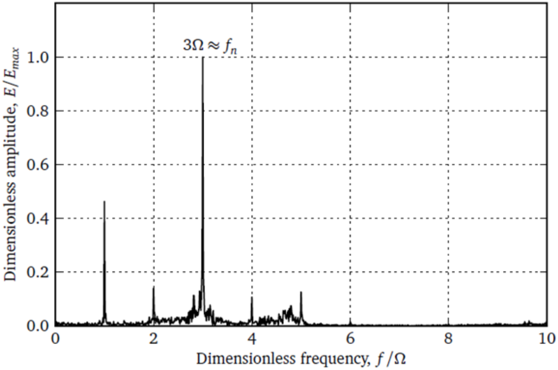
Full-scale measurements
Wind effects



Full-scale measurements

Vibration frequencies

- Fast Fourier transform (FFT) showed peaks at Ω, 2Ω and $3\Omega \approx f_n$.



Background

On-site measurements: Blade loading

Full-scale measurements

Wind effects

Vibration frequencies

Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

Fan bridge

Platform height

On-site measurements: Shaft loads

Site setup

Start/Stop

Bending moment

Simulation of fan system dynamics

Adams model

System response

System design

Excitation reconstruction algorithm

The response of a single degree of freedom system to periodic excitation

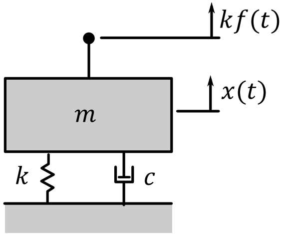
Consider single degree of freedom system in the figure

$$m\ddot{x}(t) + c\dot{x}(t) + kx(t) = kf(t)$$

with periodic function

$$f(t) = \frac{1}{2}a_0 + \mathrm{Re}\left(\sum_{p=1}^{\infty} A_p e^{ip\omega_0 t}\right)$$

where $A_p = \frac{2}{T}\int_0^T f(t)e^{-ip\omega_0 t}dt$



The steady state response is then

$$x(t) = \frac{1}{2}a_0 + \mathrm{Re}\left(\sum_{p=1}^{\infty} A_p G_p e^{ip\omega_0 t}\right)$$

with

$$G_p = \frac{1}{1 - \left(p\frac{\omega_0}{\omega_n}\right)^2 + i2\zeta p\frac{\omega_0}{\omega_n}}, \quad \omega_n = \sqrt{k/m}, \quad \zeta = \frac{c}{2m\omega_n}$$

Excitation reconstruction algorithm

Formulation

Non-linear least-squares optimization is used to fit a Fourier series to a periodic measured response, $r(t)$, using P harmonic terms where the variables are: $a_0, a_1, b_1, a_2, b_2, \dots a_P, b_P, \omega_0$.

$$Q(t) = r(t) - \left\{ \frac{1}{2} a_0 + \mathrm{Re}\left[\sum_{p=1}^{P} \left(a_p + i b_p\right) e^{i p \omega_0 t} \right] \right\} \qquad (1)$$

Then for the optimum curve fit

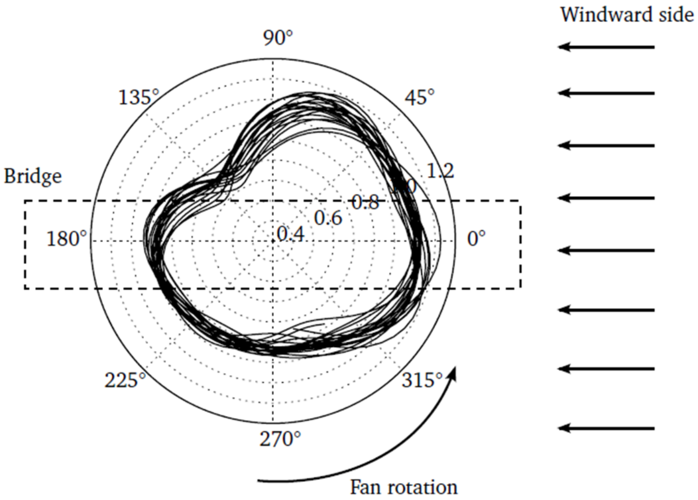
$$\left(a_p^* + i b_p^*\right) \approx A_p^* G_p \qquad \text{or} \qquad A_p^* \approx \frac{\left(a_p^* + i b_p^*\right)}{G_p} \qquad (2)$$

The reconstructed excitation, $f_r(t)$, is then given by

$$f_r(t) = \frac{1}{2} a_0 + \mathrm{Re}\left(\sum_{p=1}^{P} A_p^* e^{i p \omega_0 t} \right) \qquad (3)$$

Excitation reconstruction algorithm

Test Case A: Full scale flapwise bending force results



Dynamic Response

Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

On-site measurements: Shaft loads
- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics
- Adams model
- System response
- System design

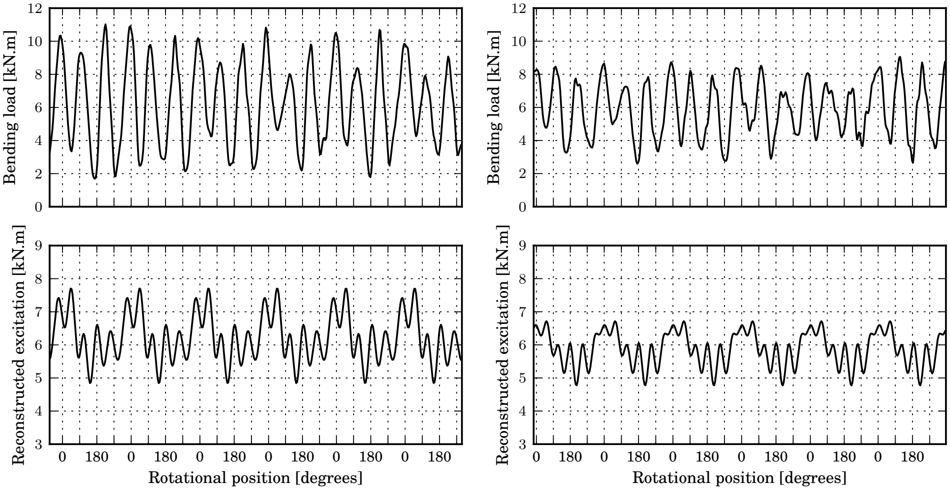
Excitation reconstruction algorithm

Full scale results

Results show similar excitation for both cases with a lower peak on the windward side during decreased winds.

Higher wind speed

Lower wind speed

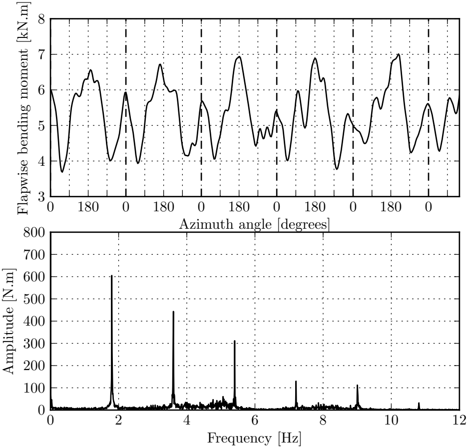


Analysis of vibration sources

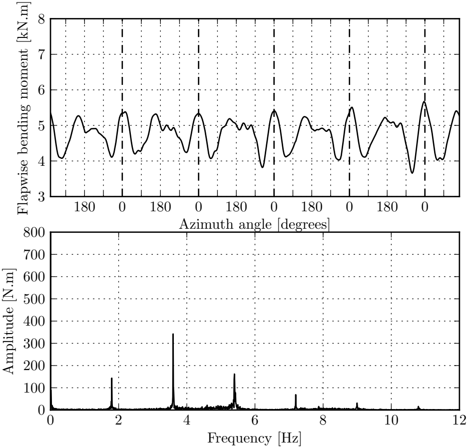
Test Case X – No resonance!

Measurements recorded at a different plant, Test Case X, where $f_n \neq 3\Omega$ did not include large blade vibrations.

Higher wind speed

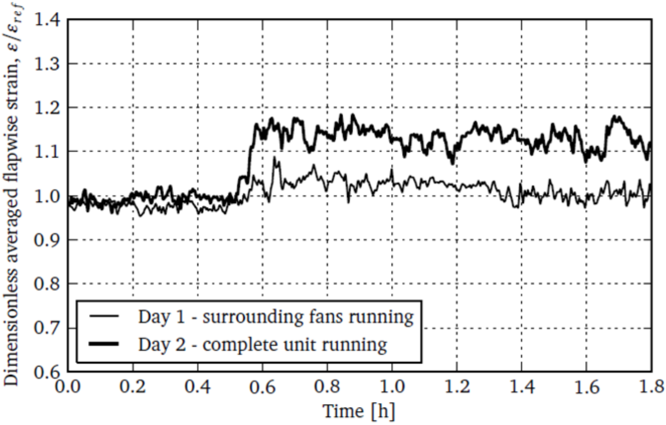


Lower wind speed



Full-scale measurements

Test Case X – Effect of surrounding fans



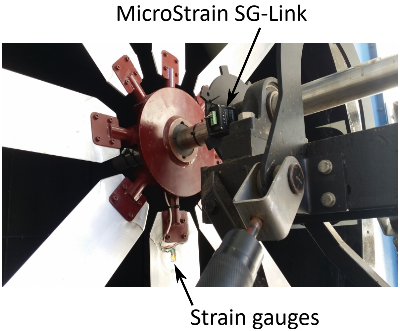
Laboratory measurements: Analysis of vibration sources

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

Analysis of vibration source

The effect of the fan bridge on fan blade vibration[3]

Strain gauges were attached to a flat plate fan blade to determine the effect of bridge solidity and distance from the rotor.



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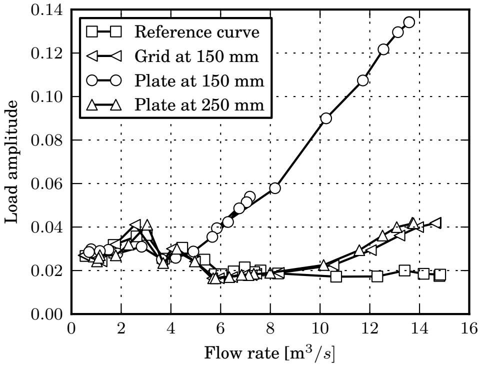
[3] Work performed in conjunction with the final-year project of Nico R. Basson.

Analysis of vibration source

The effect of the fan bridge on fan blade vibration

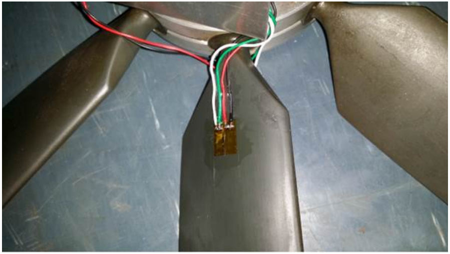
It was found that the amplitude of vibration increases with:

- Increasing flow rate
- Decreased distance between fan rotor and bridge
- Increasing bridge solidity



Analysis of vibration source

The effect of the platform height



Background

On-site measurements: Blade loading

- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

- Fan bridge
- Platform height

On-site measurements: Shaft loads

- Site setup
- Start/Stop
- Bending moment

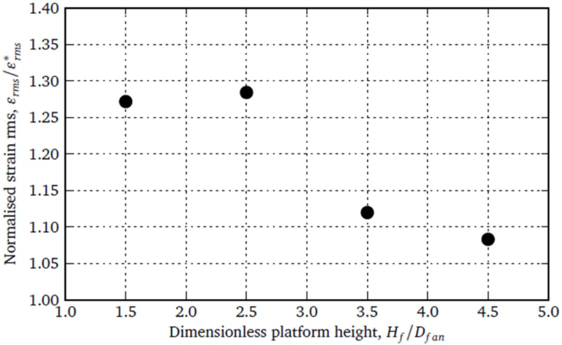
Simulation of fan system dynamics

- Adams model
- System response
- System design

Analysis of vibration source

The effect of the platform height

- Increase of the measured vibration as the platform height is reduced from $4.5D_{fan}$ to $2.5D_{fan}$
- A slight decrease $1.5D_{fan}$, change in excitation mode



Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

On-site measurements: Shaft loads
- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics
- Adams model
- System response
- System design

On-site measurements: Shaft loads

Background

On-site measurements: Blade loading

Full-scale measurements

Wind effects

Vibration frequencies

Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

Fan bridge

Platform height

On-site measurements: Shaft loads

Site setup

Start/Stop

Bending moment

Simulation of fan system dynamics

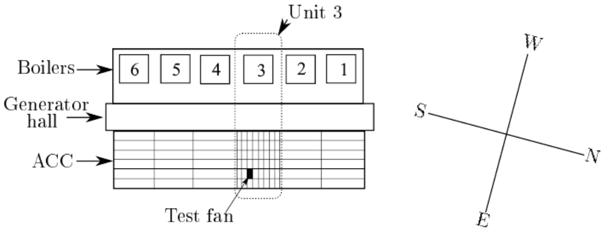
Adams model

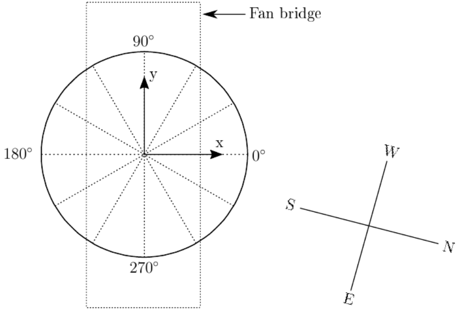
System response

System design

Shaft loads

Site setup Test Case A





Dynamic Response

Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

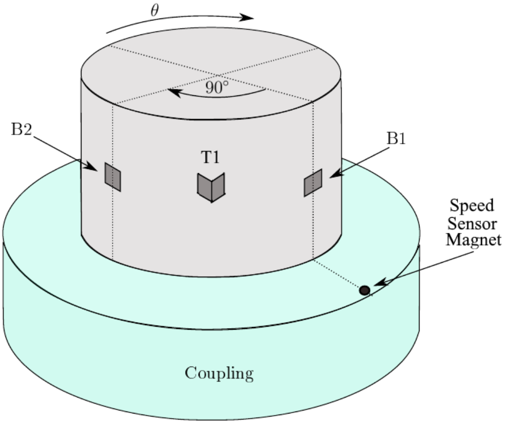
On-site measurements: Shaft loads
- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics
- Adams model
- System response
- System design

Shaft loads

Instrumentation

- Full bridge torque strain gauge
- Full bridge bending moment strain gauge $\times 2$
- Speed sensor



Low speed shaft

Background

On-site measurements: Blade loading

Full-scale measurements

Wind effects

Vibration frequencies

Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

Fan bridge

Platform height

On-site measurements: Shaft loads

Site setup

Start/Stop

Bending moment

Simulation of fan system dynamics

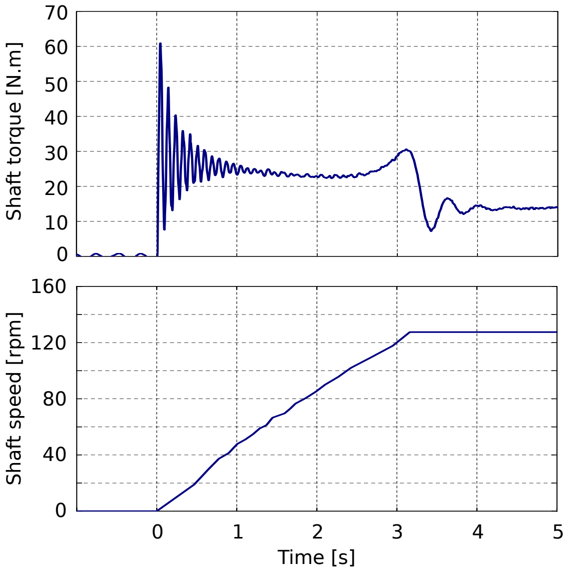
Adams model

System response

System design

Shaft loads

Startup Torque



Background

On-site measurements: Blade loading

- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

- Fan bridge
- Platform height

On-site measurements: Shaft loads

- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics

- Adams model
- System response
- System design

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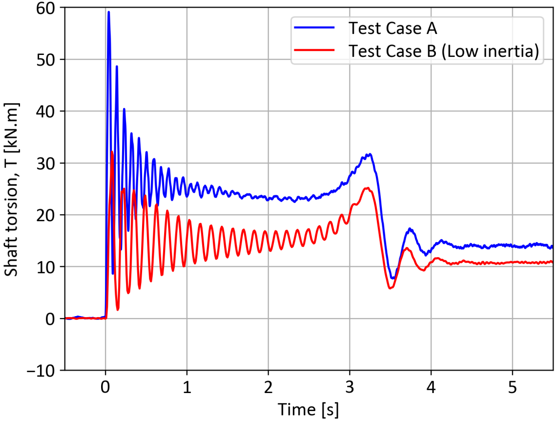
Shaft loads

Startup torque low inertia fan blade comparison: Test Case B

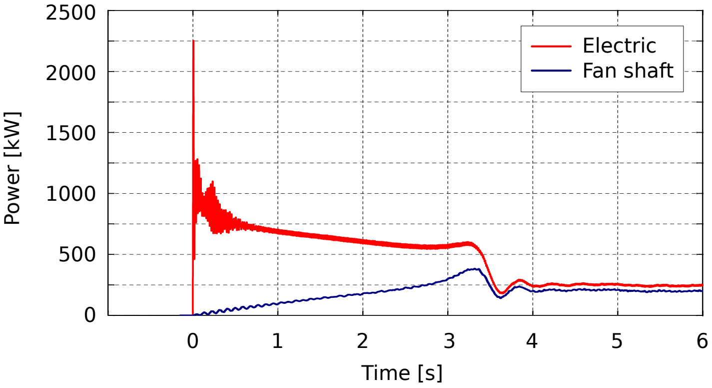
Test Case B

New generation low inertia fan blade that was tested under full scale conditions.



Shaft loads

Startup Power



Background

On-site measurements: Blade loading

Full-scale measurements

Wind effects

Vibration frequencies

Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

Fan bridge

Platform height

On-site measurements: Shaft loads

Site setup

Start/Stop

Bending moment

Simulation of fan system dynamics

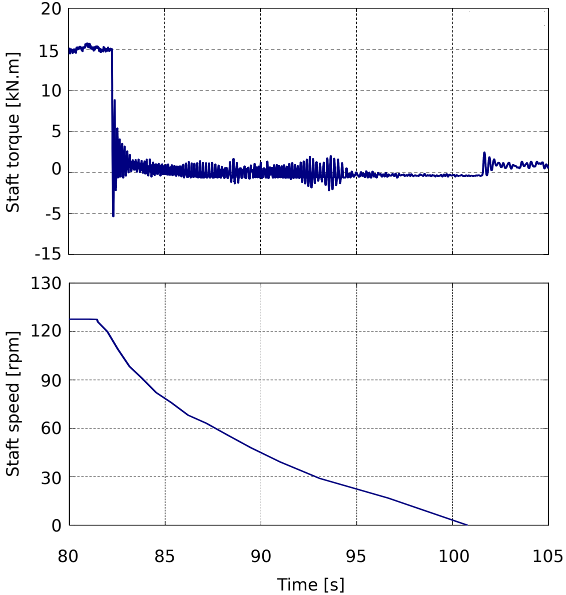
Adams model

System response

System design

Shaft loads

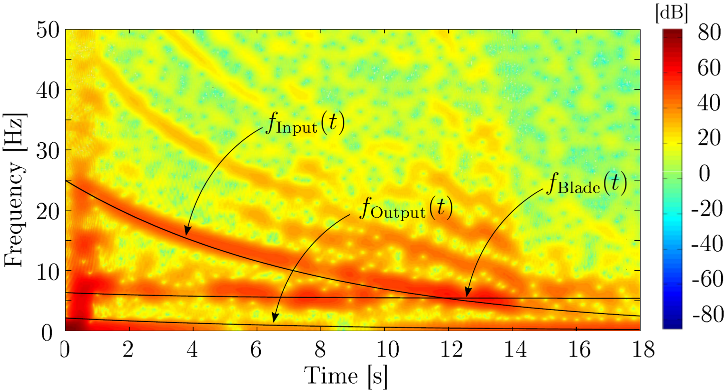
Shutdown



Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

Shaft loads

Shutdown Spectogram



Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

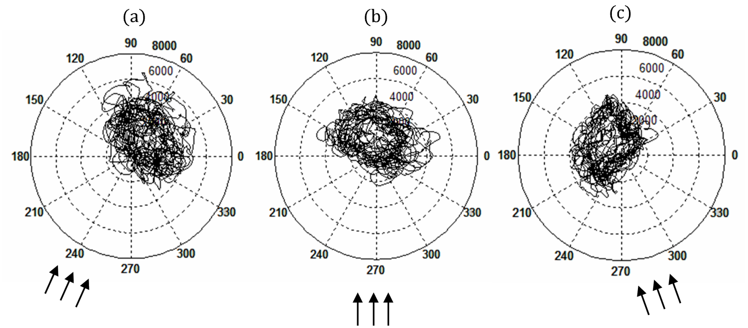
Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

On-site measurements: Shaft loads
- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics
- Adams model
- System response
- System design

Shaft loads

Low speed shaft bending



Total force × length (moment) on output shaft relative to gearbox
Wind speed 25 m/s

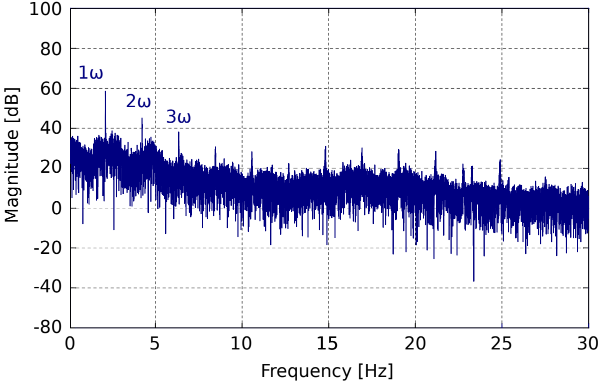
- (a) wind direction 66°
- (b) wind direction 92°
- (c) wind direction 115°

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

ENEXIO

Shaft loads

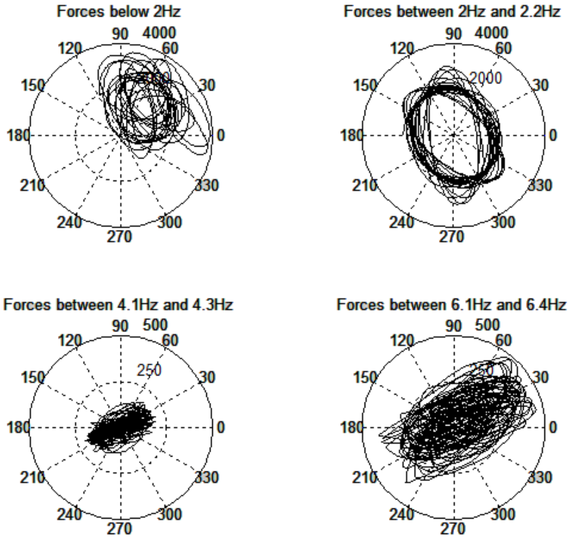
FFT



- Rotation speed 1ω (2.11 Hz)
- Walkway load pulse 2ω (4.23 Hz)
- Blade first bending mode $\approx 3\omega$ (6.35 Hz)

Shaft loads

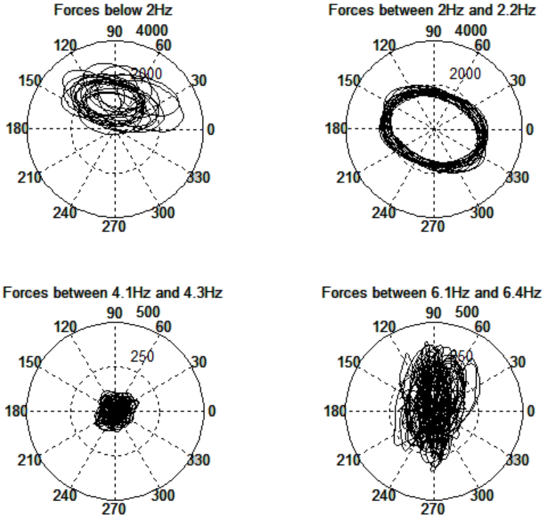
Low speed shaft bending



wind direction 66°

Shaft loads

Low speed shaft bending

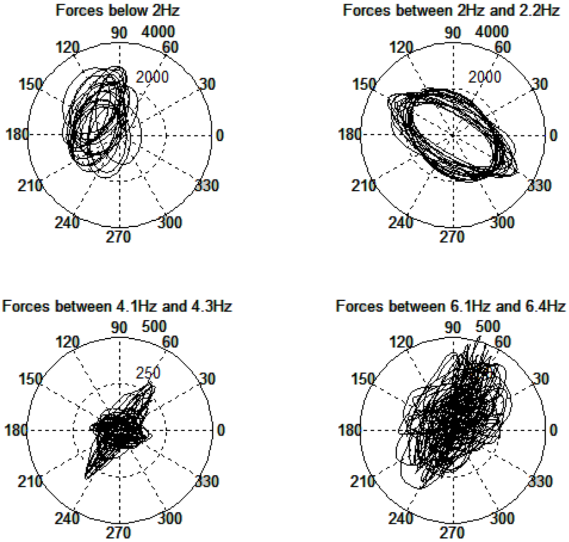


wind direction 92°

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

Shaft loads

Low speed shaft bending



wind direction 115°

Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

Simulation of fan system dynamics

Dynamic Response

Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

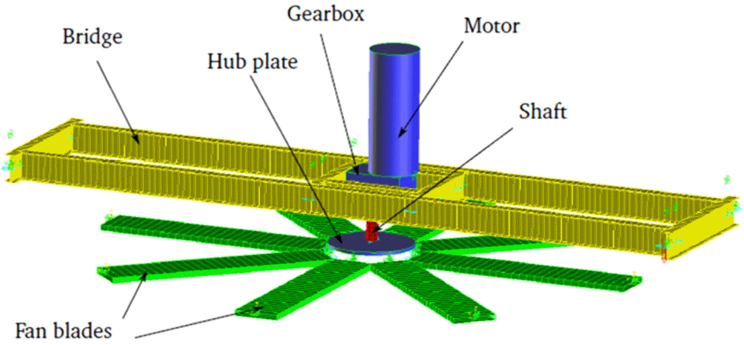
On-site measurements: Shaft loads
- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics
- Adams model
- System response
- System design

Simulation of fan system dynamics

Adams model

- MSC ADAMS used for the dynamic simulation of the fan system
- Flexible bodies used
- Fan blade properties selected to be the same as the finite element fan blade to provide a blade with similar vibrational characteristics as the full-scale fan blade.

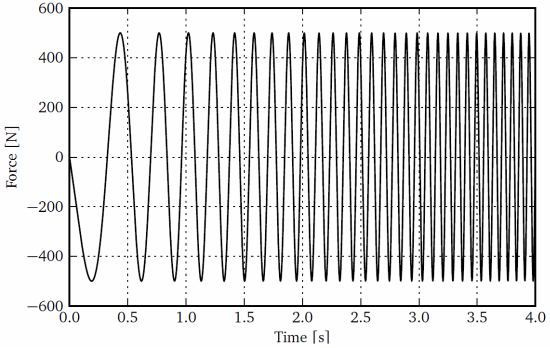


Background
On-site measurements: Blade loading
Full-scale measurements
Wind effects
Vibration frequencies
Excitation reconstruction algorithm
Laboratory measurements: Analysis of vibration sources
Fan bridge
Platform height
On-site measurements: Shaft loads
Site setup
Start/Stop
Bending moment
Simulation of fan system dynamics
Adams model
System response
System design

Simulation of fan system dynamics

Vibration characteristics

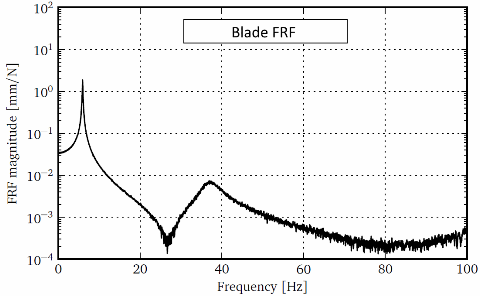
- Impractical to solve eigenvalue problem
- Virtual experiment by applying a force to a model with sweep or a chirp force function and measuring the response at a point.

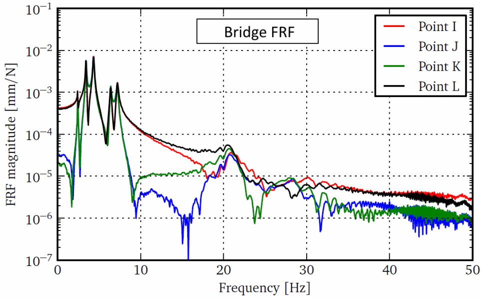


Linear sweep

Simulation of fan system dynamics

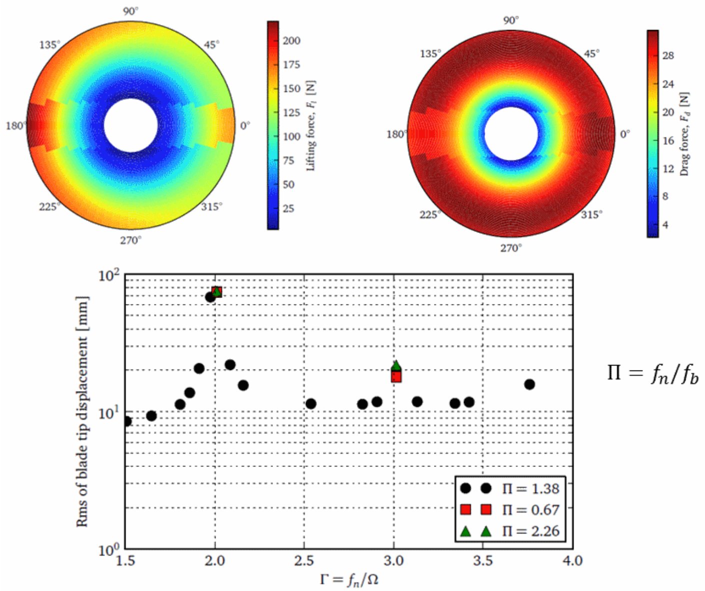
ADAMS vibration characteristics





Simulation of fan system dynamics

System vibration characteristics



$$\Pi = f_n/f_b$$

Dynamic Response

Background

On-site measurements: Blade loading
- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources
- Fan bridge
- Platform height

On-site measurements: Shaft loads
- Site setup
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Simulation of fan system dynamics
- Adams model
- System response
- System design

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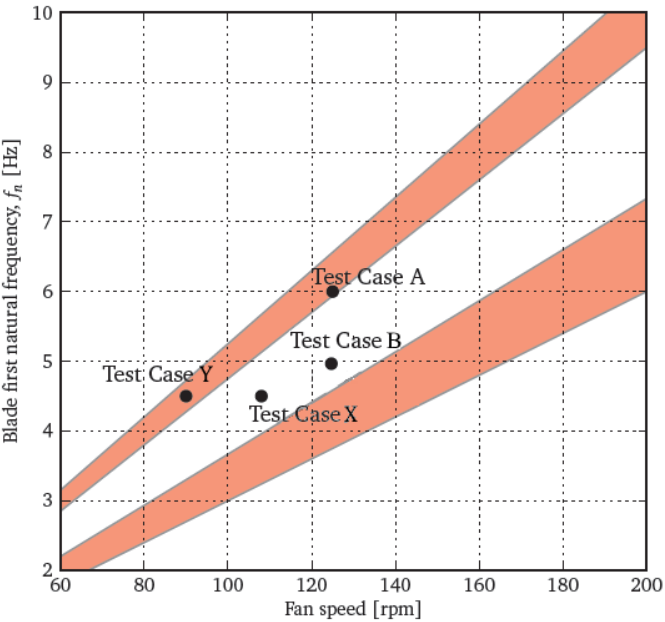
System design recommendations



Background

On-site measurements: Blade loading

- Full-scale measurements
- Wind effects
- Vibration frequencies
- Excitation reconstruction algorithm

Laboratory measurements: Analysis of vibration sources

- Fan bridge
- Platform height

On-site measurements: Shaft loads

- Site setup
- Start/Stop
- Bending moment

Simulation of fan system dynamics

- Adams model
- System response
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