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Air Cooled Condenser Fan Blade Failure

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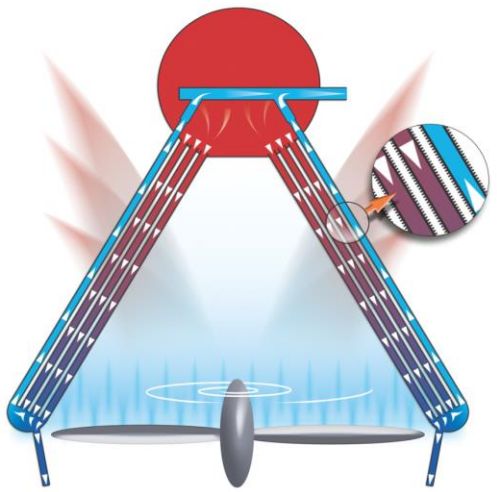
Biographies

- **Patrick J. Smith** is a Fellow at Air Products and Chemicals, Inc. and is based in Allentown, PA. He is the Global Machinery Technology Manager and the Global Machinery Lead in the Operational Excellence Technical Team. He has over 35 years of rotating machinery experience.
- **Cindy Li** is a Machinery Engineering Manager in the Global Engineering organization at Air Products & Chemicals. She is based in Shanghai, China and has 25 years of rotating machinery experience.

ACC Overview

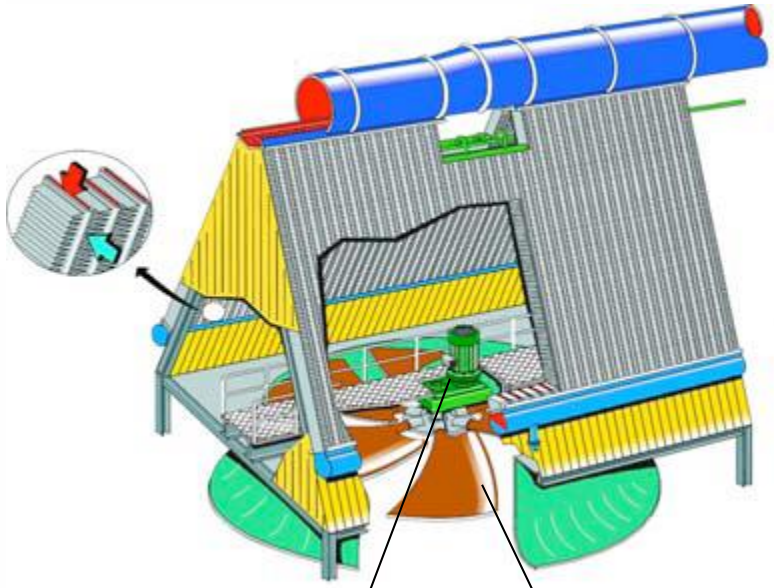
- A surface condenser is a commonly used term for a water-cooled shell and tube heat exchanger installed to condense exhaust steam from a steam turbine. These condensers convert steam from its gaseous state to its liquid state at a pressure below atmospheric pressure.
- Where cooling water is in short supply, an air-cooled condenser (ACC) is often used. An air-cooled condenser is however, significantly more expensive and cannot achieve as low a steam turbine exhaust pressure (and temperature) as a water-cooled surface condenser.
- The picture on the right shows a typical 3 cell ACC

ACC Features



ACC Condensing Flow

ACC mechanical configuration



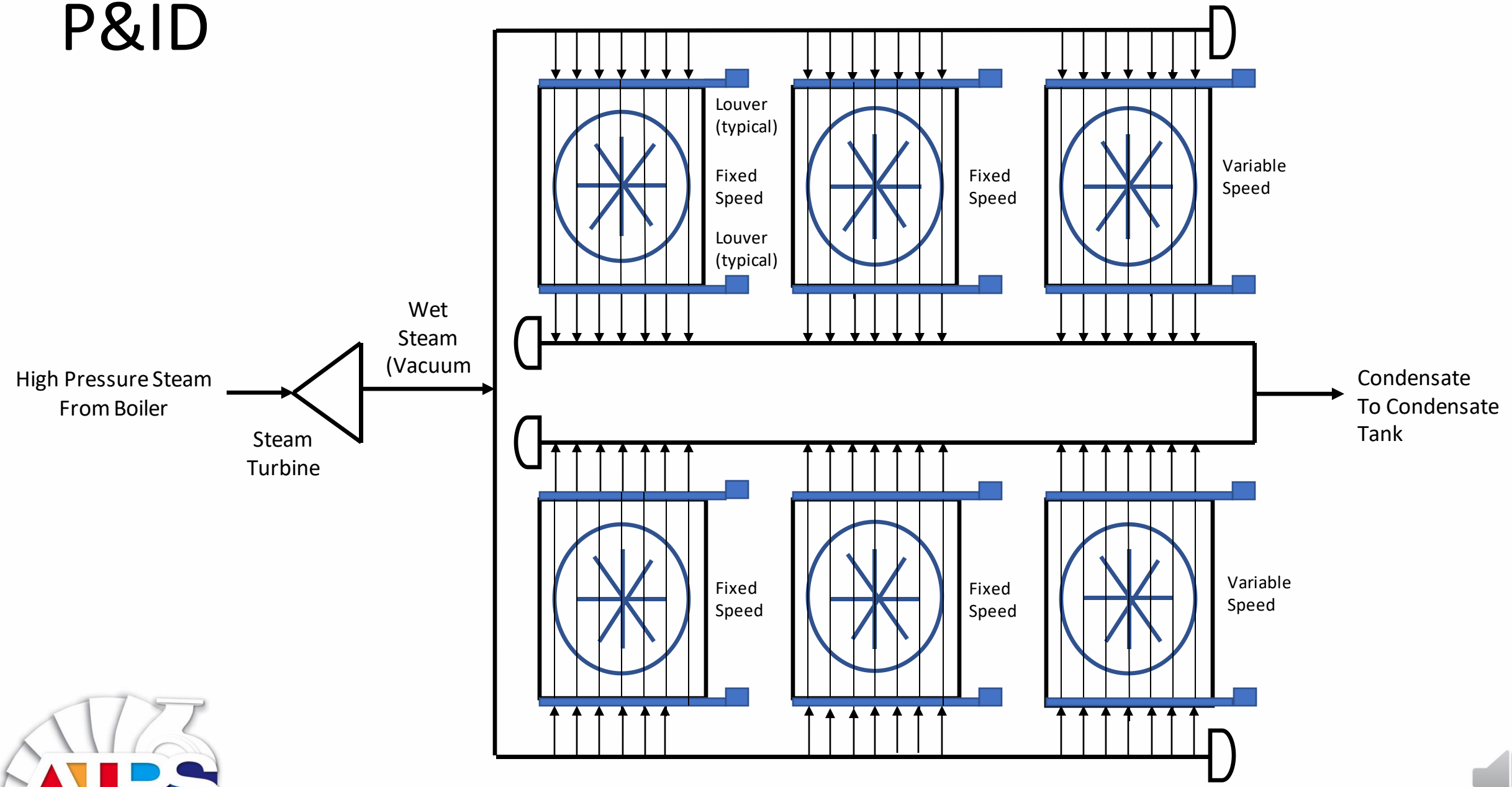
Motor and Gearbox

ACC Fan Blade

ACC under construction

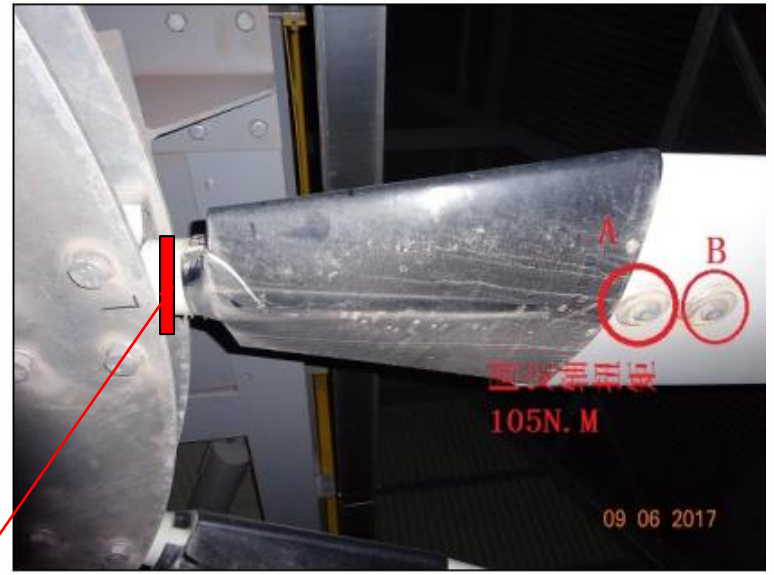
Wind Wall

P&ID


Louver
(typical)
Fixed
Speed
Louver
(typical)
Fixed
Speed
Variable
Speed
Wet
Steam
(Vacuum
High Pressure Steam
From Boiler
Steam
Turbine
Condensate
To Condensate
Tank
Fixed
Speed
Fixed
Speed
Variable
Speed

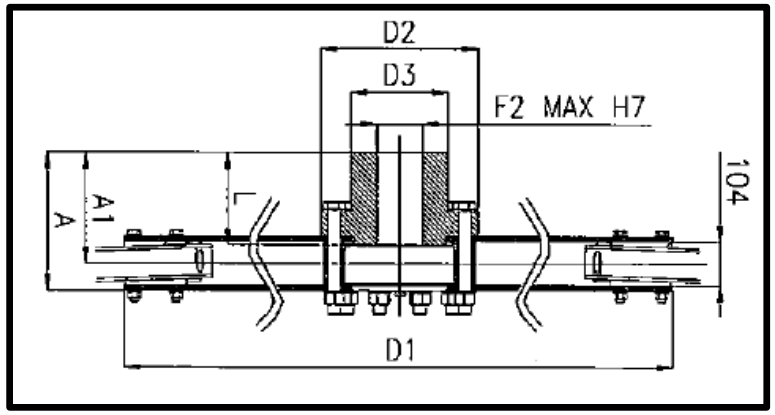
Problem Statement

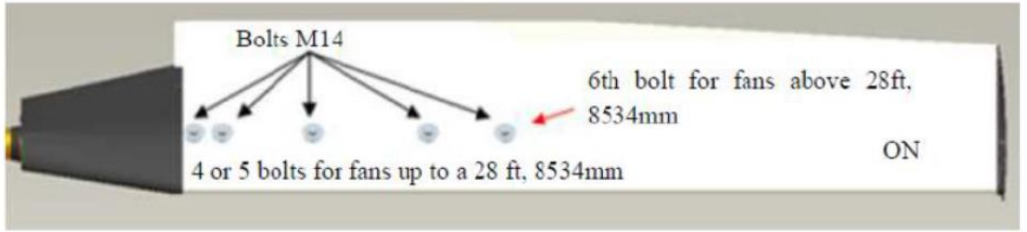
- ACC fan blade failures occurred on several fans at two Air Product facilities. There are multiple trains at each facility.
- The fan design and construction in all the trains was similar and all the blade failures had similar characteristics.
- Failures included broken blades, cracked blades and loose bolts.
- The failures only occurred on the variable speed fans.

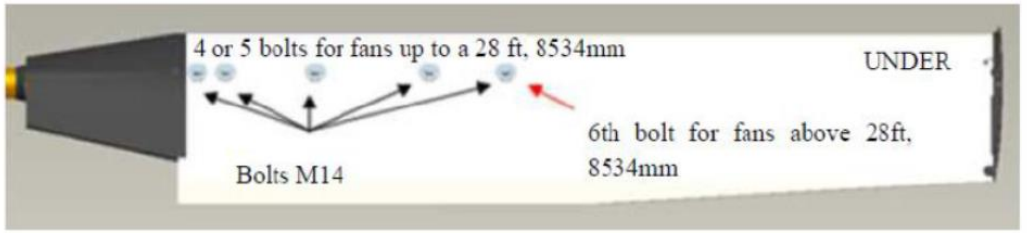


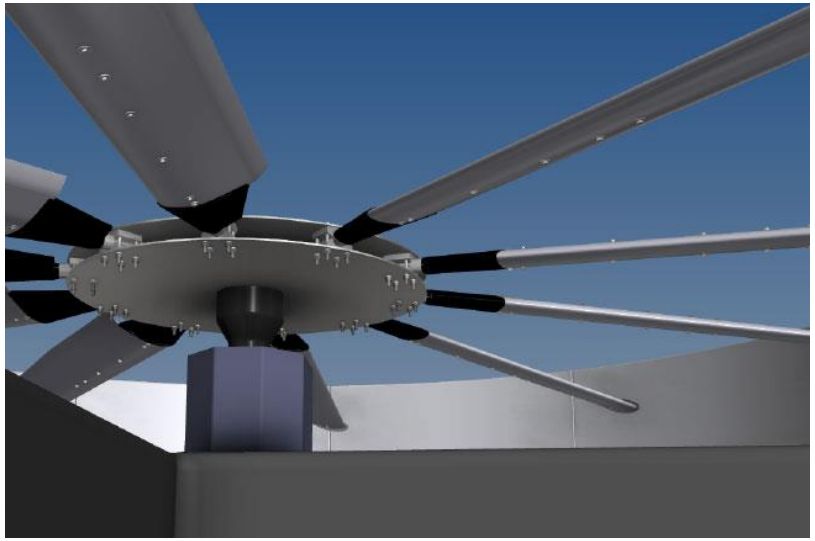
Broken Location

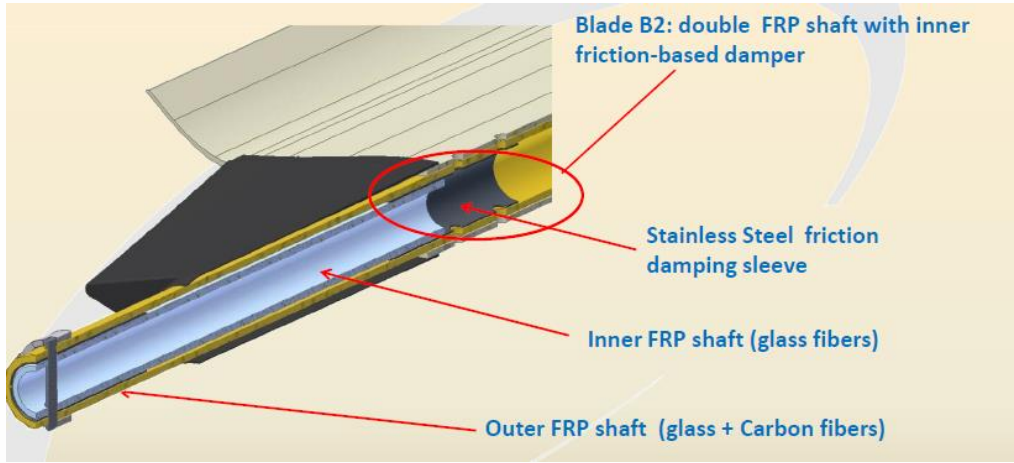
Blade Construction and Mounting





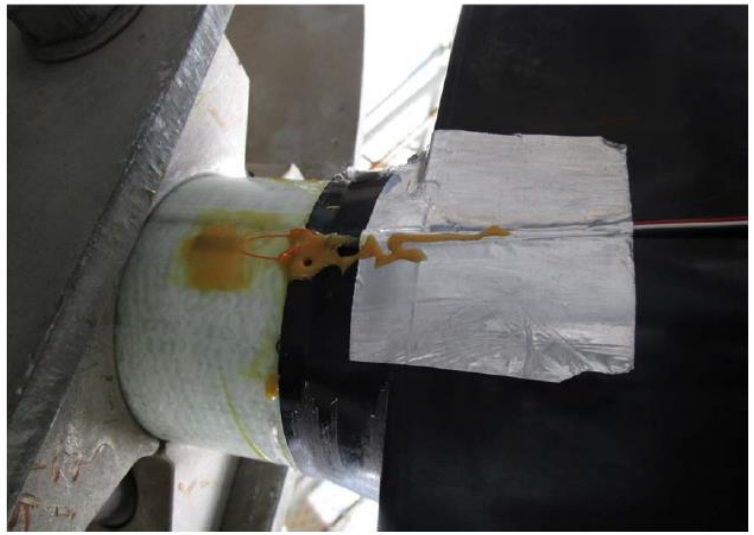


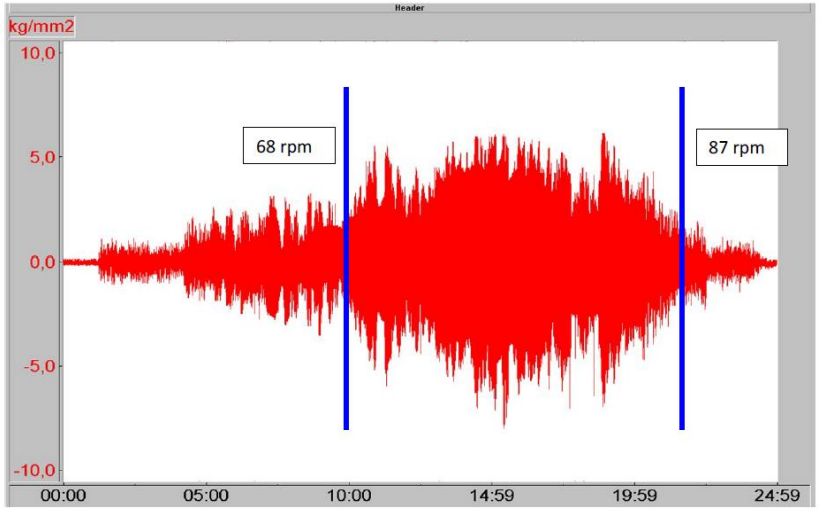




Investigation and Assessment

- Site investigation and assessments were made after several failures.
- In order to check the stress acting on the blades in operation and evaluate possible anomalies, strain gauges were installed to measure the stress in longitudinal direction along the entire speed range. The location corresponded to the highest stressed area of the blade.
  - Measurements showed a large increase in the alternating stress in the speed range from 68 rpm to 87 rpm (See right bottom diagram).

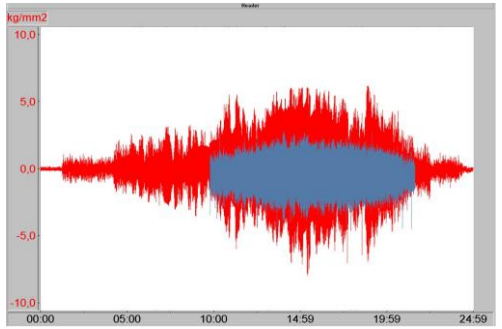


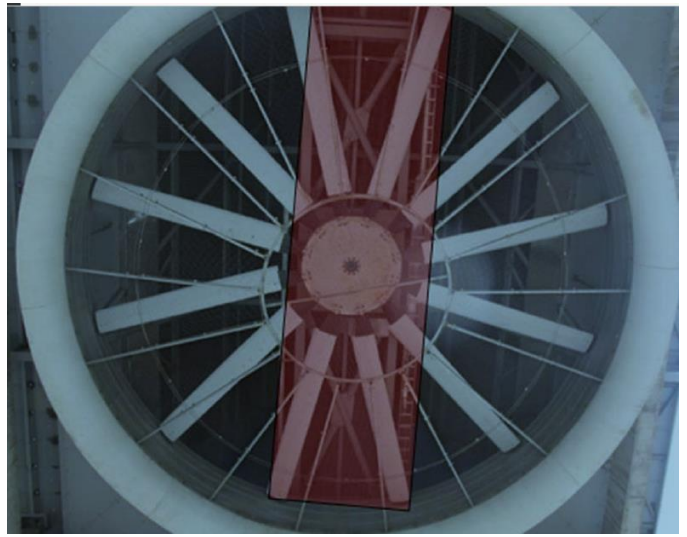


Preliminary assessment

- No issue found with the installation of the blades on the hub
- **The huge increase of the alternated stress in the speed range from 68 rpm to 87 rpm was due to a resonance operating condition.**
- It was found, when fans under resonance condition, the alternated stress increase on the blade is very sensitive to external factors , e.g.,
  1) *Crosswind*
  2) *Flow obstruction (like Bridge dimensions)*

From above findings, we can see the root cause of blade vibration is related to resonance.





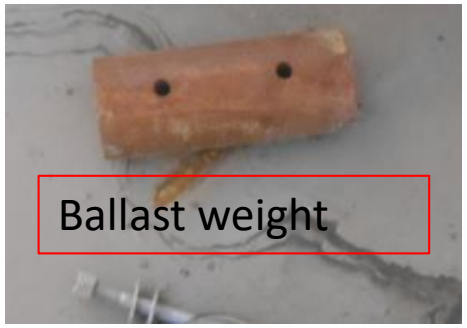
Site Retrofit

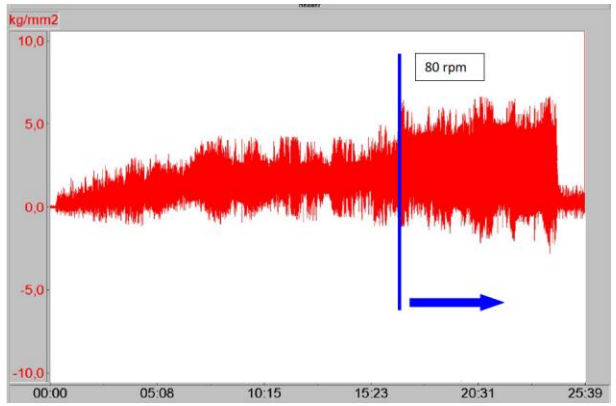
- **Site Retrofit work done**

The following modifications were made at one plant to shift the blade natural frequency out of the operating speed range.

  - *Upgrade airfoil to shaft attachment bolts.*
  - *Remove the ballast (weight installed at the tip of blade) on the blades driven by VFD to increase the blade natural frequency above 80 cpm.*
  - *Limit the maximum fan speed to 80 rpm.*
  - *Re-pitch of the blades to compensate for the design speed reduction.*

- **Measurement after the modification showed a significant reduction in stress at the root of blade**





Failure 3 Months After the Retrofit

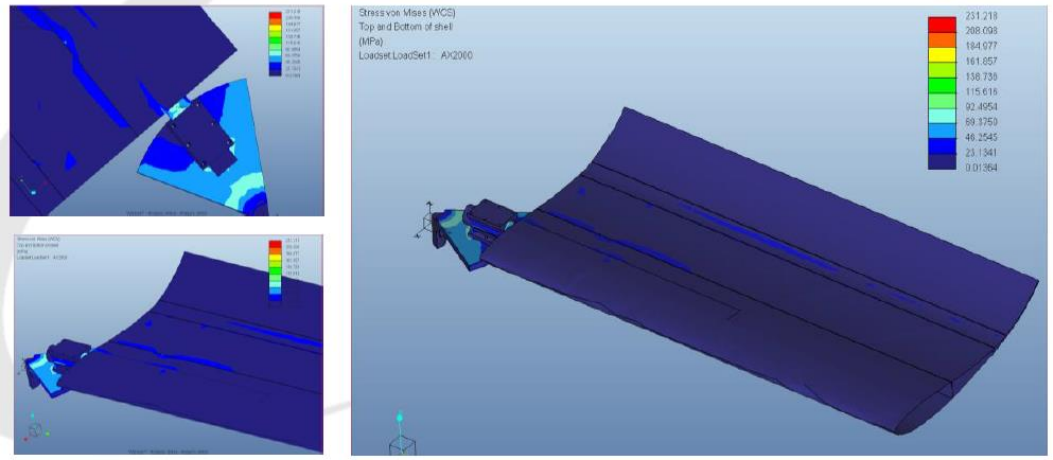
- Train 1, fan C -- 10 out of 12 blades cracked, total 17 bolts broken
- Train 2, fan C -- 11 out of 12 blades cracked, total 38 bolts broken
- Train 3, fan F -- 10 out of 12 blades cracked, total 22 bolts broken

Possible reasons that the corrective action didn't work:

1. *The resonance condition still exists and the influence from other factors, such as crosswind, may have made the situation worse.*
2. *The static load (from the combination of traction force +centrifugal force)+ alternated load acting on the blade led to fatigue failures.*

Corrective Action

2nd round of root cause analysis and measurement done. It is defined that resonance is still the main reason for blade failures. Fan OEM proposed to use an upgraded fan blade construction:



Main features for new blade:

1. *Stronger blade shaft material – steel versus FRP.*
2. *Higher blade natural frequency -- 402 CPM versus 126 CPM.*
3. *FEA done supports the new blade solution*

Results

- For plant A:
  - *The blades on all the VFD fans were replaced with steel fan blades in May 2018. Since making this change there have been no fan blade failures.*

- For plant B:
  - *The replacement of VFD fan blades to be implemented soon.*

Conclusions

- Be aware of the blade natural frequencies, particularly when operating ACC fans at variable speed over a large speed range.
- Pay particular attention to:
  - The one times running speed frequency
  - The blade passing frequency
- According to API 661, Petroleum, Petrochemical, and Natural Gas Industries—Air-cooled Heat Exchangers, states, "…The natural frequency of the fan or fan components shall not be within 10 % of the blade-pass frequency. Blade-pass frequency (in passes per second) equals the number of blades multiplied by the fan speed (in revolutions per second).
- **Consider a piece design fan blade with a natural frequency well above the maximum speed for fans operating at variable speed conditions.**

Thank you

Please feel free to contact me at smithpj@airproducts.com of Cindy Li at lich@airproducts.com.
Also please join the Zoom post presentation session for further questions/discussion