NewEnergyUpdate

Wind Turbine Common Failures and Solutions

This article was produced in association with the Wind Operations & Maintenance Canada 2017 Conference

Experience is improving estimates of failure times for critical components such as bearings, said experts at the 3rd Annual Wind Optimization & Maintenance Canada conference.

For example, it is now possible to roughly predict failure occurrence rates and total cost of repair for four common wind drivetrain failures, affecting main shaft spherical and tapered roller bearings and gearbox high-speed and planet bearings.

"All the bearings have their strengths and weaknesses," said Richard Brooks, wind aftermarket manager at The Timken Company, which engineers and manufactures mechanical power transmission components.

Thus, main shaft spherical roller bearing (SRB) failures typically occur in less than 10 years and carry a high total cost because repairs usually require a crane removal and a shop-based rebuild.

On some turbine models, Brooks said, it may also be necessary to remove the gearbox. And gearboxes may be prone to consequential damage from excessive thrust following an SRB failure. Main shaft SRB damage usually falls into three categories, he noted.

These are micropitting, cage damage and edge loading, which Brooks said is more common in narrow, 230 Series bearings. As well as these direct forms of damage, it is common for SRB failures to generate debris which then affects the working of other components.

"Once you start to accumulate debris in the grease, it's going to stay there," Brooks commented.

Main shaft SRB damage is inherent in the design of the components and cannot be fully prevented. However, maintaining or exceeding the manufacturer's recommended quantities and frequencies for lubrication can help cut the chances of failure.

TECHNOLOGY	DESCRIPTION	BENEFITS
Roller Finishing	Low Roughness, Isotropic Finish	Reduced Asperity Contact & Stress
Roller Coating	WC/aC:H Coating 1 μm thick	Increased Wear Resistance, Increased Fatigue Life, Increased Debris Resistance.
Internal Geometry	Roller/IR Conformity	Decreases Roller Stress, Reduces Potential Roller Skew Creates Favorable Traction
Split Cage	Two-Piece Machined Brass Cage with no Guide Ring	Lowers Possible Operating Forces Removes source of debris generation

Main shaft SRB enhancements. Source: Timken.

Brooks said maintenance teams might also consider purging or flushing the main shaft lubrication every few years, depending on its condition.

Detecting failures in the first place would require looking at temperature trends, sampling the iron content in main shaft grease or tracking vibration data with special algorithms, he said.

Machines suffering from main shaft SRB failures could be treated with enhancements to the bearings or a redesign to replace SRBs with tapered roller bearings (TRBs), which can accept much greater thrust loads.

Enhancements may include roller finishing to reduce asperity, or the application of diamond-like coating to improve wear resistance.

Alternatively, replacing SRBs with TRBs could reduce the axial thrust into the gearbox by up to two thirds, increasing the gearbox's life span.

TRBs are already widely used in direct-drive turbines. In these, "you don't see many bearing failures," Brooks said, but when they occur "it's ridiculously expensive" because of the need for a crane and a shop-based rebuild.

Most direct-drive main shaft TRB damage stems from a loss of pre-load on the bearing, which is usually a manufacturing error, or from design-related cage problems.

This means direct-drive main shaft TRB problems are hard to prevent, other than by maintaining a well-lubricated environment.

TRB damage

Furthermore, using vibration methods to detect TRB faults "can be a real challenge because the generator creates a lot of noise that makes it difficult to do the analysis," Brooks said.

The best way to deal with direct-drive main shaft TRB challenges was highly turbine dependent, said Brooks, and usually required some action on the part of the equipment manufacturer.

Asset owners that do not have direct-drive machines will need to factor in failure rates from gearbox bearings. Planet carrier and low-speed position bearings have low occurrence rates but tend to be subject to thrust damage.

Planetary positions, meanwhile, have medium failure rates and often see debris and load damage. "Typically you're going to see your first failure in planet bearings around year seven," Brooks said.

The cost for repairing such failures is coming down as more work is done up-tower, although some turbine models require main shaft removal, Brooks cautioned.

Another trend in planet bearings is for the components to be integrated, which helps reduce creeping and heavy or uneven loading. "The integrated taper bearing is the best design if it's done properly," Brooks said.

To detect gearbox planet bearing wastage, it can help to perform online oil testing and vibration analysis, he said.

And when considering repairs, it might pay to check on the overall condition of the gearbox in case it makes sense to overhaul the whole assembly rather than just addressing the bearing issues. Finally, high-speed bearings have high failure rates.

Planet bearings

Avoiding problems such as smearing, inclusion axial cracking or web etch area cracks is normally a matter maintaining good, water-free lubrication and carrying out online vibration analysis and oil sampling, according to Brooks.

In general, however, the typical cost of repairs is low since work can usually be performed up-tower. This is actually the case with a growing number of turbine failures, said Alex Vezina, technical manager at Delom Services.

"We all want to avoid taking a generator down," he said, because of cost of cranes, downtime and shop repairs.

To check whether an up-tower repair is feasible, though, it is important to first carry out a number of tests on ground and between-turns insulation, for instance with Megger ohmmeter polarization index, step voltage, dielectric discharge, Hi-Pot and surge tests.

Technicians should perform electrical tests to ground and then check in-between turns, Vezina said.

Depending on the findings, it might be useful to carry out visual and borescope inspections inside the generator, perform a vibration analysis, check slip rings, brushes and brush holders, and clean out any contamination.

The clip-ring cabinet can be a significant cause of debris, Vezina said. "It will create carbon dust that will get almost everywhere in the turbine and create problems," he commented.

With the correct checks, however, it is now possible to carry out a wide of repair tasks up-tower, from mending rotor leads and unevenly worn slip rings to replacing leads, bus bars and insulators in the wake of an electrical explosion.

Enhancement	White Etch	Inclusions	Smearing
Steel Cleanliness	+	+++	
Black Oxide	+ (early stages)		++ (early stages)
'DLC' Coatings	+		+++
Case Carburized	+++	++	

High-speed bearing enhancements. Source: Timken.

Some types of repairs remain beyond the scope of up-tower work, Vezina admitted. In one case, he said, a borescope inspection revealed worn windings on a generator. "With this type of failure there is nothing we can do in the up-tower environment," he said.

Whether repairs are ultimately carried out up-tower or not, a key challenge for wind farm operators is to reduce the lead time for remediation, or the interval between a fault being detected and it being fixed.

"One of the things I've been asked several times is 'how much time do I have?'," said Reynir Hilmisson, a lead global remote monitoring and diagnostic engineer for Brüel & Kjær Vibro, which provides condition monitoring systems (CMS) for the wind industry.

But defining that lead time "is not an easy thing," he said, for a number of reasons.

For example, sometimes CMS data can hint at the presence of a fault that is not apparent during a visual inspection. In such a case, there could be a delay in repairs while a second inspection is carried out.

Similarly, in some cases it might not be possible to carry out repairs because of weather conditions. Even with these external factors, though Hilmisson said it would repay asset owners to install CMS.

"A lot of people think it's too much hassle," he said, but "with one, we did in the installation in three months and the payback was in four months."

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Lessons Learned: Common Wind Turbine Bearing Failures, Costs & Solutions

Presented by Richard Brooks
Wind O&M Canada 2016

Stronger.

Stronger. **Commitment.** Stronger. **Value.** Stronger. **Worldwide.** Stronger. **Together.** | **Stronger.** By Design.

Four Common Wind Drivetrain Failure modes

- Main shaft – Spherical Roller Bearing in Modular Turbines
- Main shaft - Tapered Roller Bearing in Direct Drive Turbines
- Gearbox High Speed Bearing
- Gearbox Planet Bearing

- Not Covered Today:
  - *Generator Bearing*
  - *Pitch Bearing*

Bearing Type Comparison

- Spherical Roller Bearing
  - Radial Internal Clearance (RIC)
  - Line Contact (mostly)
    - +Radial Load
    - + Thrust Load <25%

SRB

- Cylindrical Roller Bearing
  - Radial Internal Clearance (RIC)
  - Line Contact
    - +Radial Load
    - - Thrust Load (<10%)
    - -- Misalignment

CRB

- Tapered Roller Bearing
  - Can be Pre-Loaded
  - Line Contact
    - +Radial Load
    - ++ Thrust Load (100%+)

TRB

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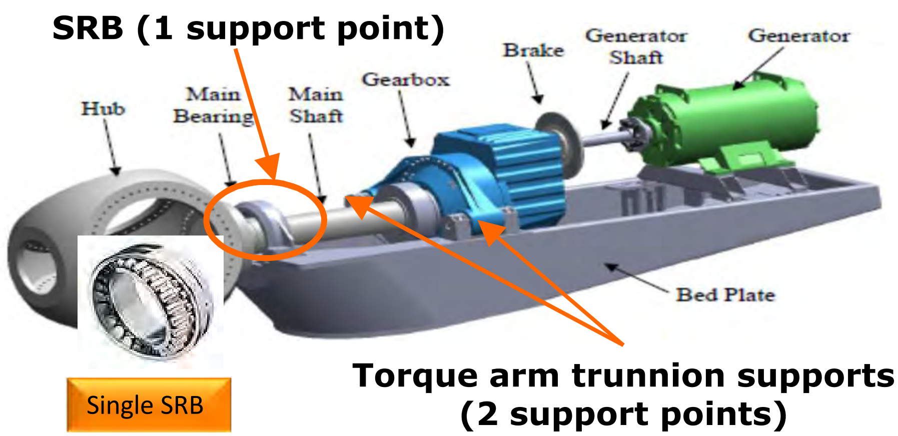
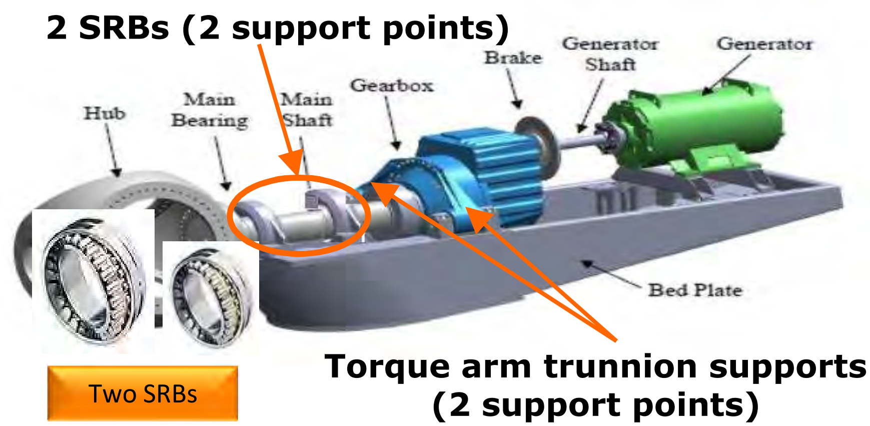
MAIN SHAFT – SPHERICAL ROLLER BEARING ARRANGEMENTS

3-Point Mount



Highest failure rate

4-Point Mount



Failures less common, but can happen on Downwind bearing

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Main shaft – Spherical Roller Bearing Failure Financial Impact

- Occurrence Rate: Medium
  - Varies by turbine & site conditions
  - Typical L10* ≈ <10 years
- Total Cost: High
  - Requires crane & rebuild in a shop
  - Some turbine models also require gearbox removal
- Possible Consequential Damage:
  - Gearbox damage from excessive thrust

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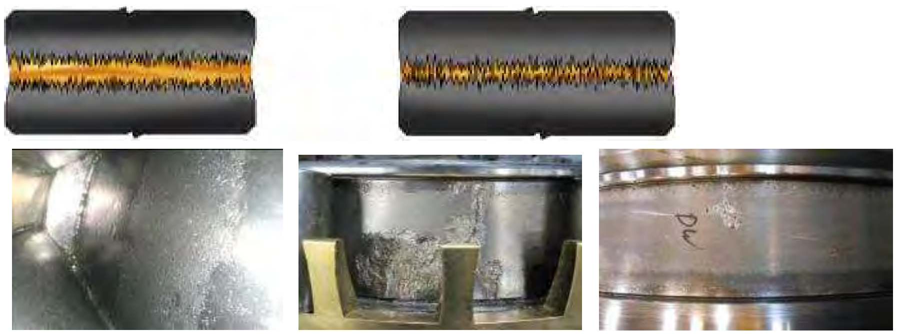
Main shaft SRB — Observed Damage

Micropitting



Edge Loading

Cage Damage

Debris Damage

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Main shaft SRB

Prevention

- Cannot be fully prevented: Inherent to the design
- Lubrication:
  - Follow or exceed OE recommended quantities and frequency
  - Consider a purge or flush after several years based on condition

Detection

- Temperature trend looking for park outliers
- Grease sampling for Iron content
- Vibration (may require special algorithms)

Solutions: Main Shaft SRB
#1: Enhancements

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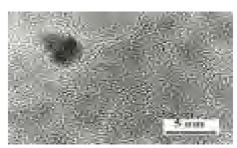
Texturing

Coating



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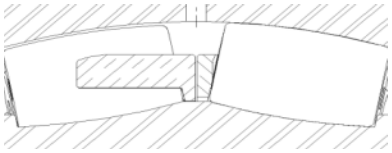
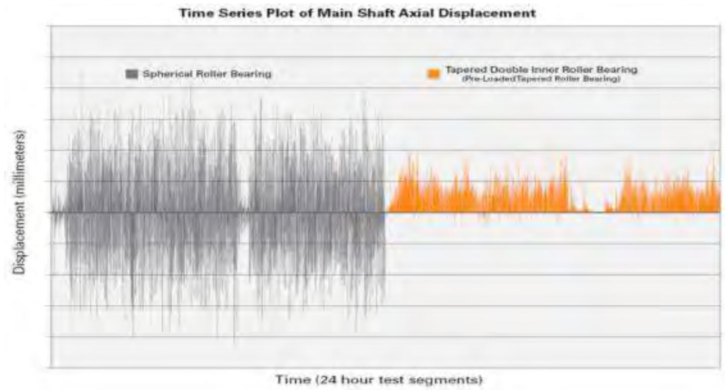
Solutions: Main Shaft SRB
#2: Re-Design – Replace with TRB

Spherical Roller Bearing (SRB)

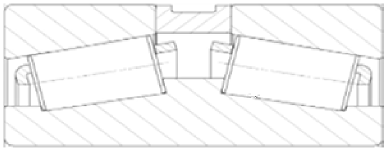
- Internal clearance
- Limited thrust capability
- Helpful with misalignment
- Not true rolling motion





Tapered Roller Bearing (TDI)

- Preloaded
- High thrust and radial capacity
- Must control misalignment
- True rolling motion



A reduction of axial thrust into gearbox by 67% will decrease stress.

This can increase bearing and gearbox life.

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Main shaft - Tapered Roller Bearings in Direct Drive

Taper plus CRB

Single Row Taper

Double Row Taper

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Main shaft – TRBs in Direct Drive
Financial Impact

- Occurrence Rate: Low
  - Varies by turbine & site conditions
  - Typical L10* ≈ ? years
- Total Cost: High
  - Requires crane & may require rebuild in a shop
- Possible Consequential Damage:
  - Generator damage

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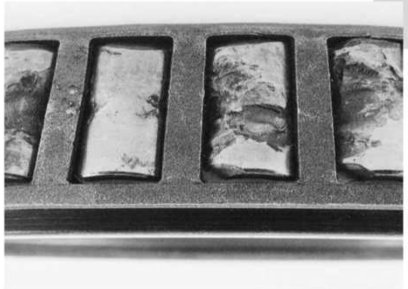
Main shaft, Direct Drive TRBs— Observed Damage

- Damage from loss of Pre-Load
  - Typically caused by assembly



- Cage
  - Often design related

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Main shaft, Direct Drive TRBs

Prevention

- Cannot be fully prevented: Inherent to the design
- Keep bolts tensions on some models
- Lubrication:
  - Follow or exceed OE recommended quantities and frequency

Detection

- Temperature trend looking for park outliers
- Grease sampling for Iron and Cage material content
- Check bolt tension on some models
- Vibration (very difficult due to generator interference)

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SOLUTIONS

- Highly turbine dependent
  - Often includes new bearing design

- Usually an OE only solution

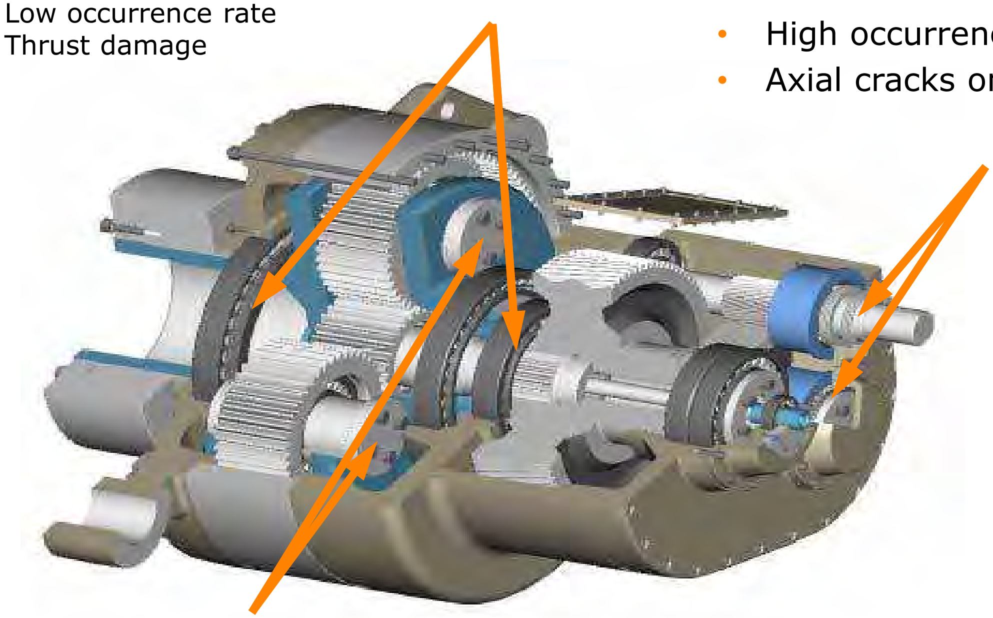
WIND GEARBOX BEARINGS

Planet Carrier & Low Speed Positions:

- Low occurrence rate
- Thrust damage

High Speed & Intermediate Results:

- High occurrence rate
- Axial cracks on inners



Planetary positions:

- Medium occurrence rate
- Debris & load damage

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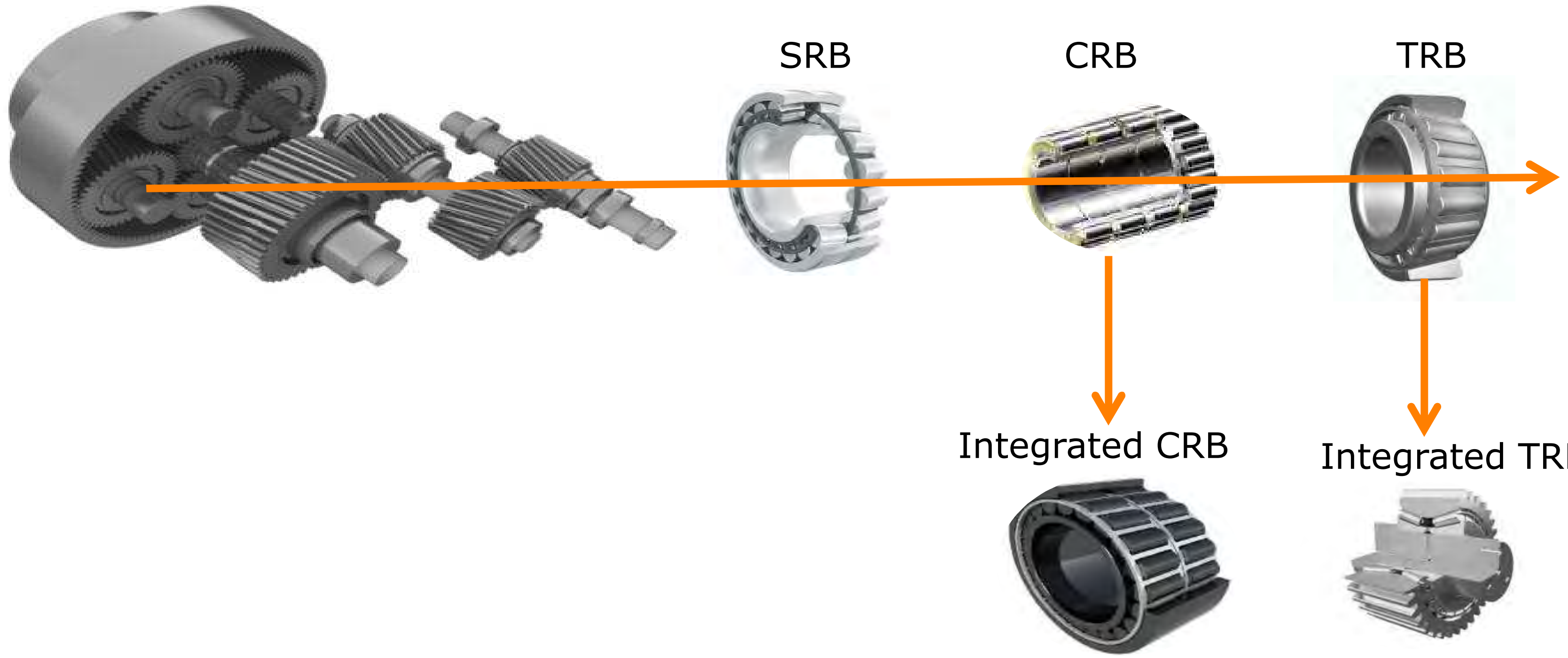
PLANET BEARING ARRANGEMENTS



Gearbox Planet Bearing Financial Impact

- Occurrence Rate: Medium
  - Varies by turbine & Gearbox model
  - Typical L10* ≈ 10 years
- Total Cost: Medium
  - May require crane & rebuild in a shop, but more being done up-tower
  - Some turbine models also require main shaft removal
- Possible Consequential Damage:
  - Damage to the rest of the gearbox from debris

Planet Bearing – Observed Damage Modes

	Non-Integrated	Integrated
TRB	• Debris damage • Creeping Outer	• Debris damage
CRB	• Debris damage • Thrust load • Heavy / Uneven loading • Smearing • Creeping outer	• Debris damage • Thrust Loading • Smearing

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Gearbox Planet Bearings

Prevention

- Monitor main bearings for excessive wear

Detection

- Oil testing sampling for Iron content, online preferred
- Vibration analysis, online preferred
- Check position of torque arms in mountings

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SOLUTIONS

- SRB
  - Replace with new design
- CRB
  - Case carburized
  - DLC / Black Oxide coating
  - Modified controlled clearances
- TRB
  - Case carburized
  - Integrated design

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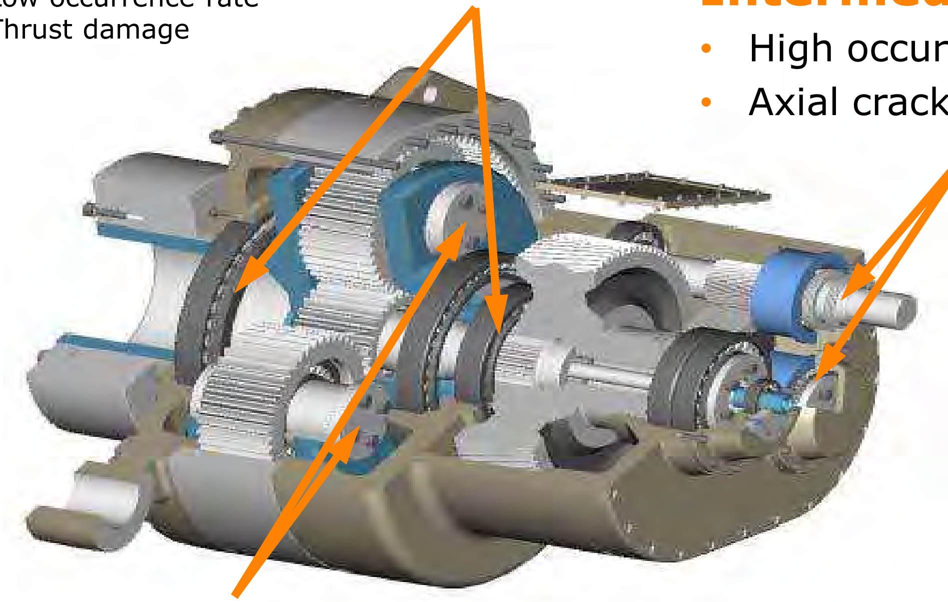
WIND GEARBOX BEARINGS

Planet Carrier & Low Speed Positions:
- Low occurrence rate
- Thrust damage

High Speed & Intermediate Results:
- High occurrence rate
- Axial cracks on inners



Planetary positions:
- Medium occurrence rate
- Debris & load damage

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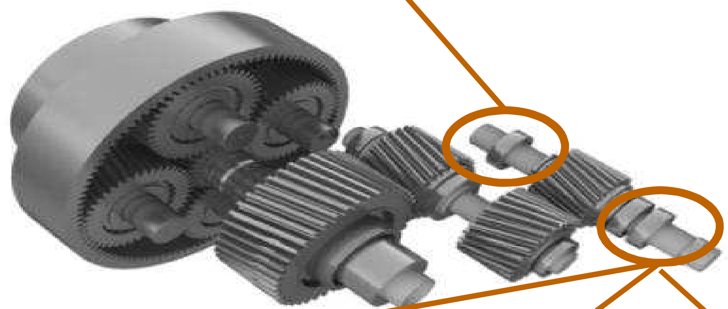
High Speed and Intermediate Common Gearbox Bearing Arrangements

CRB



Option 1

CRB + Ball Bearing

Option 2

Double TRB

Option 3

Single TRB

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Gearbox High Speed Bearing Financial Impact

- Occurrence Rate: High
  - Varies by turbine & Gearbox model
  - Typical L10* ≈ 5 years
- Total Cost: Low
  - Typically performed up-tower
- Possible Consequential Damage:
  - Damage to the rest of the gearbox from debris

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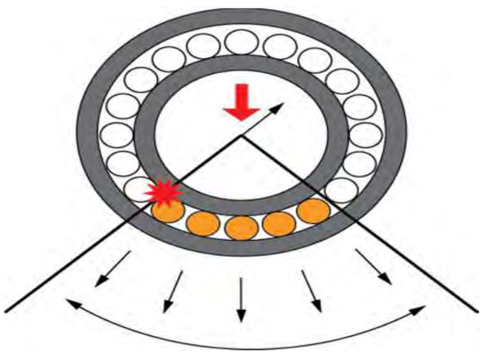
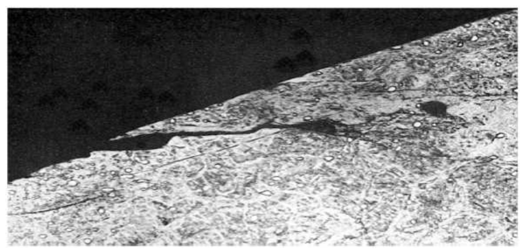
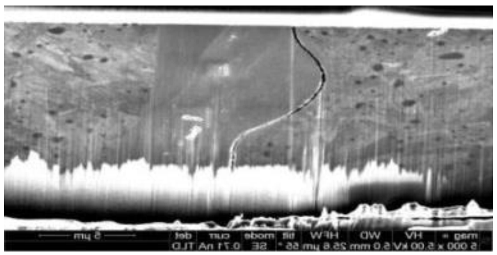
High Speed & Intermediate Bearings – Observed Damage Modes



Smearing

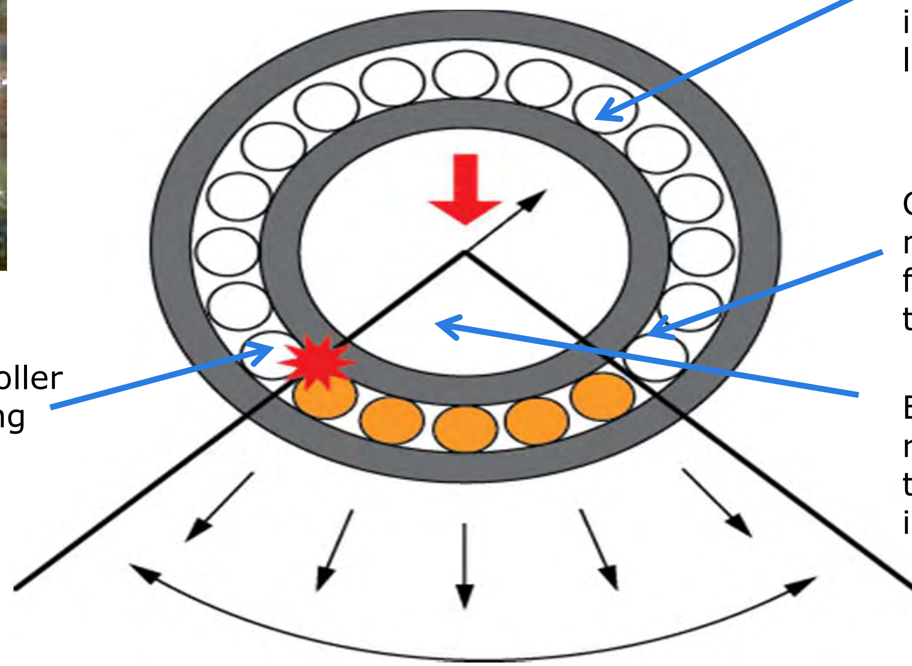


Inclusion Axial Cracking/Spalling



White Etch Area Axial Cracking/Flaking

Roller Sliding/Smearing in CRB



D – Roller sliding increases outside the loadzone

C – Load zone exit – most of the traction forces are lost beyond this point

A – Smearing as roller accelerates entering the load zone

B – Traction forces restore roller velocity to pure rolling motion in load zone

Load Zone

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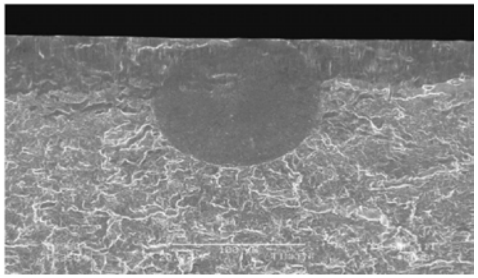
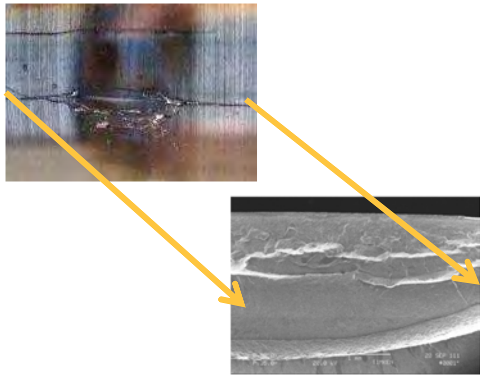
INCLUSION RELATED AXIAL CRACKING

- Caused by non-ferrous contaminants in the steel
- Commonly manifests as white etch butterflies
- Material transforms in the area of the inclusion
- Crack forms and prorogates to the surface or spalls





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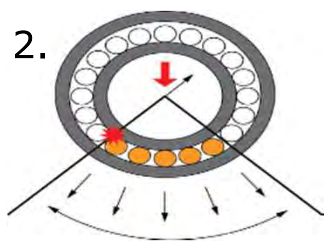
Web Etch Areas Cracks

1. Hoop stress from original press fit on shaft
2. Tensile stresses from roller sliding & skewing
3. Dynamic conditions begin the subsurface transformation
4. Crack forms in the heard & brittle transformed area
5. Crack propagates to the surface

2.



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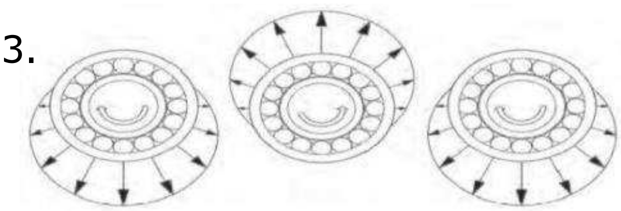

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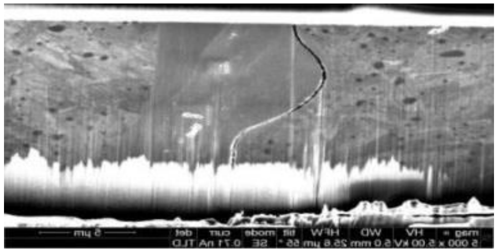

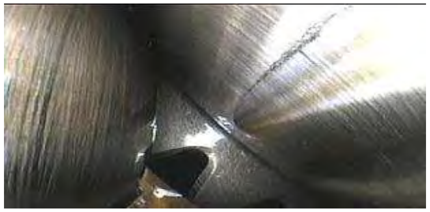

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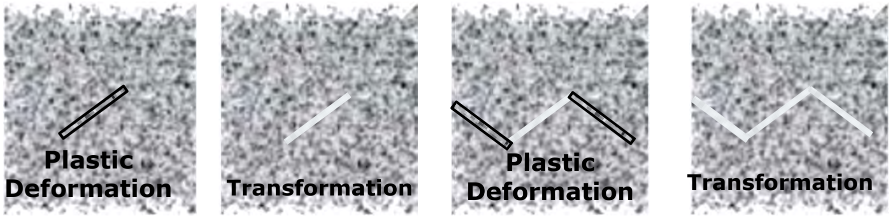

Dynamic Event | Normal Load | Dynamic Event | Normal Load

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Gearbox High Speed Bearing

Prevention

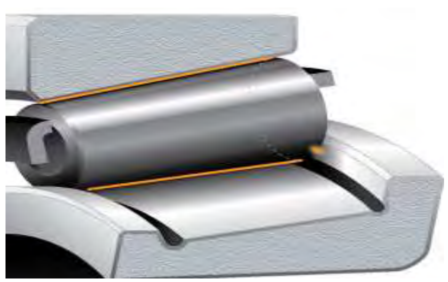
- Maintain good lubrication practices- avoid too much water
- Torque limiting devices?

Detection

- Vibration analysis, online preferred
- Oil testing sampling for Iron content, online preferred

SOLUTIONS: HIGH SPEED BEARING

Enhancement	White Etch	Inclusions	Smearing
Steel Cleanliness	+	+++	
Black Oxide	+ *(early stages)*		++ *(early stages)*
'DLC' Coatings	+		+++
Case Carburized	+++	++	



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Brüel & Kjær Vibro

3rd Annual Wind O&M Canada 2016

Lead-time to drivetrain component failure and the impact of your O&M strategy

Nov. 29-30, 2016

A SHORT INTRODUCTION TO BRÜEL & KJÆR VIBRO

Brüel & Kjær Vibro

- **60+** years of experience in Condition Monitoring
- Pioneers within the wind turbine monitoring industry
- First CMS solution installed in **1999**
- Thousands of wind turbines monitored daily
- World-wide remote diagnostics coverage via centers in the US, China and Denmark

GL CERTIFIED

Brüel & Kjær Vibro

”LEAD-TIME” IN PREDICTIVE MAINTENANCE DEMYSTIFIED

WHY CONDITION MONITORING (CMS) FOR WIND TURBINES?

1. No catastrophic failures
2. More efficient use of cranes
3. Reduction of downtimes
4. AEP

Lead-time =

"The latency between the **initiation** and **execution** of a process."
(Source: Wikipedi)

The early detection of a fault

The replacement of the dama component.

Lead-time to failure depends on

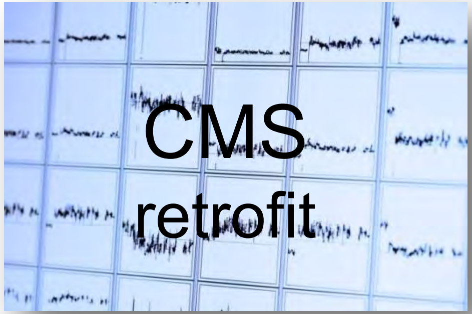
a) The component/failure mode.

Example: Multi-stage gearbox

Lead-time to failure depends on

b) The quality of the
service provider and
the information they deliver

Case:



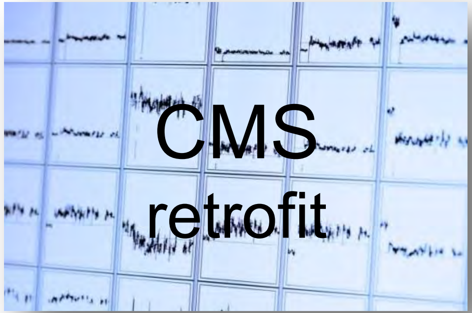
Windpark I – coming out of warranty; O&O „A“

Developing fault reported

Second inspection

Fault confirmed, replacement planned

Secondary damages and major repair due to delay in spare part delivery



Windpark II; past warranty; O&O „B“

Developing fault reported

Limited access to site

Replacement scheduled based on weather conditions, not on remaining life-time

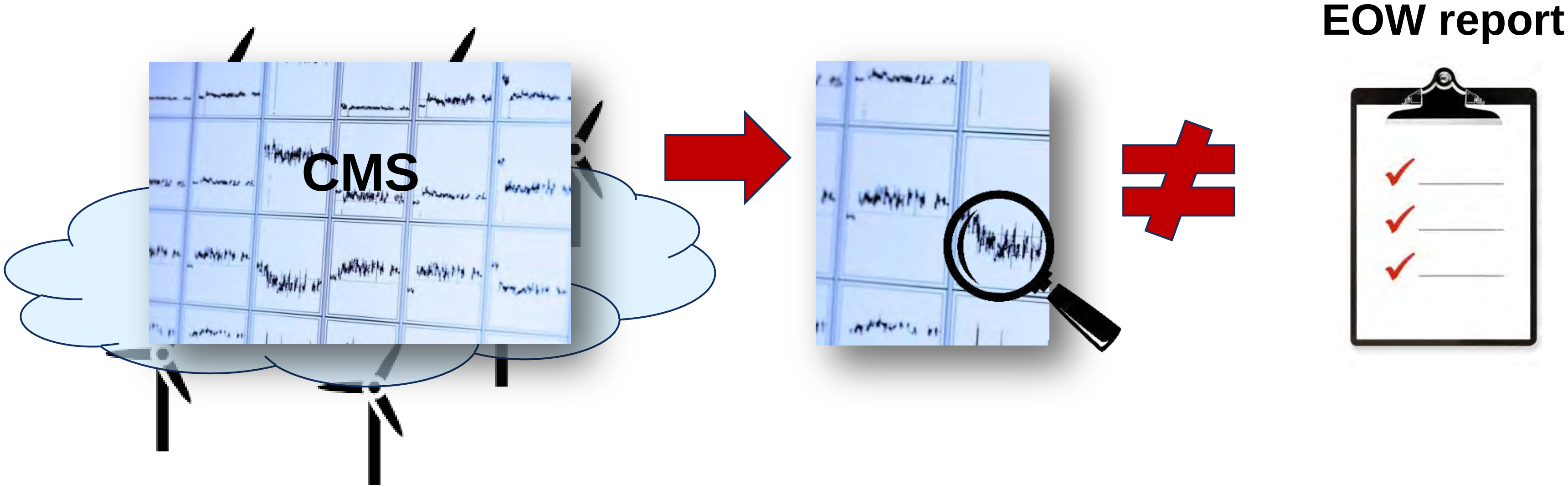
Brüel & Kjær Vibro

The planning after a fault has been detected early depends on the O&M strategy

“Lead-time“ ≠ “Lead-time“!

EARLY FAULT DETECTION AND THE EYE OF THE BEHOLDER

Case:



CMS:

- Optimum O&M activities ✓
- Critical input to the O&O's planning/scheduling process ✓
- Fleet meets and exceeds its design life ✓

MAINTENANCE STRATEGY MODELS

Owner & Operator

Initiation
(Fault detection)

Execution
(Maintenance & Repair)

Owner & Operator

Service provider A

Service provider B

Initiation
(Fault detection)

Execution
(Maintenance & Repair)

Service provider	Owner & Operator
Initiation (Fault detection)	Execution (Maintenance & Repair)

TAKE AWAYS & KEY LEARNINGS

When you are handed the keys by your OEM at the end of warranty,

do you really know
how your turbines are doing?

Are your service partners

- ❑ Independent (no conflict of interest)?
- ❑ Unbiased and provide unrestricted information?
- ❑ Available 24/7 and provide local support?
- ❑ An experienced team?

IT IS NOT ALL ABOUT PRICING BUT RATHER ABOUT PROTECTING YOUR INVESTMENT!

FINAL THOUGHTS

Lead-time to drivetrain component failure depends on:

- ❑ Your O&M strategy
- ❑ The quality of your partner(s) with respect to their product, skillset and proven record
- ❑ The knowledge you have about your assets and available resources!

CMS Benefits:

- **Compelling value propositions** to everyone (Owners & Operators, OEMs and service providers)
- Deployments can be made easy, bringing instant **business value**!
- The right CMS solution not only protects your assets, it guarantees **a quick payback**!

Brüel & Kjær Vibro

THANK YOU FOR YOUR ATTENTION

Brüel & Kjær Vibro

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- First CMS solution installed in **1999**
- Thousands of wind turbines monitored daily
- World-wide remote diagnostics coverage via centers in the US, China and Denmark

GL
CERTIFIED

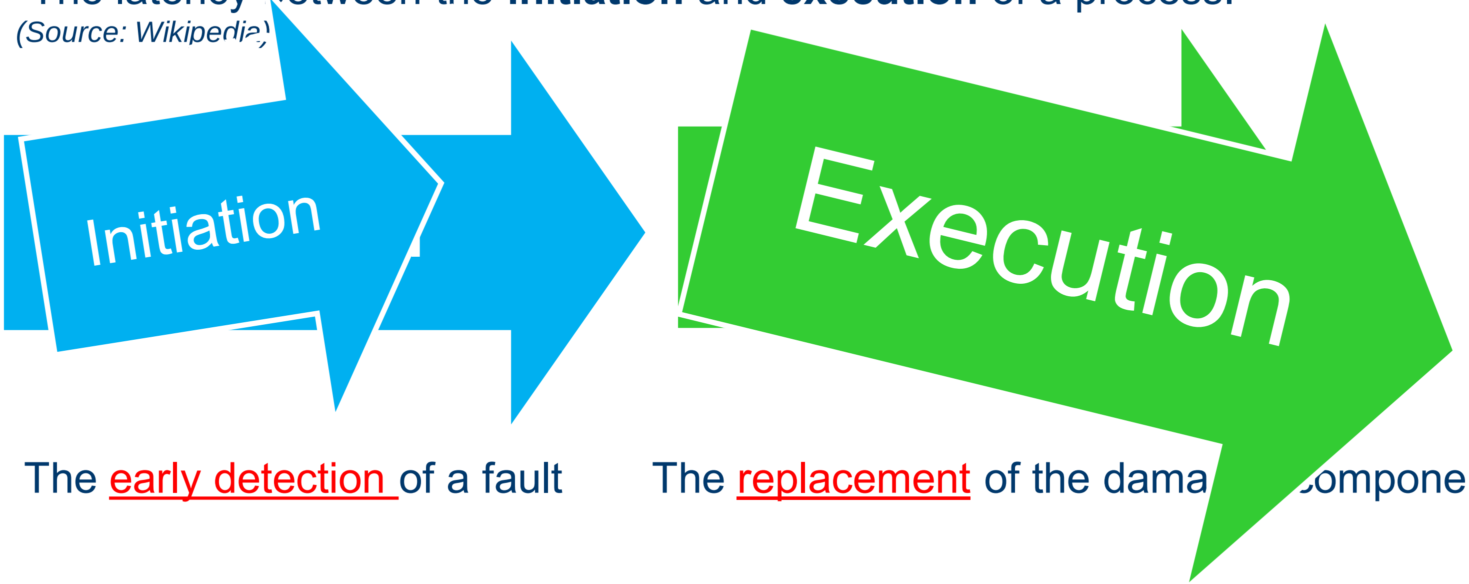
”LEAD-TIME” IN PREDICTIVE MAINTENANCE DEMYSTIFIED

WHY CONDITION MONITORING (CMS) FOR WIND TURBINES?

1. No catastrophic failures
2. More efficient use of cranes
3. Reduction of downtimes
4. AEP

Lead-time =

"The latency between the **initiation** and **execution** of a process."
(Source: Wikipedia)



The early detection of a fault

The replacement of the dama component.

Lead-time to failure depends on

a) The component/failure mode.

Example: Multi-stage gearbox

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Lead-time to failure depends on

b) The quality of the
service provider and
the information they deliver

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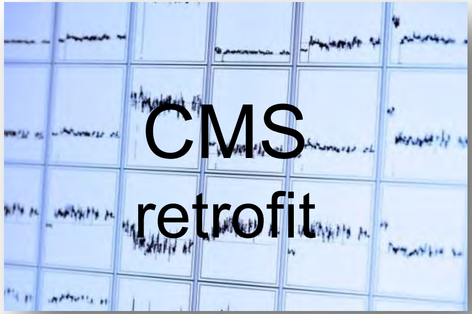
Case:



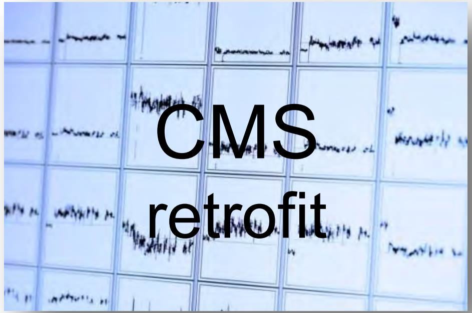
Windpark I – coming out of warranty; O&O „A“

Developing fault reported

Second inspection

Fault confirmed, replacement planned

Secondary damages and major repair due to delay in spare part delivery



Windpark II; past warranty; O&O „B“

Developing fault reported

Limited access to site

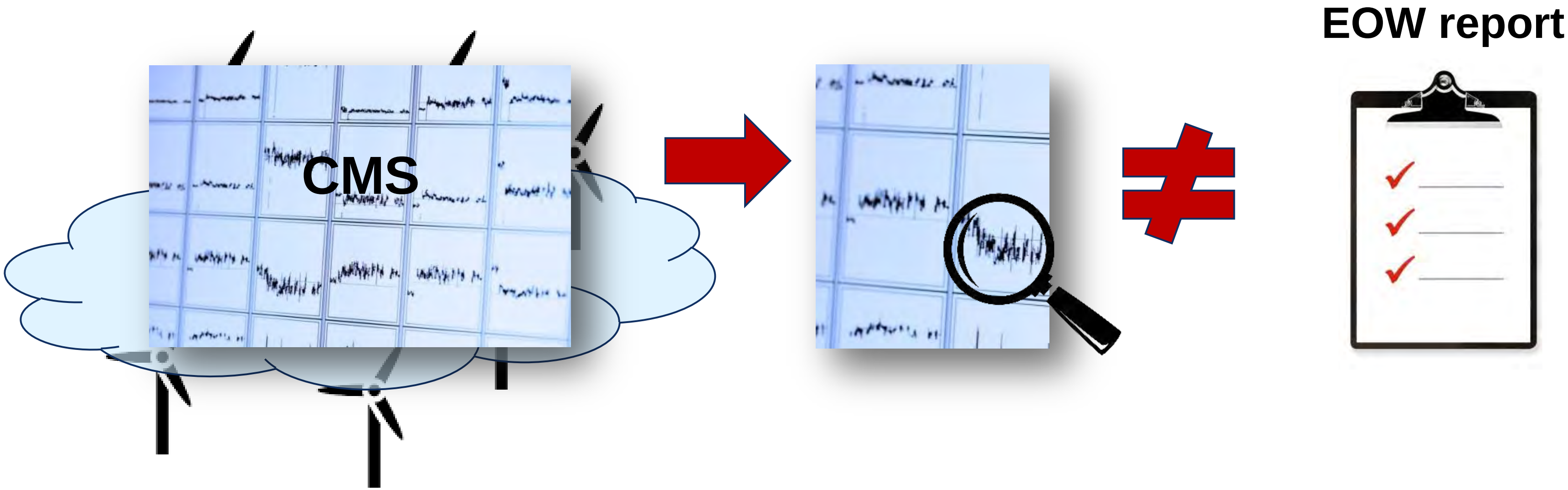
Replacement scheduled based on weather conditions, not on remaining life-time

The planning after a fault has been detected early depends on the O&M strategy

“Lead-time“ ≠ “Lead-time“!

EARLY FAULT DETECTION AND THE EYE OF THE BEHOLDER

Case:



CMS:

- Optimum O&M activities ✓
- Critical input to the O&O's planning/scheduling process ✓
- Fleet meets and exceeds its design life ✓

MAINTENANCE STRATEGY MODELS

Owner & Operator

Initiation
(Fault detection)

Execution
(Maintenance & Repair)

Owner & Operator

Service provider A

Service provider B

Initiation
(Fault detection)

Execution
(Maintenance & Repair)

Service provider	↔	Owner & Operator
Initiation (Fault detection)		Execution (Maintenance & Repair)

TAKE AWAYS & KEY LEARNINGS

When you are handed the keys by your OEM at the end of warranty,

do you <u>really</u> know
how your turbines are doing?

Are your service partners

- ❑ Independent (no conflict of interest)?
- ❑ Unbiased and provide unrestricted information?
- ❑ Available 24/7 and provide local support?
- ❑ An experienced team?

IT IS NOT ALL ABOUT PRICING BUT RATHER ABOUT PROTECTING YOUR INVESTMENT!

Brüel & Kjær Vibro

FINAL THOUGHTS

Lead-time to drivetrain component failure depends on:

- ❑ Your O&M strategy
- ❑ The quality of your partner(s) with respect to their product, skillset and proven record
- ❑ The knowledge you have about your assets and available resources!

CMS Benefits:

- **Compelling value propositions** to everyone (Owners & Operators, OEMs and service providers)
- Deployments can be made easy, bringing instant **business value**!
- The right CMS solution not only protects your assets, it guarantees **a quick payback**!

THANK YOU FOR YOUR ATTENTION

Running on expertise !

Understanding Uptower Generator Diagnostics & Repairs

DELOM SERVICES WIND DIVISION

Alexandre Vézina, P.Eng.
Technical Manager Wind Division

DELOM

AGENDA

1. WIND GENERATOR'S FABRICATION
2. ELECTRICAL TESTS
3. CASE STUDIES

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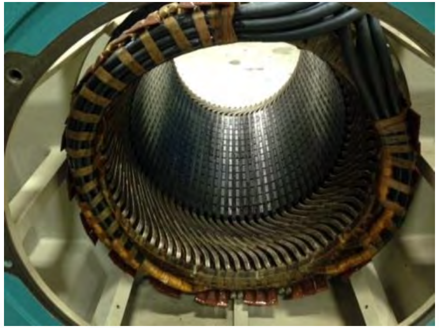
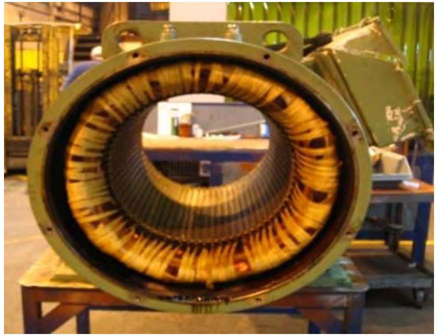
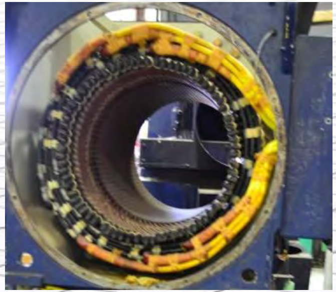
2. Wind generator's fabrication

Stator





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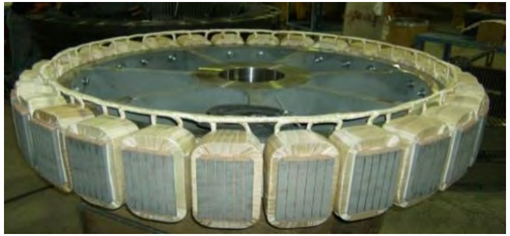
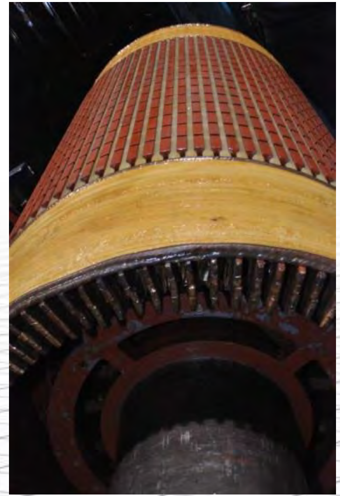
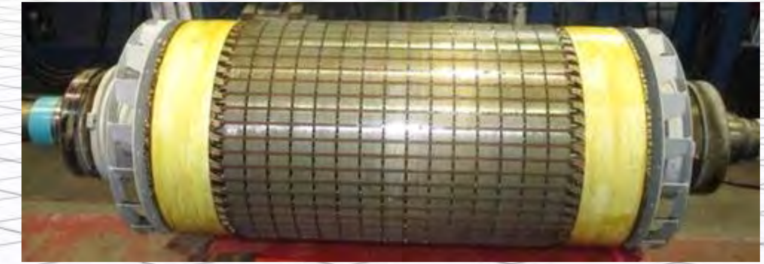
2. Wind generator's fabrication

Rotor

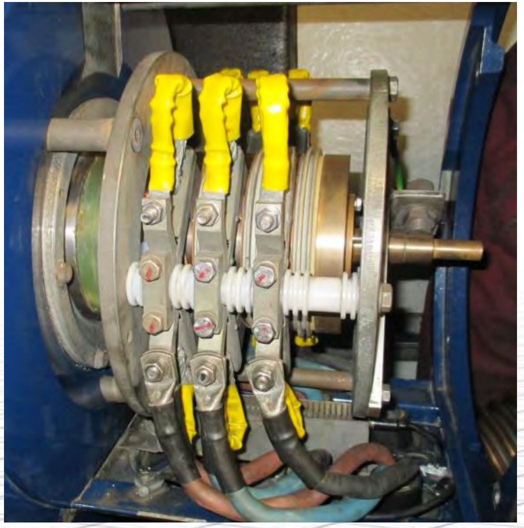






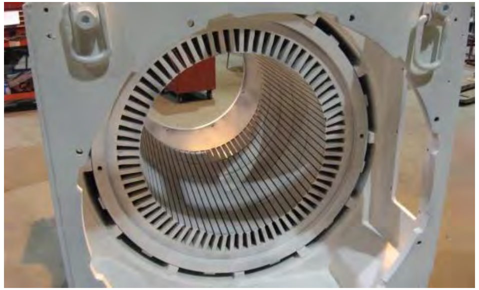
2. Wind generator's fabrication

<u>Slip ring cabinet</u>



3. Electrical tests

Ground insulation



Between turns insulation

3. Electrical tests

Ground insulation

- Megger
- Polarisation index (PI)
- Step Voltage (SV)
- Dielectric discharge (DD)
- Hi-Pot

Between turns insulation

- Winding resistance
- Winding impedance
- Surge

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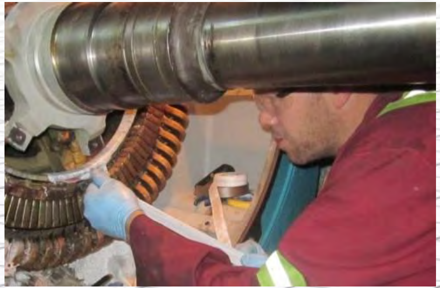
3. Electrical tests

<u>How to determine if the generator can be repaired uptower?</u>

- Lockout Tagout
- Perform electrical tests to ground
- Perform electrical tests in-between turns
- Depending on the findings:
  - Visual & borescope inspection inside the generator
  - Vibration analysis
  - Slip-ring, brushes and brush holders verification
  - Clean the contamination



4. Case studies

4.1 Electrical failure on rotor

Inspection requested by a customer

- Wind turbine tripping during high wind / full production
- Generator’s rotor failure suspected

4. Case studies

4.1 Rotor leads upgrade

Electrical tests

Rotor winding	Results
Megger reading	150 MΩ
PI	2,3

Rotor winding	Impedance
L1 – L2	14,5 Ω
L2 – L3	14,0 Ω
L1 – L3	16,2 Ω

4. Case studies

4.1 Rotor leads upgrade

Borescope inspection

Anomalies found: Rotor leads movement

Wye joint connexion heavily bent

4. Case studies

4.1 Rotor leads upgrade

Electrical tests results

Rotor winding	Results
Megger reading	1250 MΩ
PI	3,2

Rotor winding	Impedance *
L1 – L2	16,0 Ω
L2 – L3	16,2 Ω
L1 – L3	16,0 Ω

Note: After replacing the bent rotor connexion

Solutions: Replace & solidify the rotor leads uptower

Replace the Wye ring uptower

4. Case studies

4.2 Failed rotor

Inspection requested by a customer

- Wind turbine will not start
- Generator's rotor failure suspected

4. Case studies

4.2 Failed rotor

Borescope inspection

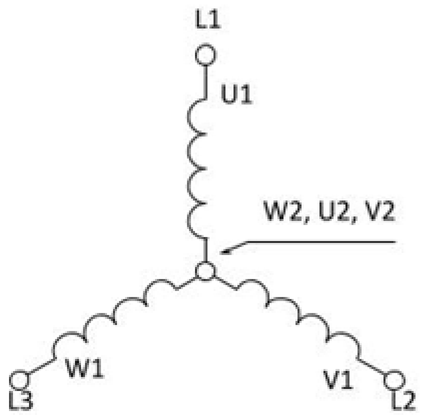
4. Case studies

4.2 Failed rotor

Electrical tests

Rotor winding	Results
Megger reading	200 MΩ
PI	2,3

Rotor winding	Impedance
L1 – L2	24,6 Ω
L2 – L3	24,3 Ω
L1 – L3	24,8 Ω



VERDICT: Repairable uptower

4. Case studies

4.3 Unevenly worn slip ring

Picture received from customer

Anomalies found

- Slip ring needed to be changed every 1-2 months
- Condition getting worst over time
- Uneven wear on the 3 rings and 3 brushes

4. Case studies

4.3 Unevenly worn slip ring

Electrical verifications

Rotor winding	Results
Megger reading	> 5000 MΩ
PI	3,7

Stator winding	Results
Megger reading	> 5000 MΩ
PI	4,4

Rotor winding	Impedance
L1 – L2	16,8 Ω
L2 – L3	16,8 Ω
L1 – L3	17,0 Ω

Stator winding	Impedance
L1 – L2	1.52 Ω
L2 – L3	1.52 Ω
L1 – L3	1.52 Ω

No problem found on the generator windings

4. Case studies

4.3 Unevenly worn slip ring

Mechanical verifications

ODE shaft runout	Results
Upon arrival	0,0030 in
After 24hr cooldown	0,0010 in
After 1000rpm no load run	0,0035 in

Solution: Solidify the stub shaft uptower

4. Case studies

4.3 Unevenly worn slip ring

Final results

- Steady runout of < 0,001 in after repair
- Back to normal brush wear after 1 year of operation

4. Case studies

4.4 Short circuit in stator leads

Pictures received from customer

Anomalies found

- Electrical explosion inside the stator connexion box

4. Case studies

4.4 Short circuit in stator leads

Electrical verifications

Stator winding	Results
Megger reading	17 000 MΩ
PI	2.6

Stator winding	Impedance *
L1 – L2	0.75 Ω
L2 – L3	0.76 Ω
L1 – L3	0.76 Ω

Note: After cutting the damaged leads

Solution: Leads replacement uptower

4. Case studies

4.4 Short circuit in stator leads

Final results

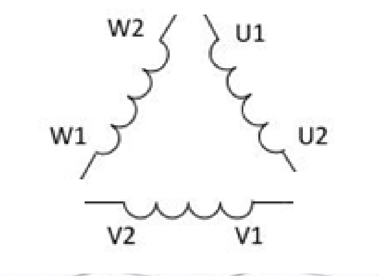
- 12 leads replaced and identified
- 1 bus bar and 6 insulators replaced
- Complete electrical tests after welding

4. Case studies

4.5 Failed stator

Electrical tests received from customer

Stator winding	Megger reading
L1 - Ground	1,4 MΩ
L2 – Ground	1,5 MΩ
L3 – Ground	1,3 MΩ



4. Case studies

4.5 Failed stator

Borescope inspection

VERDICT: Replace the generator and rewind the stator in shop

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QUESTIONS?

THANK YOU!