Investigation of Various Wind Turbine Drivetrain Condition Monitoring Techniques

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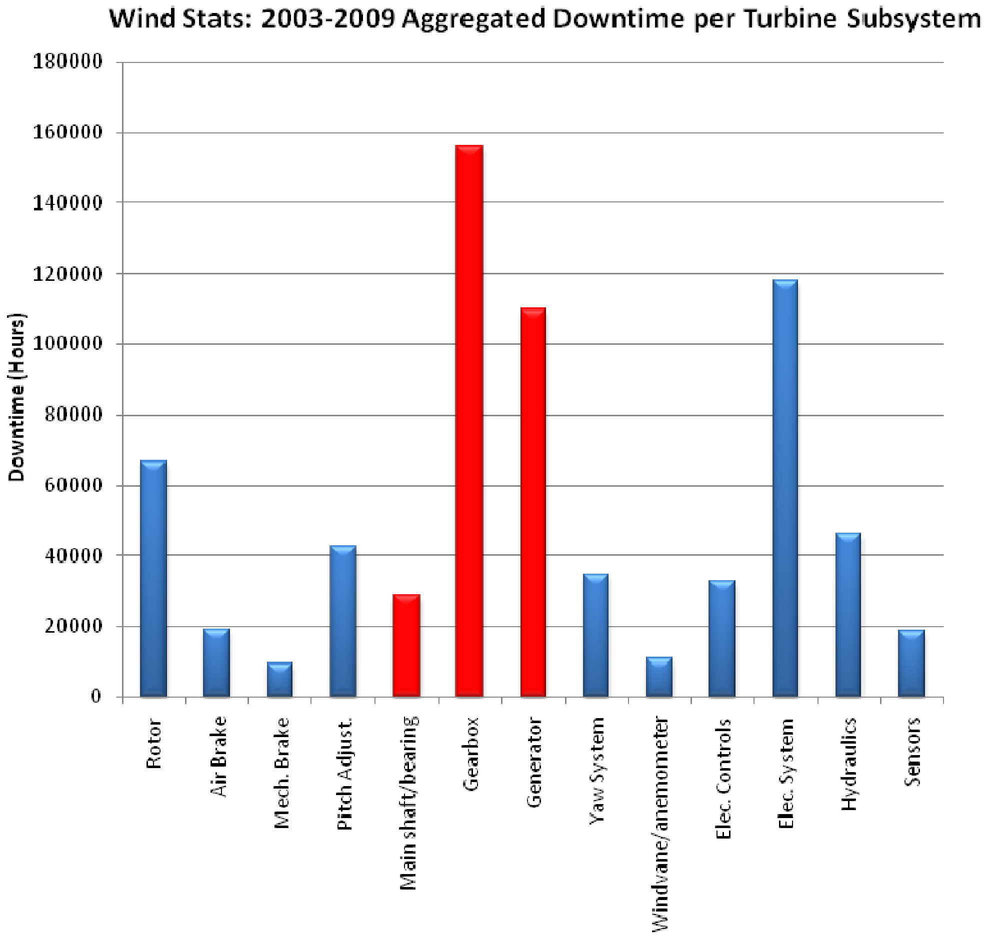
Outline

- Introduction
  - Downtime caused by turbine subsystems
  - Annual failure frequency of turbine subsystems
  - Cost benefits of condition monitoring (CM)
- Drivetrain CM
  - Approach and rationale
  - Implementation
- Tests
- Results and Observations

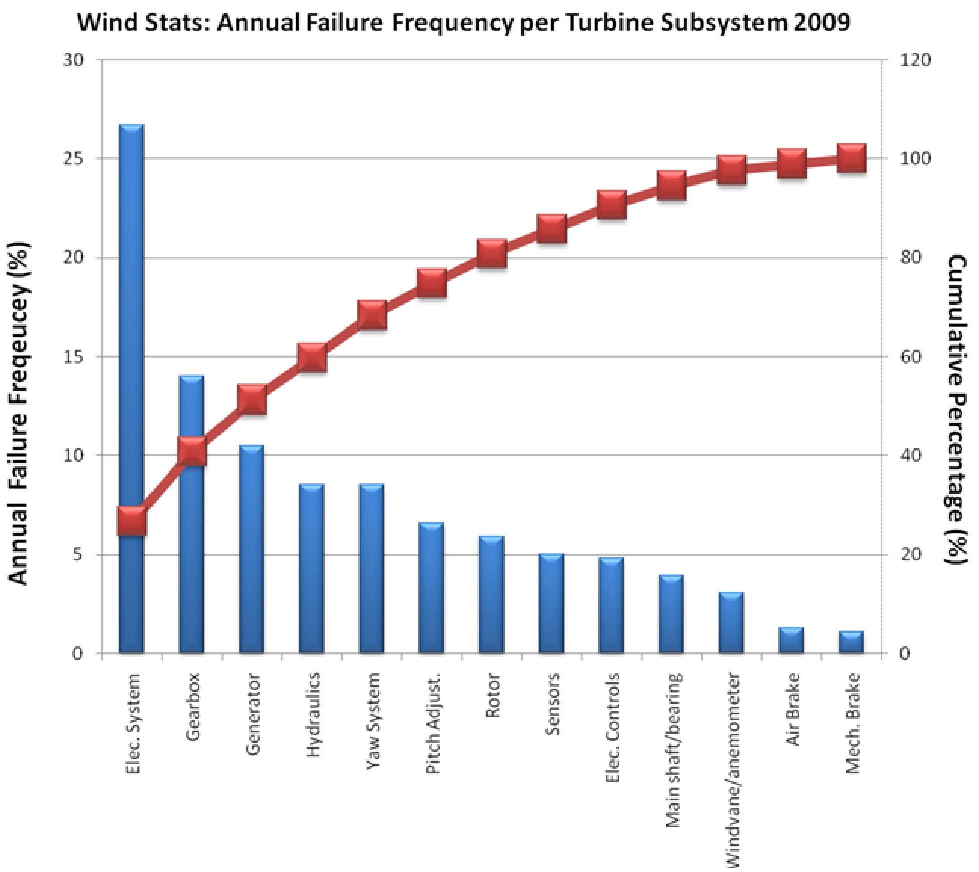
Introduction: Downtime

- Data Source: Wind Stats Newsletter, Vol. 16 Issue 1 to Vol. 22 Issue 4, covering 2003 to 2009[1]
- Based on the data reported to Wind Stats for the first quarter of 2010, the data represents: about 27,000 turbines, ranging from 500 kW to 5 MW.
- Highest: Gearbox
- Top Three: Gearbox, Generator and Electric Systems
- Take crane cost into consideration:
  - Main bearing also needs attention.
  - Electric systems often do not need an expensive crane rental.



Introduction: Annual Failure Frequency

- Data Source: Wind Stats 2009 data
- Top Three: electric systems, gearbox and generator
- 27% and equivalent to 0.6 failures/turbine subsystem/year based on data reported by Reliawind*
- Take crane cost into consideration:
  - Reliability improvement first needed on gearbox, generator, main bearing and rotor
  - Health monitoring helps in providing individual turbine health information and extending turbine uptime
  - Condition Monitoring (CM) for first three
  - Structural health monitoring for rotor



*source: www.reliawind.eu/files/publications/pdf_13.pdf

Introduction: Cost Benefits

- Experience at Schenck [2]

Operator / Owner	# of Turbines Duration of Service	Costs CMS plus Service in €	Detected Damages	Costs unplanned Replacement Costs planned Repair in €	Total Savings in €
enviaM	15 WTG‘s 5 years	150,000	3 x Gearbox	405,000 101,250	303,750 In 5 years
e.disnatur	130 WTG‘s 5 years	1,300,000	12 x Gearbox 40 x Generator bearing	4,620,000 1,155,000	3,465,000 In 5 years
juwi Management	59 WTG‘s 3 years	472,000	20 x Gearbox 1 x Generator bearing 1 x Main bearing	2,811,000 702,750	2,108,250 In 3 years

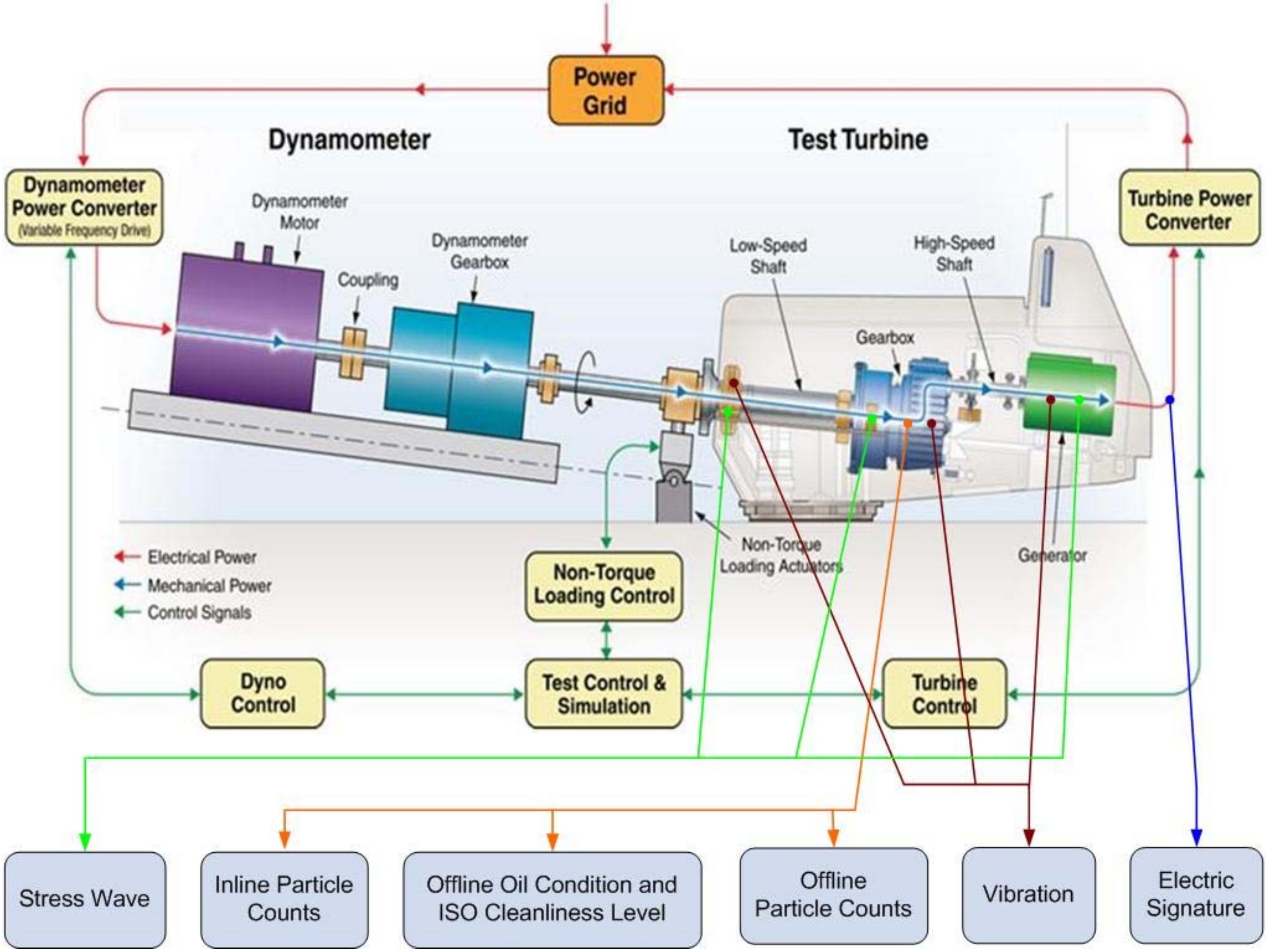
- Based on 1.5 MW wind turbine with replacement costs of about €150,000 for gearbox, €38,000 for a generator and €25,000 for a main bearing (DEWI)
- Costs for planned repair < 30% for unplanned replacement (DEWI)
- Cost per CM system approximately €5,000 plus €1,000 per year per wind turbine (service)
- Above cost savings do not include loss of production

Return on Investment for all three cases less than 3 years

Drivetrain CM: Approach and Rationale

- One area of research under Gearbox Reliability Collaborative (GRC)
- Integrated Approach
  - Acoustic emission (specifically, stress wave)
  - Vibration analysis
  - Oil debris and condition monitoring techniques
  - Electric signature-based technique
- Rationale
  - Each technique has its own strengths and limitations
  - Combine active machine wear detection capability of lubrication oil monitoring techniques with crack location pinpointing capability of AE and vibration analysis
  - Investigate potential technique for direct-drive turbines

Drivetrain CM: Implementation

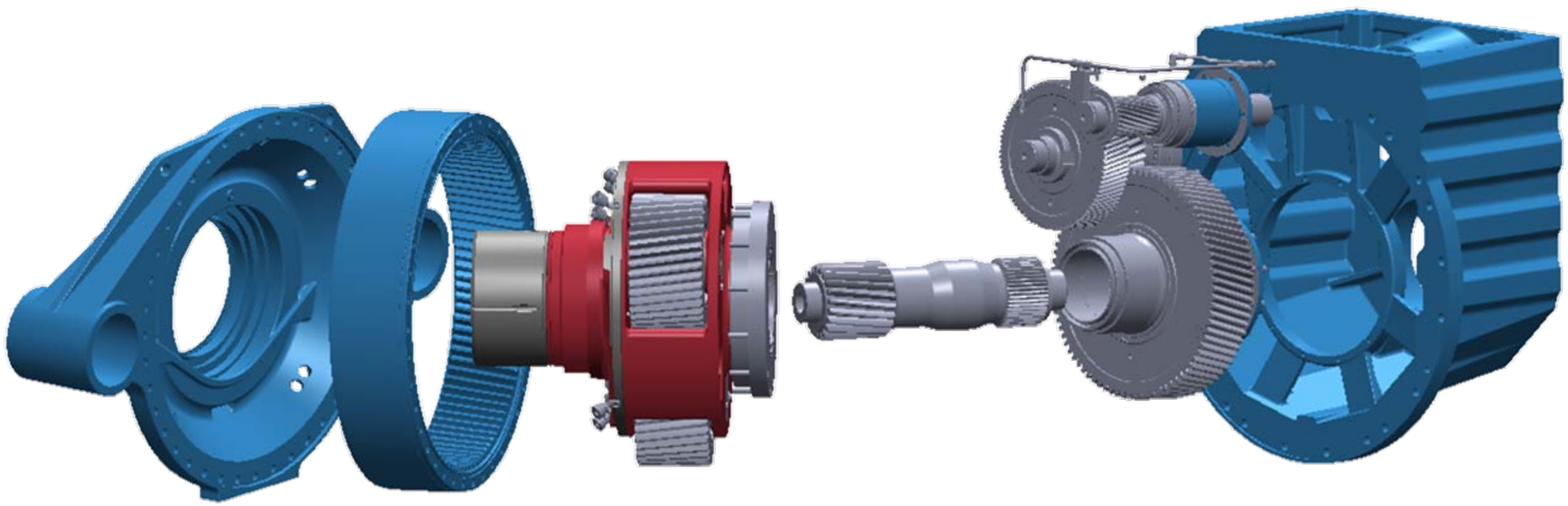


- Stress wave analysis
- Vibration analysis
- Inline (main filter loop) particle counting
- Offline filter loop particle counting, oil condition monitoring (i.e., moisture, total ferrous debris, and oil quality)
- Electric signature monitoring
- Periodic oil sample analysis

As a research project, this set up is beyond the typical drivetrain CM configuration seen in the industry.

Tests: Test Articles

- Two gearboxes rated at 750 kW
  - One planet stage and two parallel stages
  - Redesign
    - Floating sun, cylindrical roller planet bearings, tapered roller bearings in parallel stages, pressurized lubrication, offline filtration and desiccant breather
  - Up to 150 channels of measurements for loads, displacements, and temperature



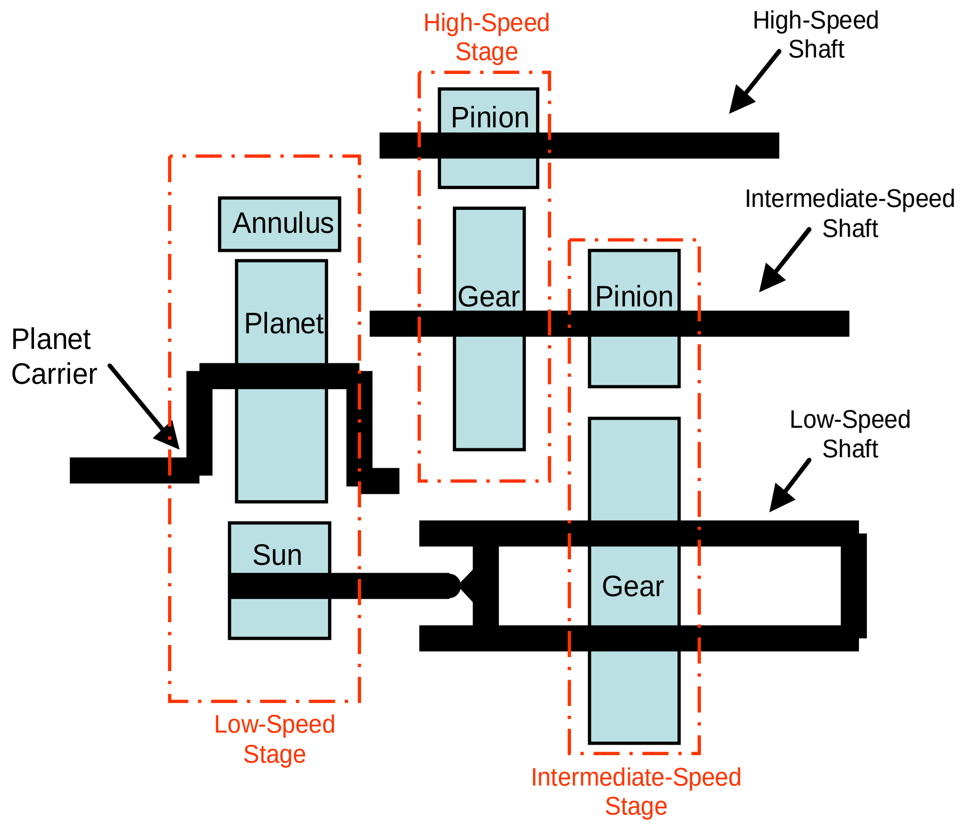
Tests: Conducted Tests

- Dynamometer test of GRC gearbox #1: run-in
- Field test of GRC gearbox #1
- Dynamometer test of GRC gearbox #2: run-in and non-torque loading
- Retest of GRC gearbox #1 in the dynamometer

NREL 2.5 MW Dynamometer/PIX16913

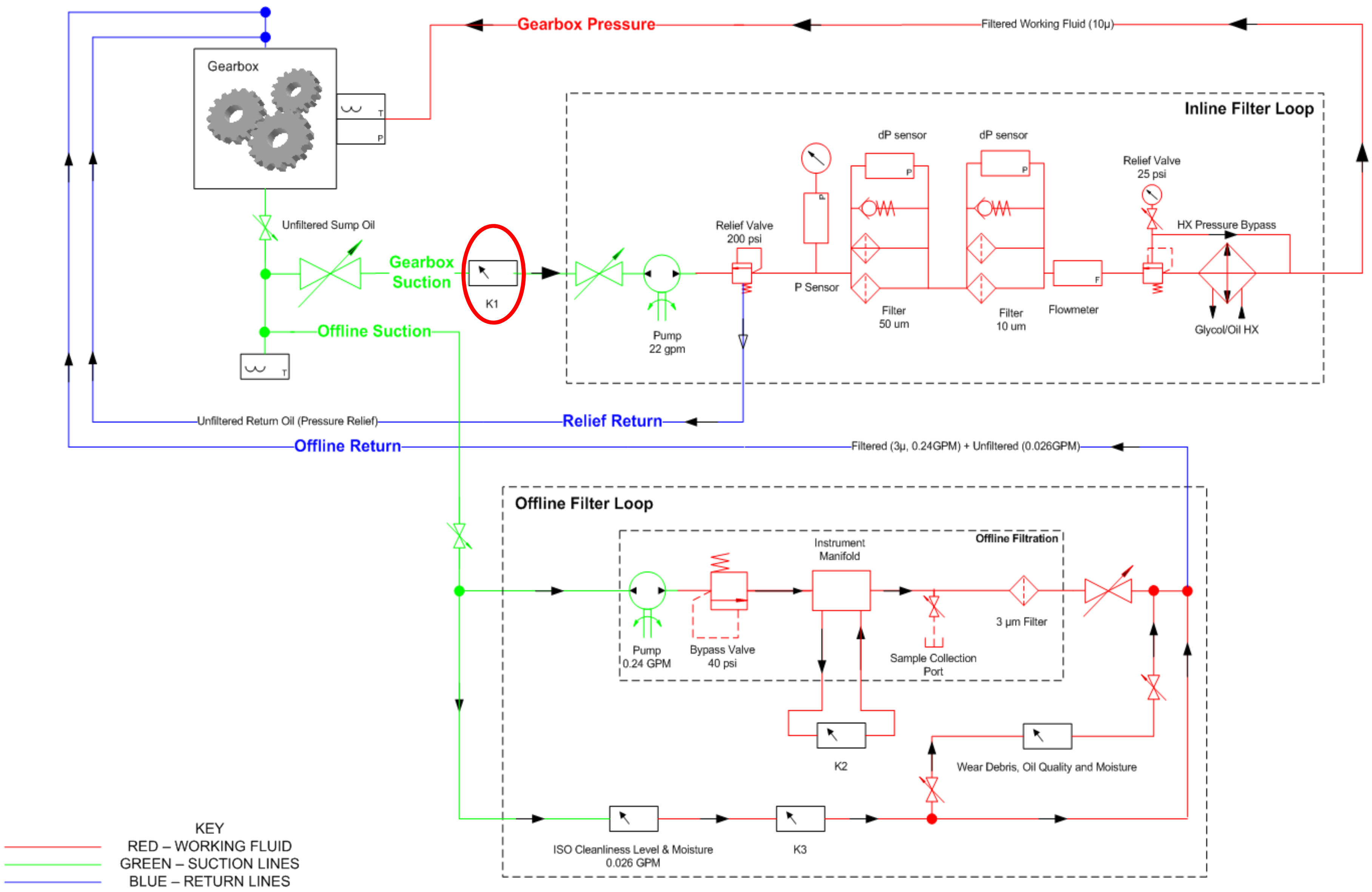
Tests: Damaged Gearbox

1. Completed dynamometer run-in test
2. Sent for field test: experienced two oil losses
3. Stopped field test
4. Retested in the dynamometer under controlled conditions

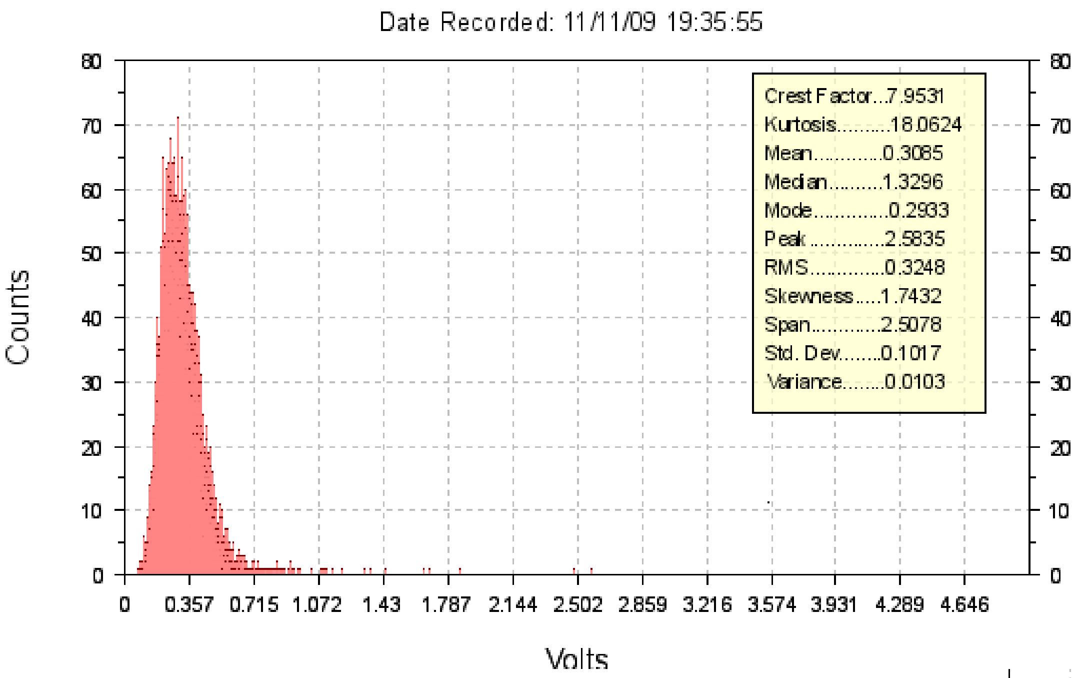


High-Speed Stage Gear

Tests: Lubrication System Diagram

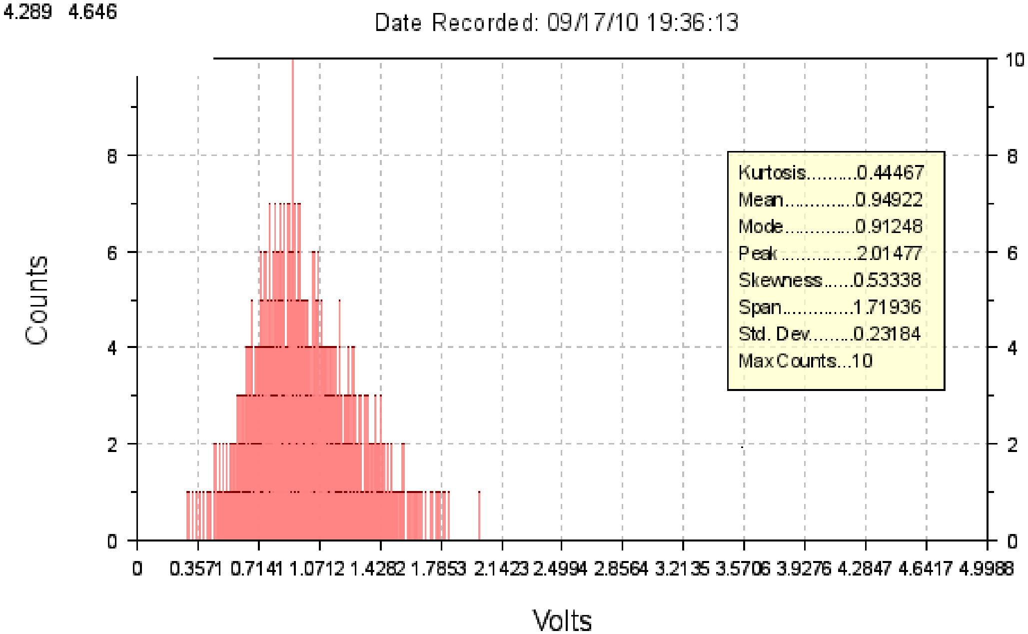


Results: Stress Wave Amplitude Histogram



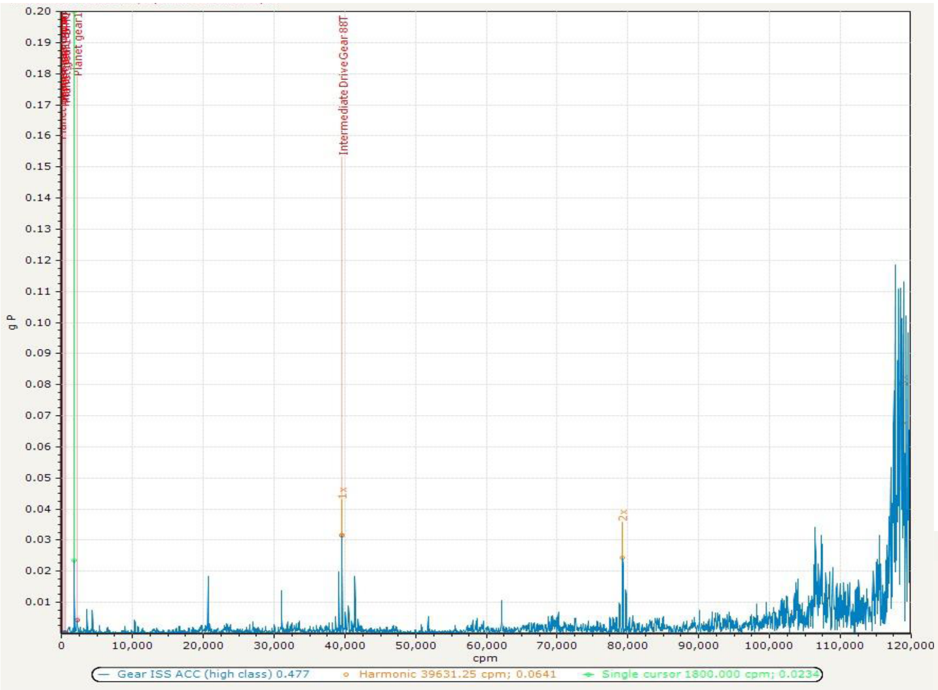
- Parallel stages sensor
- GRC gearbox #2 dynamometer test (left) indicated healthy gearbox behavior

- Dynamometer retest of GRC gearbox #1 (right) indicated abnormal gearbox behavior

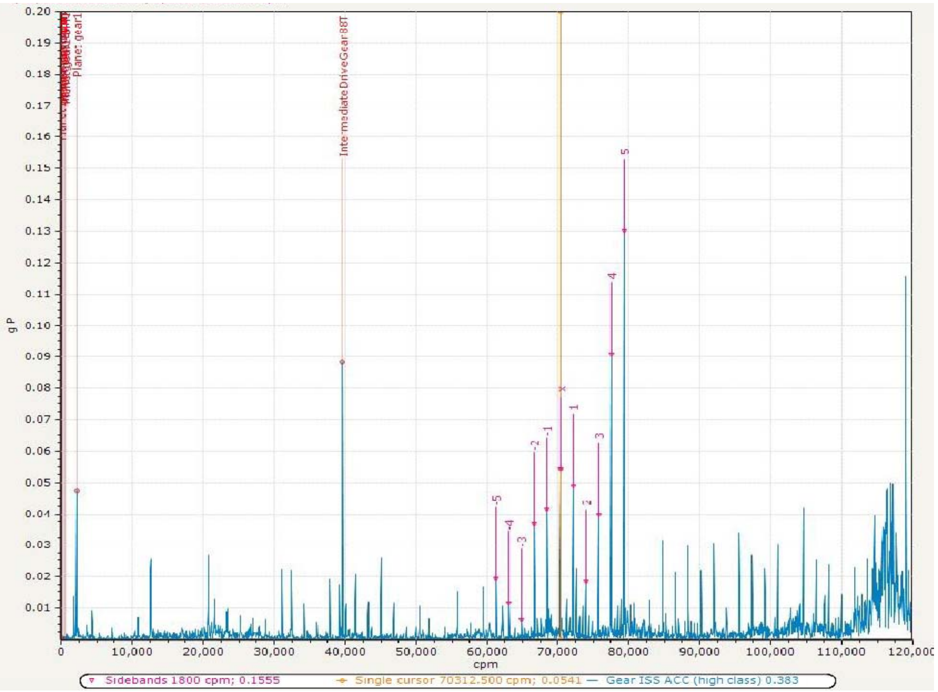


Results: Vibration Analysis

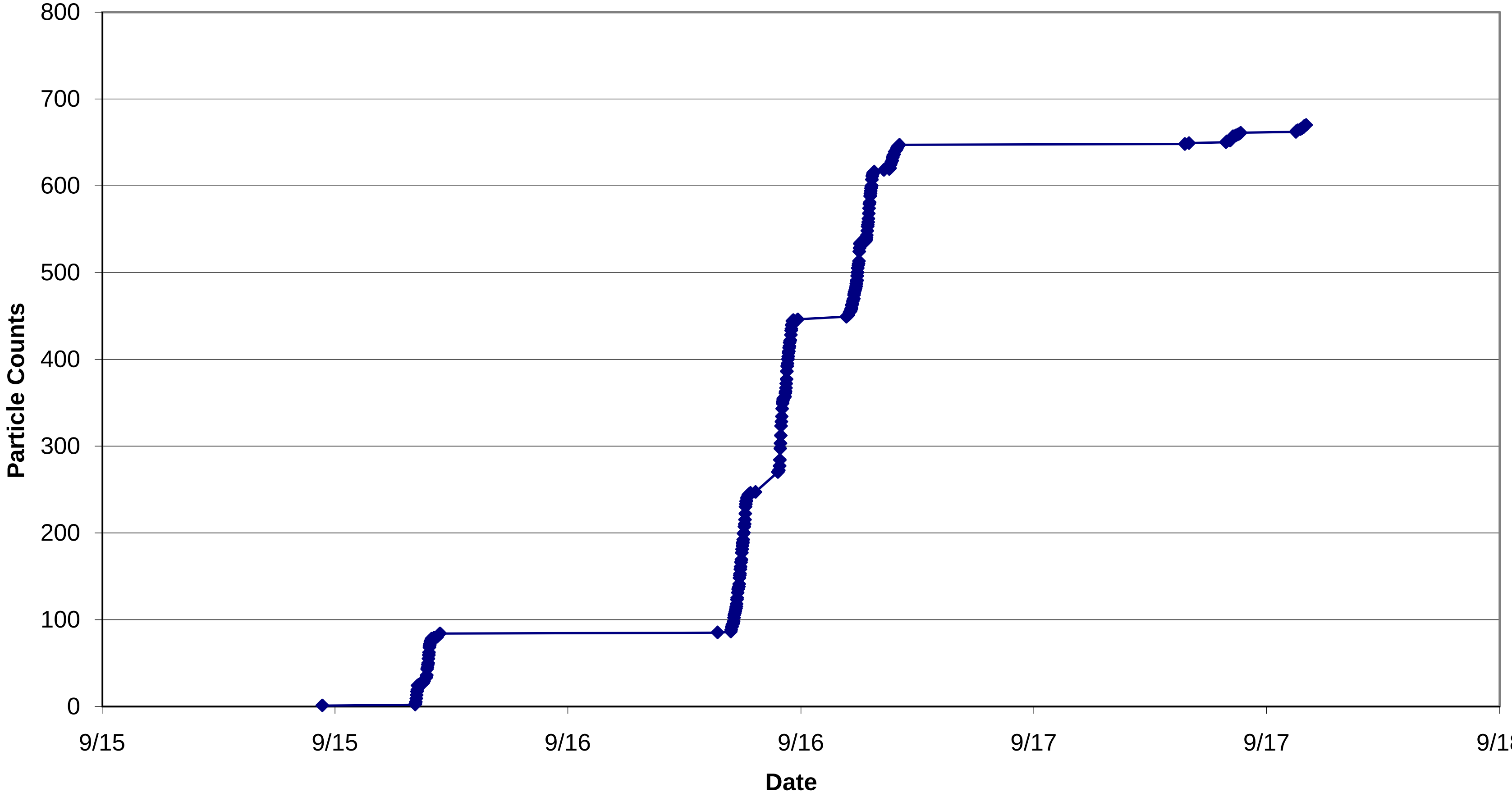
- Intermediate speed shaft sensor
- GRC gearbox #2 dynamometer test (left) indicated healthy gearbox behavior



- Dynamometer retest of GRC gearbox #1 (right) indicated abnormal gearbox behavior
  - More sideband frequencies
  - Elevated gear meshing frequency amplitudes

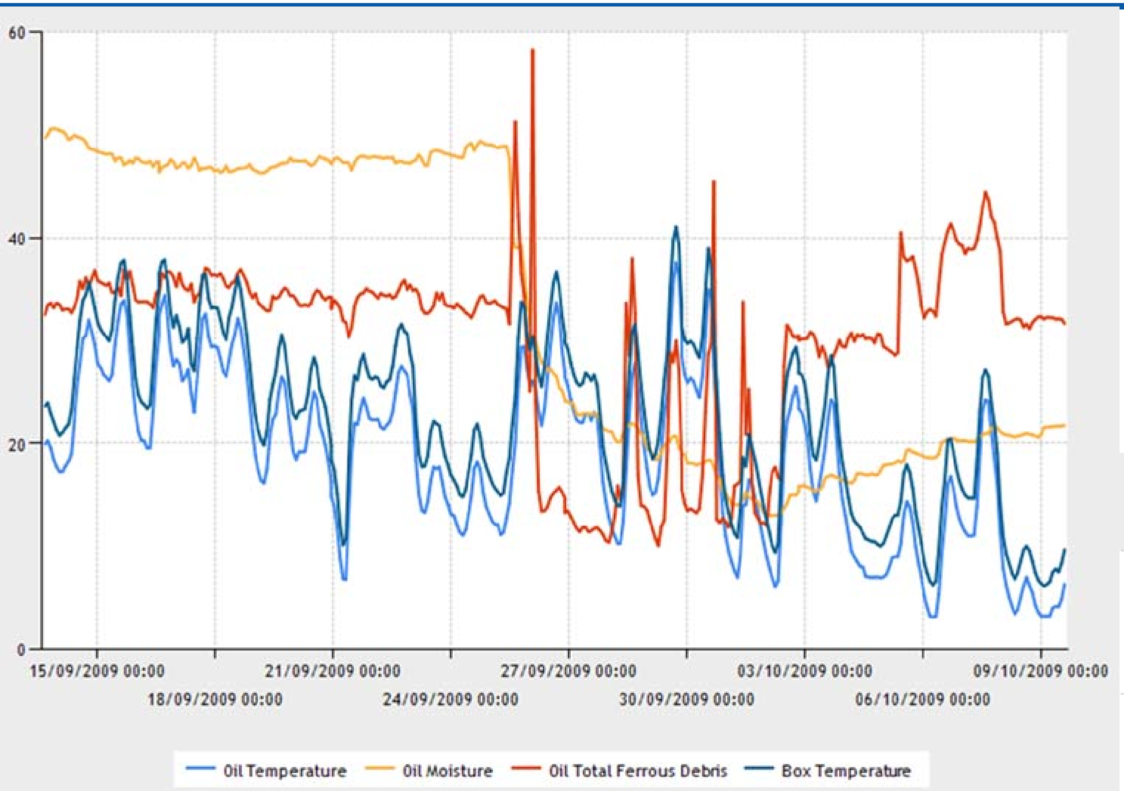


Results: Oil Debris Monitoring

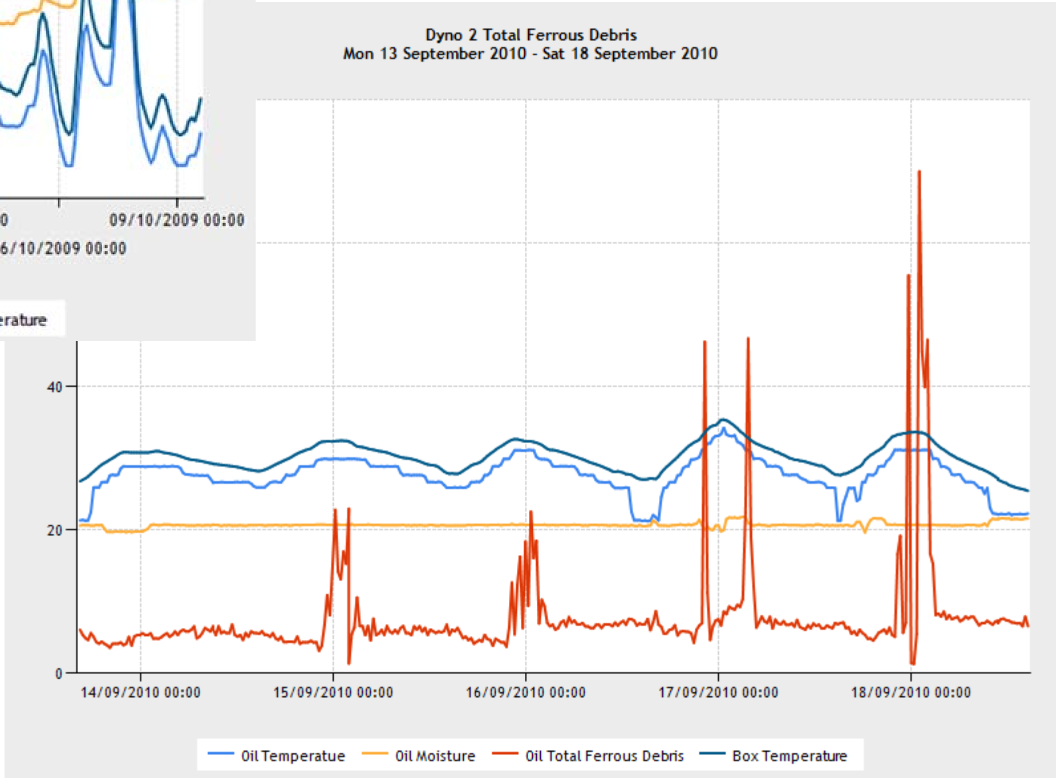


- Particle generation rates:
  - Damaged GRC gearbox #1: 70 particles/hour on 9/16
  - Healthy GRC gearbox #2: 11 particles over a period of 4 hours

Results: Oil Condition Monitoring



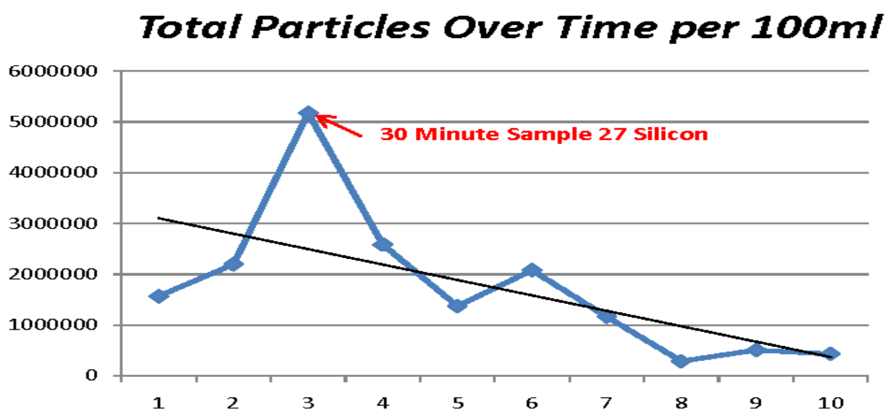
- Field test of GRC gearbox #1 (left):
  - Wild dynamics
  - Possible damage



- Retest of GRC gearbox #1 (right):
  - Well controlled test conditions
  - Possible damage

Results: Oil Sample Analysis

- Results: GRC gearbox #2
  - Particle counts: important to identify particle types[3]



ISO 4406 Code

21/17/12
22/18/12
23/22/20
22/21/16
21/18/13
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  - Element identification

Metals	Reference Limits	Analysis Results					
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

Observations

- Stress wave amplitude histogram appears effective for detecting gearbox abnormal health conditions.
- Spectrum analysis of vibration signal (or stress waves) can, to a certain extent, pinpoint the location of damaged gearbox components.
- Oil debris monitoring, specifically particle counts, is effective for monitoring gearbox component damage, but is not effective for damage location.
- Damaged gearbox releases particles at increased rates.

Observations (*Cont.*)

- Oil condition monitoring, specifically moisture, total ferrous debris and oil quality:
  - More data is required to understand oil moisture and quality.
  - Oil total ferrous debris appears indicative for gearbox component damage.
- When obtaining particle counts through oil sample analysis, attention should be given to identifying particle types.
- Periodic oil sample analysis may help pinpoint failed component and root cause analysis.
- Electric signature-based technique did not reveal any gearbox damage in this study.

References

1. Sheng, S. and Veers, P. “Wind Turbine Drivetrain Condition Monitoring – An Overview,” *Machinery Failure Prevention Technology (MFPT) Society 2011 Conference Proceedings*, Virginia Beach, VA, USA, May 10-12, 2011.
2. Kewitsch, R. “Optimizing Life Cycle Costs (LCC) for Wind Turbines by Implementing Remote Condition Monitoring Service,” presented at *the AWEA Project Performance and Reliability Workshop*, January 12–13, 2011, San Diego, CA.
3. Herguth, W. “Gearbox Reliability Collaborative Dynamometer Test Results,” presented at *the NREL GRC All Member Meeting*, Feb. 2-3, 2010, Golden, CO.
4. Sheng, S. “Investigation of Various Condition Monitoring Techniques Based on a Damaged Wind Turbine Gearbox,” to be presented at *the 8th International Workshop on Structural Health Monitoring 2011*, Stanford, CA, USA, September 13-15, 2011.

Wind Turbine Condition Monitoring Workshop

Register at: http://www.nrel.gov/wind/workshop_20110919.html

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Hope to see most of you at the CM workshop.

Thanks for Your Attention!

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