Investigation of Oil Conditioning, Real-time Monitoring and Oil Sample Analysis for Wind Turbine Gearboxes

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Outline

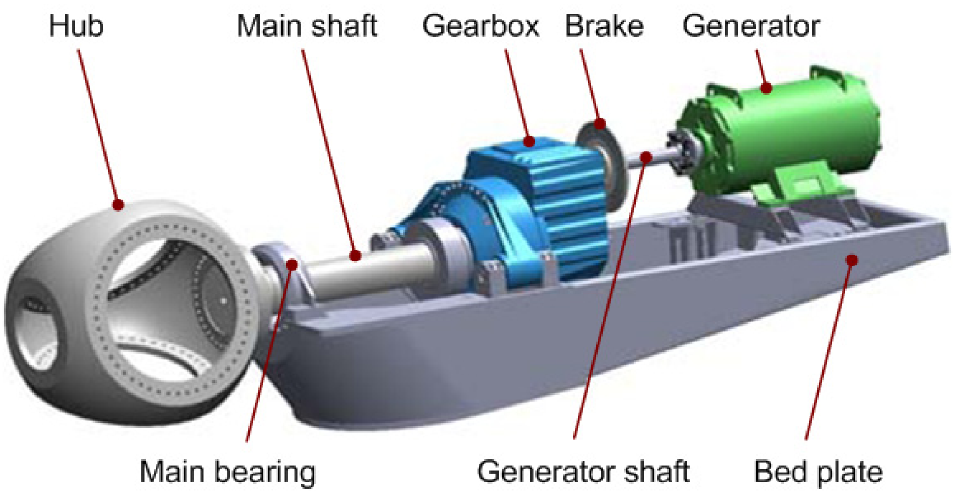
- Introduction
  - Condition monitoring (CM) for wind turbines
  - Wind turbine gearbox
  - Oil conditioning and real-time monitoring
  - Oil sample analysis
- Case Study
  - Dynamometer test setup
  - Results
- Observations and Recommendations for Practice

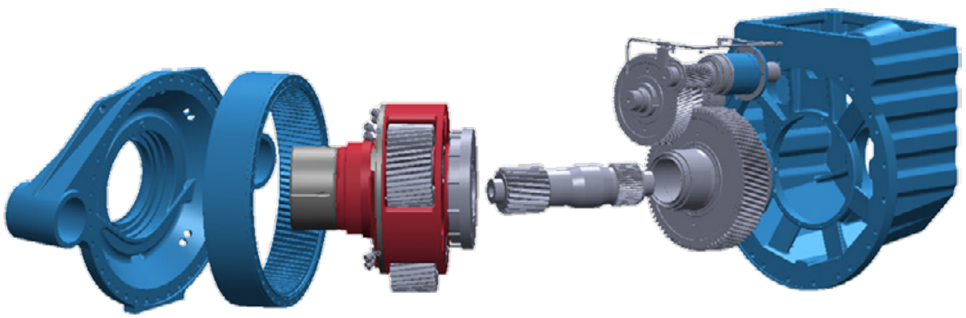
DOE 1.5 MW Wind Turbine /PIX17245

NREL 2.5 MW Dynamometer /PIX16913

CM for Wind Turbines

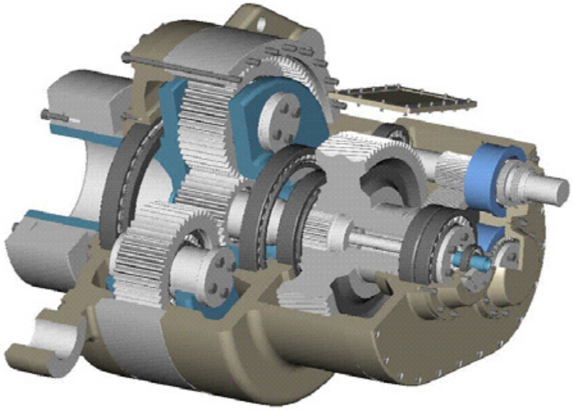
- Drivetrain
  - Main bearing
  - Gearbox
  - Generator
- Typical CM Techniques
  - Acoustic Emission or Vibration
  - Oil
- Rationale
  - Different failure modes require different monitoring techniques
  - Examples: subsurface cracks in gear and bearing components, water in lubrication oil





Wind Turbine Gearbox

- Oil-based techniques
  - Gearbox only
- Main components
  - Gears
  - Bearings
  - Oil



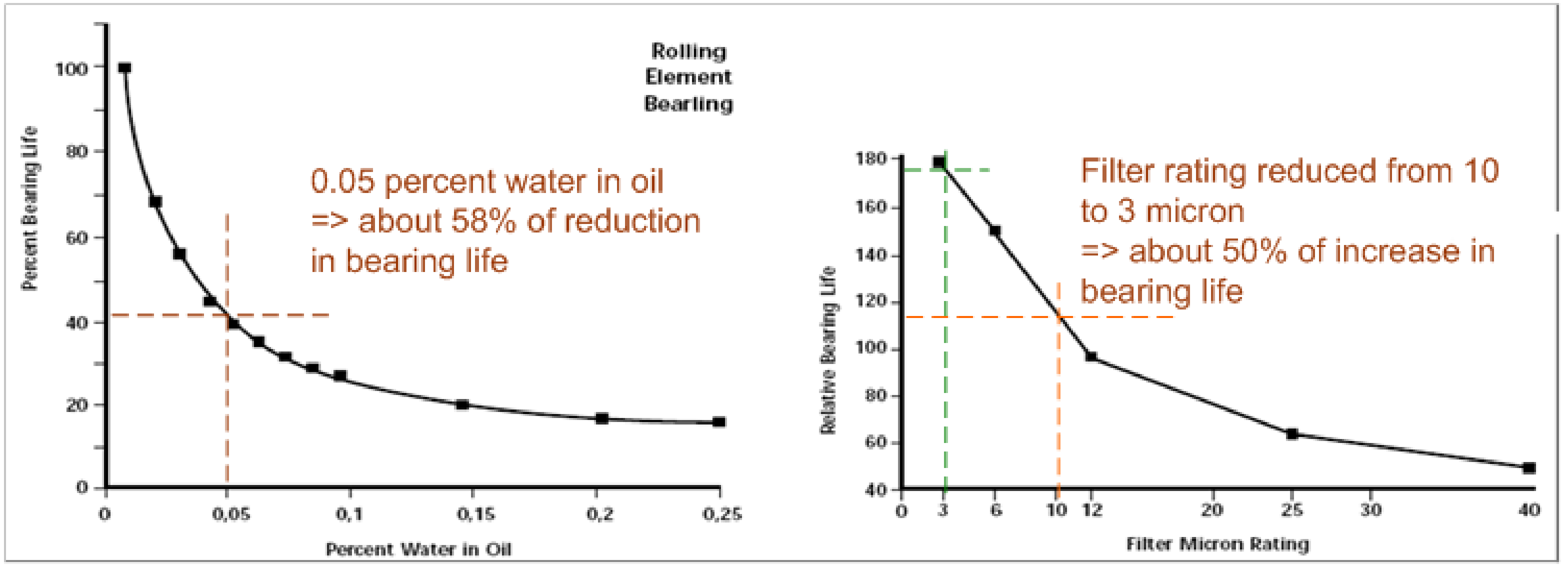
- Some failure symptoms[1-3]
  - Oil contamination: dirt, wear debris, water, wrong oil, etc.
  - Oil degradation: additives depletion, oxidation, base stock breakdown, etc.
  - Oil and lubrication system performance parameter change: temperature, pressure, etc.
  - Elevated vibrations: misalignment, imbalance, subsurface and surface cracks, etc.

Real-time Oil Condition Monitoring

- Objectives
  - Monitor lubricant contamination and degradation
  - Detect gear and bearing components deterioration
  - Lubrication system functionality monitoring
- Typical Practices
  - Particle counts: total counts, ferrous and nonferrous in different size bins
  - Oil condition: acidic level, water content, etc.
  - Temperature and pressure (normally part of turbine SCADA system)

Oil Conditioning

- Objective
  - Keep oil dry and clean[4]



- Typical Practices[1,2,5]
  - Pre-filter: remove initial contaminations in new oil
  - Inline filter: remove large particles normally down to 10 µm
  - Offline filter: remove fine particles normally down to 3 µm
  - Breather for moisture and contamination prevention
  - Heat exchanger for lubricant temperature control

Oil Sample Analysis

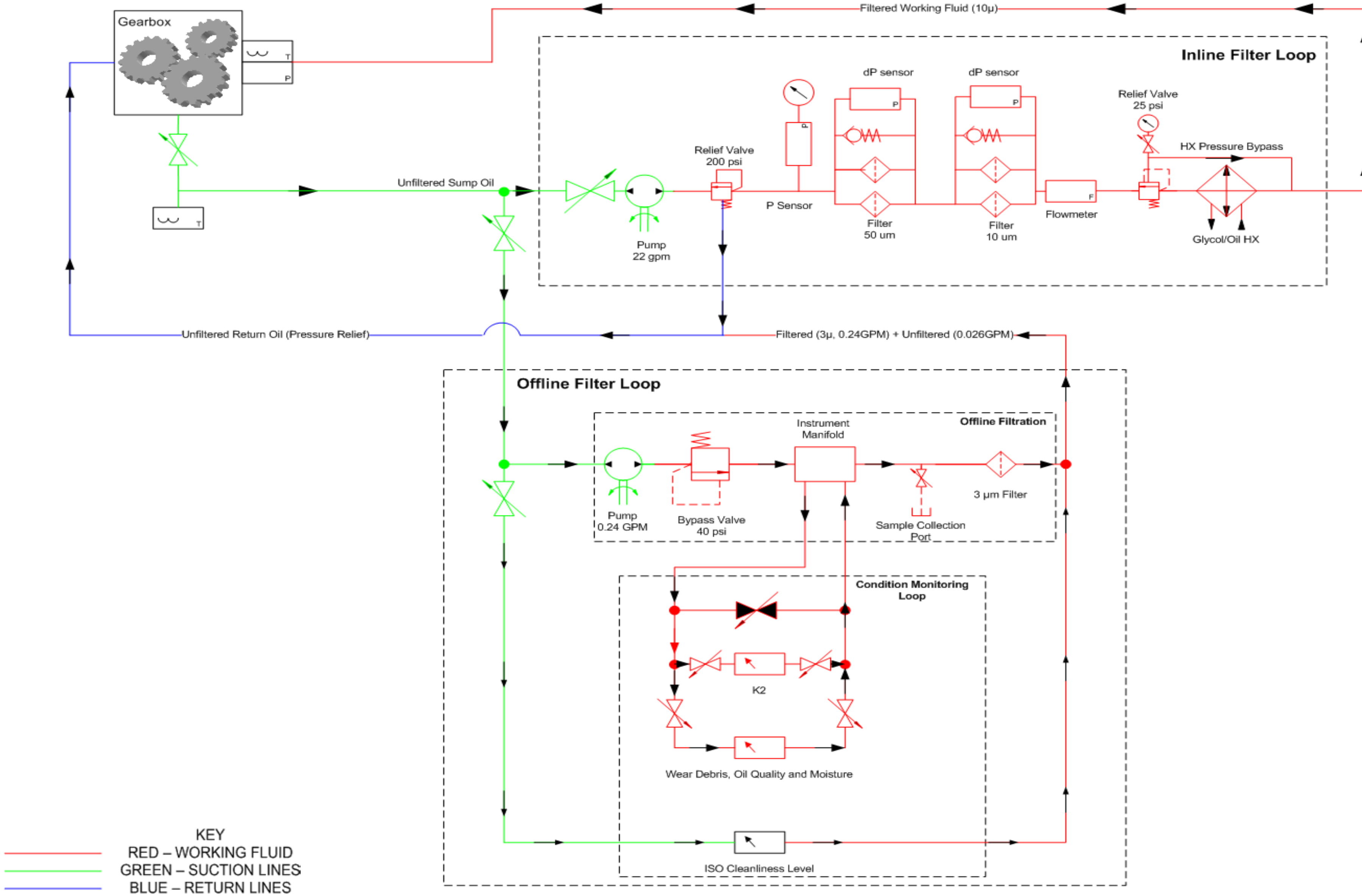
- Objectives
  - Monitor parameters not covered by real-time instruments
  - Elemental analysis to pinpoint failed components
  - Assist root cause analysis
  - Evaluate the functionality of conditioning devices

- Typical Parameters[6]
  - Particle counts
  - Water content
  - Total acid number
  - Viscosity
  - Particle element identification

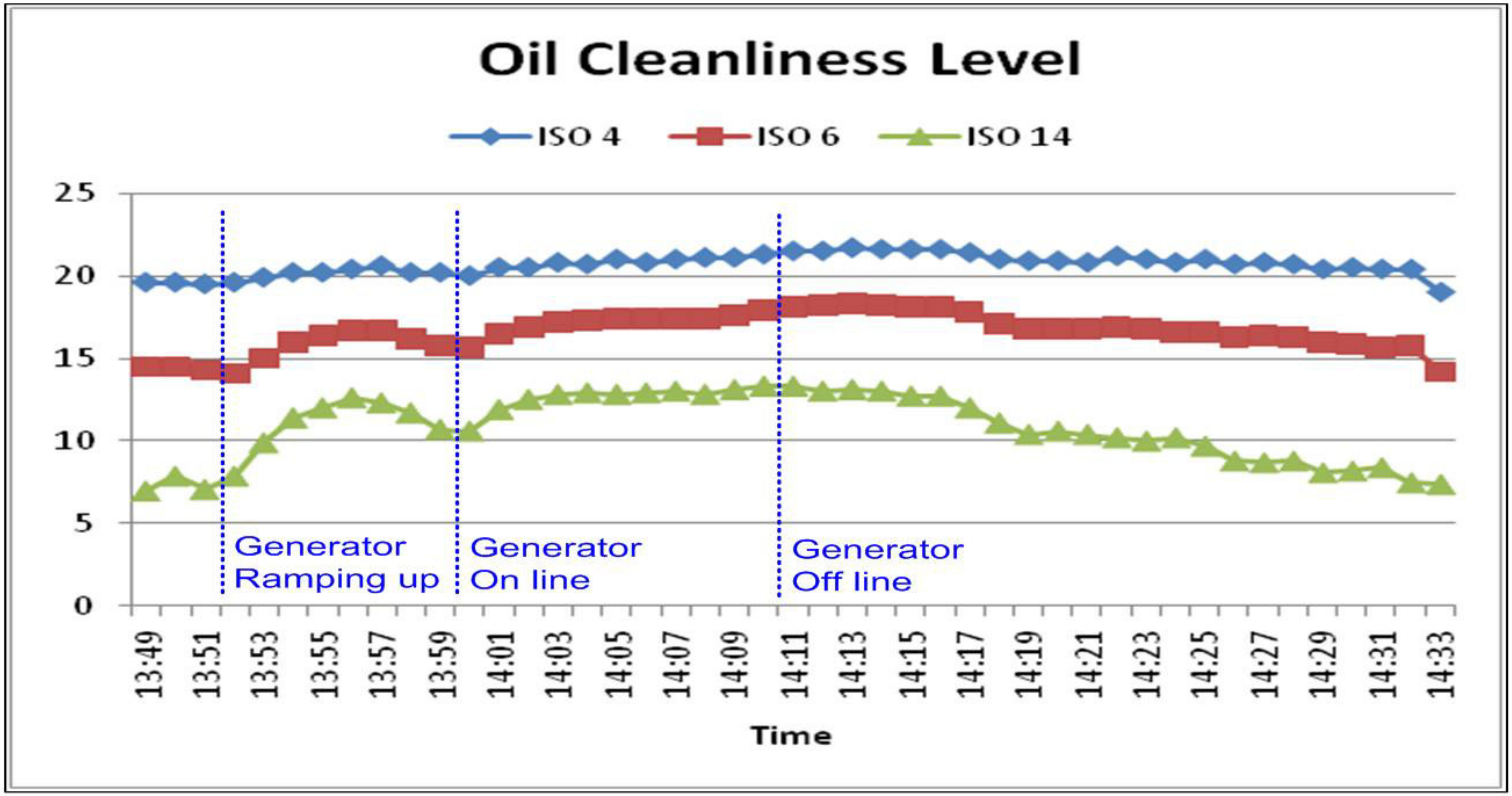
Dynamometer Test Setup

- Oil Conditioning
  - Pre-filter new oil with a 3 μm filter
  - Inline filter loop two stage filtration: 50 μm and 10 μm
  - Offline filter loop continuous filtration: 3 μm
  - Breather
  - Heat exchanger
- Real-time Monitoring
  - Inline filter loop: particle counts, greater than 300 μm, sensor K1 in later slides
  - Offline filter loop
    - ISO 4406 (1999) cleanliness level
    - Particle counts: greater than 45/50 μm for ferrous and 135/150 μm for nonferrous, each type divided into five bins, sensors K2 and K3 in later slides
    - Oil condition (total ferrous debris, temperature and relative moisture, quality: reflect changes caused by water and acid levels)
- Periodic oil sample analysis
  - Beyond typical practices mentioned earlier

Test Setup: Lubrication Diagram

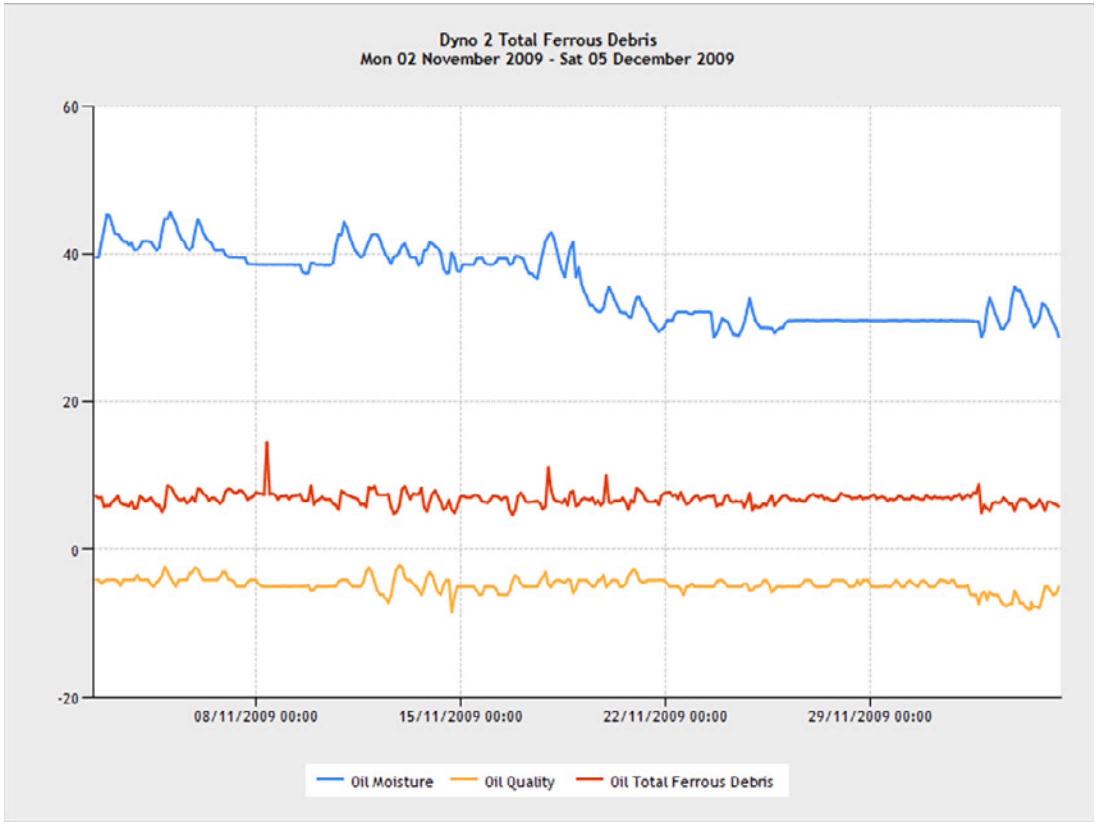


Results: Oil Cleanliness Level



- Increases when generator speed ramps up
- Decreases during generator shutdown and the use of a continuously functional lubricant filtration system
- Potentially useful for controlling the run-in of gearboxes

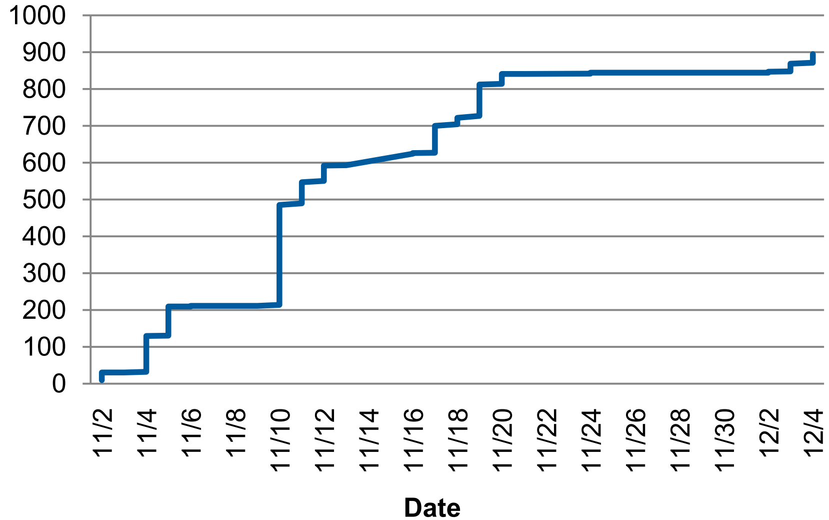
Results: Oil Condition

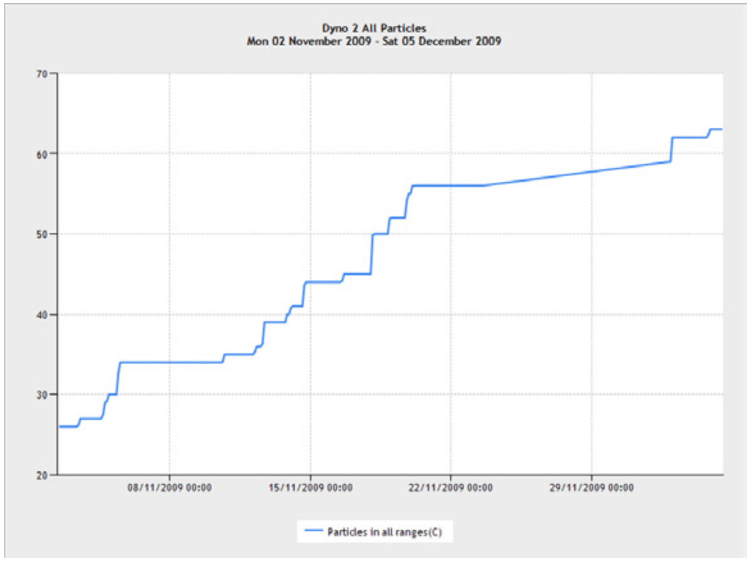


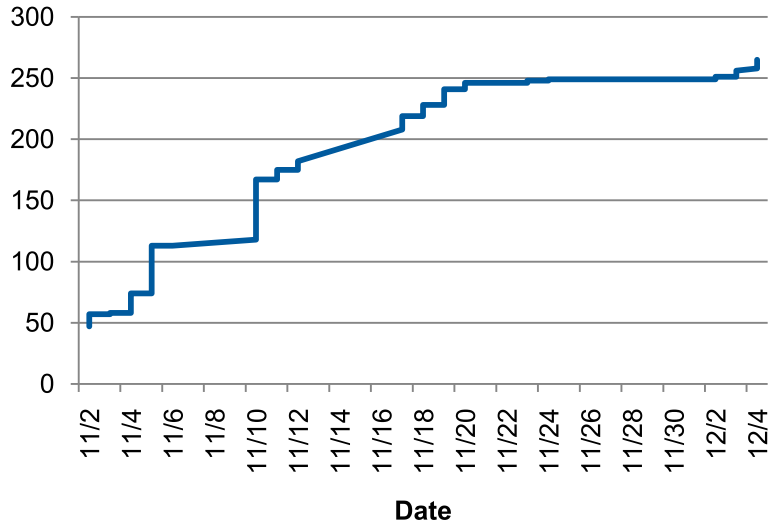
- Units
  - Moisture - %
  - Quality - customized unit, 0 (new oil) to 100 (worst quality)
  - Total ferrous debris - ppm

- Results did not show substantial changes
  - Might be due to the short operational time and mild operational conditions

Results: Particle Counts

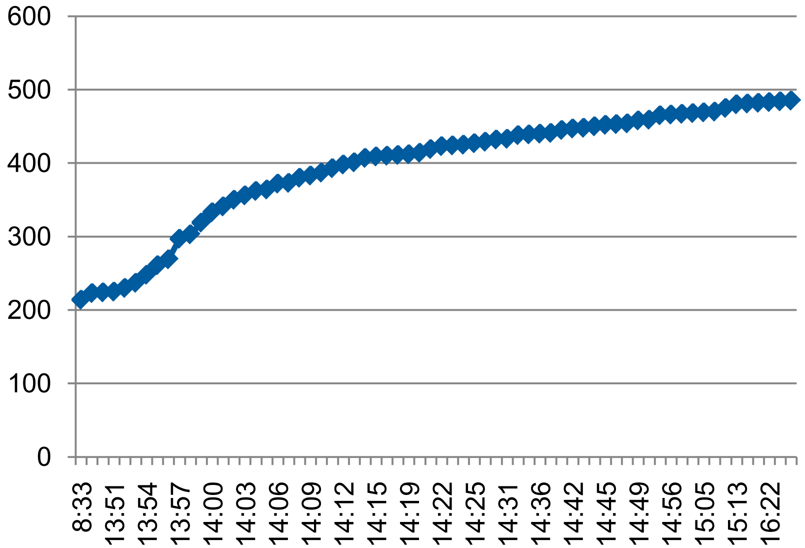


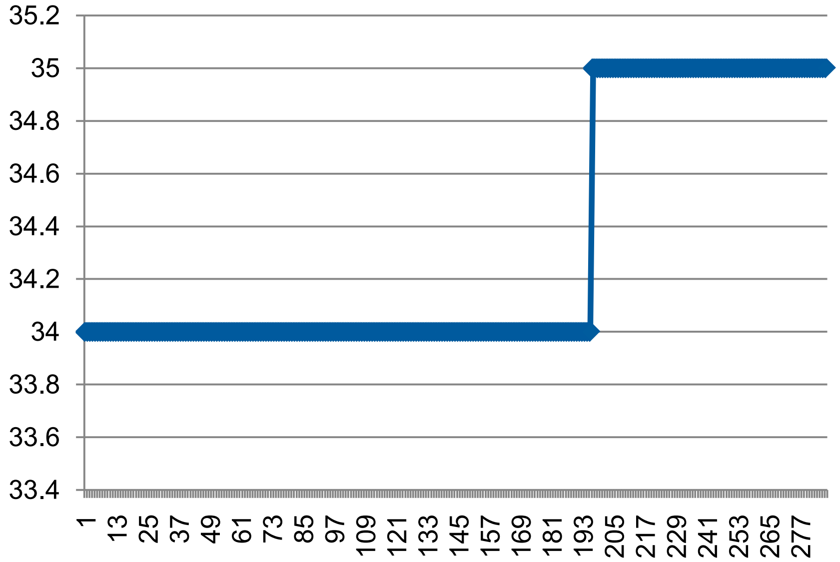


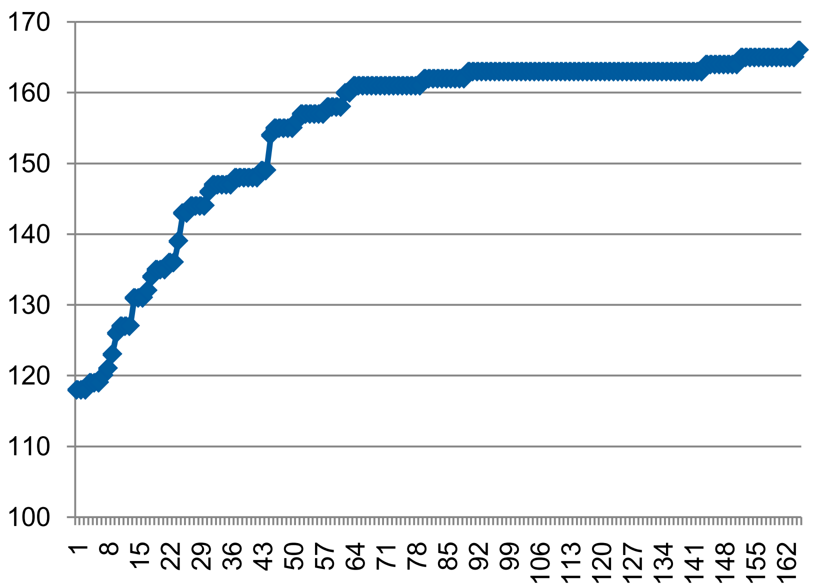


- Throughout the test period
- K1 (left top), K2 (left bottom) and K3 (right top)
- Trends are similar, though particle counts vary

Results: Particle Counts (*Cont.*)



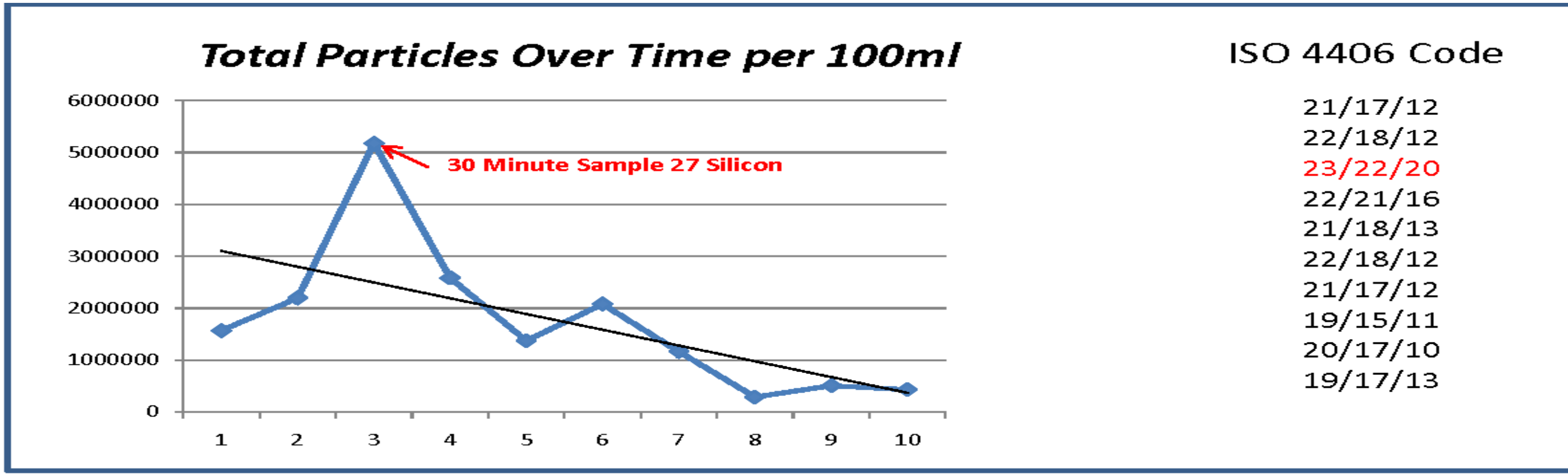




- Throughout the 25% rated load test
- K1 (left top), K2 (left bottom) and K3 (right top)
- Horizontal axis corresponds to time
- Results affected by sensor locations

Results: Oil Sample Analysis

- Particle counts: important to identify particle types[7]



- Element identification

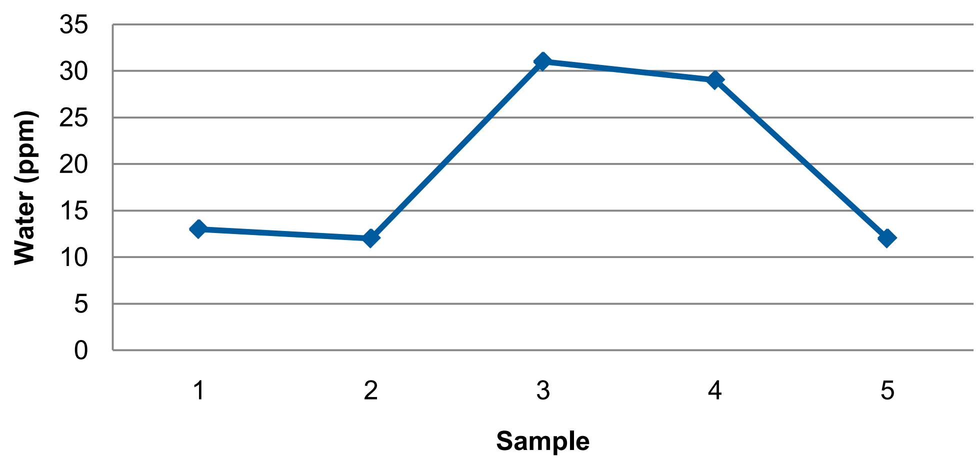
Metals							
Iron ppm	2	<1	1	1	1	1	1
Aluminum ppm	4	<1	<1	<1	<1	<1	<1
Chromium ppm	4	<1	<1	<1	<1	<1	<1
Copper ppm	2	<1	1	1	1	1	1
Lead ppm	1	<1	1	1	1	1	1
Tin ppm	4	<1	<1	<1	<1	<1	<1
Nickel ppm	4	<1	<1	<1	<1	<1	<1
Silver ppm	4.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Silicon ppm	20	<1	3	4	3	3	5
Sodium ppm		<2	<2	<2	<2	<2	<2
Boron ppm		<1	2	2	1	1	1
Zinc ppm		1	21	24	24	24	29
Phosphorus ppm		4	31	38	31	31	54
Calcium ppm		11	24	27	23	24	24
Magnesium ppm		<1	<1	<1	1	<1	<1
Barium ppm		3	8	9	6	7	7
Molybdenum ppm		<1	11	12	11	11	12
Potassium ppm		<3	<3	<3	<3	<3	<3

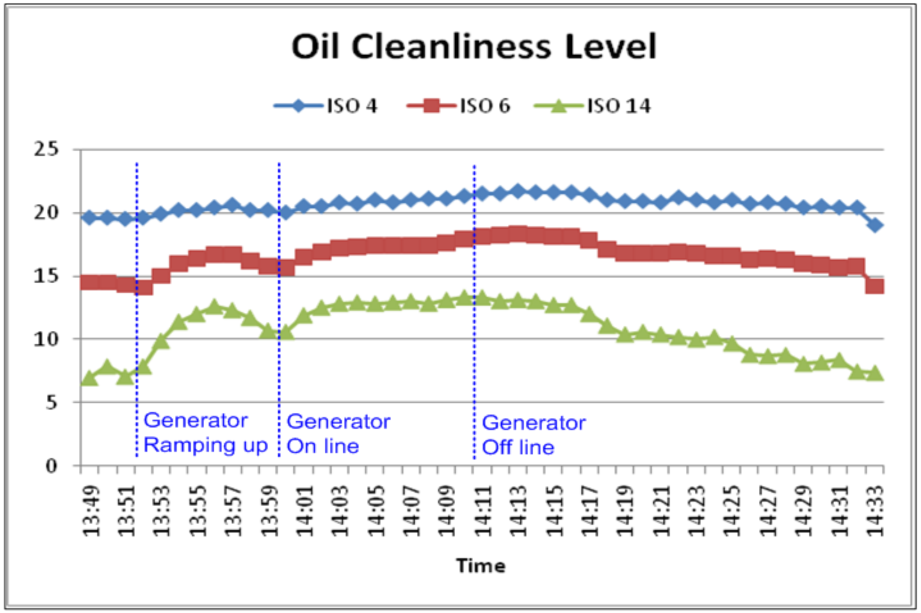
Reference Limits

Analysis Results

Performance Evaluation: Oil Conditioning

- Water:
  - Reference oil: 52 ppm
  - All samples: less than 32 ppm
- ISO Cleanliness Level
  - Dropped after the test at one loading level is completed with the filtration system left running
- Breather and filter are doing their jobs





Observations

- ISO 4406 cleanliness level measurement appears useful for controlling run-in of wind turbine gearboxes
- Particle count appears effective for monitoring machine and oil condition, but is affected by sensor mounting locations
- If location is appropriate, similar trends in particle counts between the offline filter loop and the inline filter loop can be obtained
- Periodic oil sample analysis potentially helps pinpoint failure components and root causes
- Particle counts obtained through oil sample analysis need attention on identifying particle types
- Oil conditioning equipment is useful to keep oil dry and clean

Recommendations for Practice

- Combine oil with vibration or acoustic emission-based techniques
- Take care of not only symptoms, but also root causes
- Oil Conditioning:
  - Pre-filter, inline and offline filters, breather and heat exchanger
- Real-time Monitoring
  - At minimum, monitor particle counts in either inline or offline filter loop
- Oil sample analysis
  - Regular sampling to monitor key parameters: particle counts, viscosity, water, total acid number
  - In-depth analysis when real time instruments indicate abnormal scenarios: elemental spectroscopy

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Thank you!

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