Predictive Maintenance Through Electrical Testing and Motor Diagnostics

Presented by:
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US Sales Manager

SKF Reliability Systems,
Electric Motor Condition Monitoring
Predictive Maintenance Through Electrical Testing and Motor Diagnostics

Session Objective

• Understand the uniqueness and differences between static and dynamic motor testing methods

• Discuss techniques to obtain valuable information to detect motor problems prior to failure, avoiding costly downtime
Predictive Maintenance Through Electrical Testing and Motor Diagnostics

• Predictive maintenance test methods
• Static and dynamic testing
• Electric motor components
• Causes of motor failures
• Static electrical tests
• Megohm, polarization index, hipot, surge
• Static motor testing case studies
• Static motor testing benefits
• Dynamic electrical parameters
• Connections
• Dynamic motor testing case studies
• Networked dynamic monitoring
• Dynamic motor testing benefits
The complete solution for the full lifecycle of the motor

Manufacturing  →  Operation and Maintenance  ←  Repair
Complete lifecycle testing

Dynamic Monitoring
Static Maintenance
Static Quality control
Early Warning

What If you could prevent premature motor failures by identifying motor fault areas in advance?

Well, you can!!!

How? By adding motor testing to your PdM program.
Predictive Motor Testing Methods

Electric motor management drives predictive maintenance and quality assurance programs

Online Motor Analysis System  Dynamic Motor Analyzer  Static Motor Analyzer
What are we really after?

• Reduce unscheduled downtime by predicting imminent motor failures and identifying problem areas

• Determine root-cause of problem

• Ultimate goals: Save time & money
90% of all motors are squirrel cage induction motors
Electric AC Motor Construction
Electric Motor Deconstruction
Motor Failure Studies

IEEE 1983
- Bearing 44%
- Stator 26%
- Rotor 8%
- Other 22%

EPRI 1984
- Bearing 41%
- Rotor 9%
- Stator 36%
- Other 14%

IEEE 1995 Petroleum Industry
- Bearing 51%
- Stator 16%
- Rotor 5%
- External 16%
- Unknown 10%
- Shaft 2%

Motor Problems

Motor Problems

Electrical
25% - 35%
No Warning? $$$

Mechanical
65% - 75%
Warning Signs – Heat Vibration Noise
Motor Insulation Components

Ground Wall Insulation – Copper-to-Earth

Turn Insulation – Copper-to-Copper
Turn to Turn Insulation Weakness
Causes of Insulation Failure

• Thermal Aging (IEEE 101)
  • For every 10°C increase in nameplate temperature of the insulation, the insulation life is decreased by 1/2.

• Contamination
  • Chemical, deposit on the winding

• Mechanical
  • Movement within the winding at start up

• Over Voltage Spikes
  • High Voltage surges caused by start up and shut-down, VFD
What Tests Can We do?

- Winding Resistance
- Meg-ohm Test
- Polarization Index (PI)
- Hipot Test
- Surge Test
Meg-Ohm Test – Predictive?

Meg-Ohm-Meter

- **It Can:**
  - Determine if the motor has failed to ground.
  - Dirty motor (Surface leakage)
  - Perform a Polarization Index and Dielectric Absorption Test.

- **It Cannot:**
  - Determine if a motor is good
  - Find a Turn-to-Turn Fault
  - Find an Open Phase
  - Find a Phase-to-Phase Fault
Polarization Index Test

The ratio of insulation resistance after ten (10) minutes - continuously applied DC, divided by the insulation resistance at one (1) Minute.

An indication of age and/or wet insulation - maybe.

Can find-
- Deteriorated ground wall insulation
- Dry-rotted, hard, brittle ground wall insulation, contamination
Hipot Testing

Step Voltage Test

Conventional Hi-Pot Test

(Micro Amp Test)

Can find –

• Weak Ground wall insulation
• Cable insulation weakness
Surge Test

Field Testing Can Find:

• Weak insulation (PPM, QA, TS)
  - Turn-To-Turn
  - Phase-To-Phase
  - Coil-To-Coil

• Work Shop Testing Can find:
  - Weak insulation turn to turn, phase to phase, coil to coil
  - Reversed coils
  - Turn-To-Turn shorts
  - Unbalanced turn count
  - Different size copper wire
  - Shorted laminations
Turn to Turn Failure

At least 80% of electrical stator failures start as turn-to-turn fault!

Most will fail to ground in the slot, but the root cause will be turn to turn failure

General Electric Paper
Dielectric Strength and Voltage Spikes

Dielectric Strength of Insulation

Deterioration over Time

Test Voltage

Operating Voltage

Time

8000V

2000V

460V Motor

Jan. 1998

July 1998

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Organizations Recommended Tests

All equipment and tests are backed by the following international standards

IEEE 522
IEEE 43
IEEE 95
IEC 34-15
NEMA MG1
NFPA 70E
EASA
Case Study 1 – Static Testing

Turn-to-Turn Weakness within Stator Windings
Case Study: Weak Insulation - Turn-to-Turn

Low Voltage Tests

<table>
<thead>
<tr>
<th>Data</th>
<th>Tests</th>
<th>Trending</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>Test ID</td>
<td>Temp</td>
</tr>
<tr>
<td>01/12/05 08:27:20</td>
<td>480V with PI</td>
<td>PASS</td>
</tr>
<tr>
<td>08/11/03 17:11:06</td>
<td>480V with PI</td>
<td>PASS</td>
</tr>
</tbody>
</table>

- **Test Date**: 01/12/05, 08/11/03
- **Test Time**: 08:27:20, 17:11:06
- **Temp Status**: Tested, Tested
- **Temp(°C)**: 20.0, 31.1
- **Resist Status**: PASS, PASS

- **Ball L1 (Ohms)**: 1.25 Corr: 1.22
- **Ball L2 (Ohms)**: 1.25 Corr: 1.22
- **Ball L3 (Ohms)**: 1.25 Corr: 1.22
- **L1-L2 (Ohms)**: 1.61 Corr: 1.64
- **L2-L3 (Ohms)**: 1.61 Corr: 1.64
- **L3-L1 (Ohms)**: 1.61 Corr: 1.64

- **Max Delta %**: 0.000%, 0.200%
- **Coil 1 (Ohms)**: 0.81 Corr: 0.82
- **Coil 2 (Ohms)**: 0.81 Corr: 0.82
- **Coil 3 (Ohms)**: 0.81 Corr: 0.82

- **Megohm Test**: PASS, PASS
- **Volts (V)**: 510, 510
- **Current (µA)**: 0.06, 0.1
- **Resist**: 5100
- **At 40°C**: 2093, 2754
- **PI Status**: PASS, PASS
- **Volts (V)**: 590, 510
- **DA Ratio**: 3.0, 1.0
- **PI Ratio**: 2.9, 6.2

**ALL GOOD!**
Case Study: Weak Insulation - Turn-to-Turn

Low Voltage Tests

Polarization Index Test (PI).

Meg-Ohm values continued to increase and current leakage decreased over time.

ALL GOOD!
Case Study: Weak Insulation - Turn-to-Turn

Surge Test is the only test capable of finding *weakness* in the turn-to-turn insulation:

**Phase 1**

**Phase 2 test good**
Phase 3 shows weak insulation, Turn-to-Turn, at about 1,000 volts.

This is not a Turn-to-Turn Short.

No other technology can find this fault!
Case Study 2 – Static Testing

Groundwall Insulation Problem found with Hi-Potential Tests
(Using the Step-Voltage Test)
Case Study: Step Voltage Test at Higher Voltage Found Unstable Ground Wall Insulation

3300 Volt Motor

300 HP

1490 speed

Tested 4 identical motors at a power plant:

3 Tested Good and 1 Showed Weakness at elevated voltage levels indicating weakness to ground.
Case Study: Step Voltage Test at Higher Voltage Found Unstable Ground Wall Insulation

Micro-Amp Leakage doubled between 8000 and 9000 volts indicating copper-to-earth weakness.

Last step Volts shows unstable ground wall insulation indicated by the “knee-effect”.

The step voltage hi-potential test allows the operator to see and trend the current leakage.

Leakage Value still very Low and Meg-Ohm value Acceptable.
Service Work & Reporting

<table>
<thead>
<tr>
<th>Results Summary</th>
<th>Test Date/Time 12/4/2008 10:25:16am</th>
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<tbody>
<tr>
<td>Test ID:</td>
<td>415V W/Rotor</td>
</tr>
<tr>
<td>Repair/Job #</td>
<td>300KW</td>
</tr>
<tr>
<td>Tested By</td>
<td>Paul Knock</td>
</tr>
<tr>
<td>Tested For</td>
<td>A Mann</td>
</tr>
<tr>
<td>Room #</td>
<td>MCC</td>
</tr>
<tr>
<td>Location</td>
<td>Main Drive</td>
</tr>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Temp Status</th>
<th>Tested</th>
<th>PI Status</th>
<th>PASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temp</td>
<td>20.0°C 68.0°F</td>
<td>Volts (V)</td>
<td>510</td>
</tr>
<tr>
<td>Resist Status</td>
<td>PASS</td>
<td>DA Ratio</td>
<td>2.7</td>
</tr>
<tr>
<td>L1-L2 (Ohms)</td>
<td>0.0275 Corr: 0.0280</td>
<td>PI Ratio</td>
<td>DA Only</td>
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<tr>
<td>L2-L3 (Ohms)</td>
<td>0.0276 Corr: 0.0282</td>
<td>Step-Voltage</td>
<td>MIN MEGOHM</td>
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<tr>
<td>L3-L1 (Ohms)</td>
<td>0.0276 Corr: 0.0282</td>
<td>Volts (V)</td>
<td>2000</td>
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<tr>
<td>Max Delta R %</td>
<td>0.533%</td>
<td>Current(µA)</td>
<td>423.00</td>
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<tr>
<td>Coil 1 (Ohms)</td>
<td>0.0138 Corr: 0.0140</td>
<td>Resist (Mohm)</td>
<td>5 At 40°C 1</td>
</tr>
<tr>
<td>Coil 2 (Ohms)</td>
<td>0.0137 Corr: 0.0140</td>
<td>Surge Status</td>
<td>ppEAR LIMIT</td>
</tr>
<tr>
<td>Coil 3 (Ohms)</td>
<td>0.0139 Corr: 0.0142</td>
<td>Peak Volt(V) L1</td>
<td>2000</td>
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<tr>
<td>Megohm Status</td>
<td>PASS</td>
<td>Peak Volt(V) L2</td>
<td>1240 Failed</td>
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<tr>
<td>Volts (V)</td>
<td>510</td>
<td>Peak Volt(V) L3</td>
<td>0</td>
</tr>
<tr>
<td>Current(µA)</td>
<td>4.10</td>
<td>Max P-P EAR%</td>
<td>6.8%,10.7%,-,-</td>
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<tr>
<td>Resist (Mohm)</td>
<td>124 At 40°C 31</td>
<td>EAR 1-2,2-3,3-1</td>
<td>30%,-,-,-</td>
</tr>
</tbody>
</table>

Comment:
Surge test failed at 1240V. Turn to Turn insulation is showing deterioration. Stepped High Voltage test also showed weak insulation to earth.

Action: Overhaul unit at next planned outage.

Next Test: 1 Month
Success Story - Rig Support

Shipping – 22 Rig Support Vessels

Each ship has between 15 to 25 critical motors on board. Predictive testing to motors has been able to reduce dry dock time for repair work. Unscheduled dry dock time quickly adds up to several thousand dollars of lost revenue for the customer.

Customer needs:

Unscheduled motor breakdowns causing expensive prolonged docking.

Testing solution:

Off-line Electric Motor Testing.

Customer benefits:

Shortened docking times – reducing costs
Fewer breakdowns, Less downtime, Reduced repair costs.

Operator:
Steve Bowman

Office:
Milton

Saved revenue:
$10,000p/yr +
Success Story - Wind Generation

Energy and Power Generation – Wind

Each site may have up to 100 wind turbines. Generation up time is very important for reliability to the grid as income is based on consistent delivery.

Customer needs:

Make Energy & Generate – downtime is very expensive due to lost income.

Testing solution:

Off-line Electric Motor Testing.

Customer benefits:

Increased Generating time – Increasing Revenue
Reduced downtime, Reduced Repair costs.

Operator: Sammy Lo
Office: Oakleigh

Cost Savings: Reduced Repair Bill $20,000+ (1 off Gen Repair)
Operating Savings: $100,000+
On site Testing – Panel or Motor?
Summary

It is Possible to “Predict” a Motor’s Condition with a great deal of accuracy provided you have the “right tools”.

Off-Line Motor Testing and Trending properly performed provides valuable information allowing YOU to determine when a motor needs attention.

Adding these tests to your present PdM program extends your capabilities and diagnostic successes!

Save Down time …. $$$$$$  Reduce Repair Costs …. $$$$$$
Defining Dynamic Electric Motor Testing

**WHAT IS IT:** The ability to find **Power Condition, Motor and Load Related** issues while the motor is running under normal conditions.

**HOW:** We measure and analyze the **Currents and Voltages** of the motor-load system (typically at the MCC).
Complete System Analysis

Motor

MCC

Load
What Does On-Line Testing Tell Us?

• **Power Quality**
  - Voltage level, voltage unbalance, harmonics distortion, Total Distortion, Power, Harmonics.

• **Machine Performance**
  - Effective Service Factor, Load, Operating Condition, Efficiency, Pay Back Period

• **Current**
  - Current Level, Current Unbalance

• **Spectrum**
  - Rotor Bar, V/I Spectra, Demodulated Spectra

• **Torque**
  - Torque Ripple, Torque Spectra

• **Connections**
  - Waveforms, ABC/SYM Components, Phasors

• **VFD Details**
  - Torque and Speed vs Time, Frequency and Voltage vs Time
Typical Panel (MCC) Conditions

- Voltage Probes
- Current CTs
Dynamic Tester using Remote HV Connection
Summary page – After each test
Efficiency – case study
Field Efficiency Test

Motor ID: HD PUMP B
Motor ID: DB

<table>
<thead>
<tr>
<th>PHASES</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>Ave/Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volt (V)</td>
<td>6867.5</td>
<td>6893.3</td>
<td>6919.3</td>
<td>6893.4</td>
</tr>
<tr>
<td>Curr (A)</td>
<td>39.3</td>
<td>40.7</td>
<td>38.3</td>
<td>39.5</td>
</tr>
<tr>
<td>Avg Freq (Hz)</td>
<td>60.0</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

NEMA Volt Unbalance (%)

NEMA Derating Factor

| Speed (RPM) | 3582.5 |
| Torque (ft-lb) | 757.7  |
| Load (Hp)   | 516.6  |
| % Load     | 103.3  |
| % Efficiency | 94.1   |

“Efficiency”

Power Condition
Motor Performance
Motor Condition
Load
Energy Assessment
Details
How does Efficiency affect Costs?

“Consider”

100kW Motor, operating 24hrs/day and 365 days/year. Energy Costs is $ 0.05kWh

85% Eff = 768,819kWh = $ 38,441.00

90% Eff = 726,107kwh = $ 36,305.00 ($2136)

95% Eff = 687,891kWh = $ 34,395.00 ($4046)
Payback Period

- Hours per Day: 24.00
- Days per Week: 7.00
- Cost per KwH: 0.0700
Payback Period

At 97.3% Load
95.6% Efficiency
Annual Cost to operate this motor at this load level
$ 92,927.84
Using Torque Ripple to Separate Electrical from Mechanical Problem

3 Identical Vertical Pumps Feeding a Manifold
- 3.3KV, 1250hp
- Pumps designed to pull 32,000Nm from motor.

Motor designed to provide 35,000Nm for full load.

One Pump pulling only 28,000Nm from motor.
Findings

Problem found in the pump – not the motor:
- First pump would only run at 28,000Nm or 75% of capacity
- Pump showed fluctuating torque

The utility wanted higher cooling capacity for summer months - pump pulled for repair

Repair cost $180,000
Torque Signature

Pump # 1

Typical - Pump # 2 & 3
Rotor Bar – case study
Known good rotor bar
Broken Rotor Bars

Vertical Line Identifies Rotor Bar Frequency

- Avg Freq [Hz] 50.0
- NEMA Volt Unbalance
- NEMA Derating Factor
- Speed [RPM]
- Torque [ft-lb]
- Load [HP]
- % Load
- % Efficiency

Autophase: Yes
Sensors: Portable EP

1000 A - 150 A - 10 A

04/25/2007 12:25:30 PM elec
Transient – Start up
Transient analysis: Common signatures
Other Capabilities

Continuous Monitoring

Continuous dynamic monitoring/recording of 42 electrical and mechanical parameters – in a portable instrument

On-line Motor Analysis System NetEP
Net EP – Motor Monitoring Made Easy

Monitor Machine Systems 24/7 From Anywhere

Get more out of your machine systems with a performance monitoring product that continuously monitors plant.
SKF Remote Monitoring Services
Alarm Reports

Web Access

Mobile Device
Summary - Benefits of Dynamic testing

- Helps separate Mechanical from Electrical issues
- Provides information about the entire “machine”
- Provides “early warning” information
- Provides “support” for other technologies
- Provides information no other technology can provide
- It is safe, fast and non-intrusive
- Will become “the tool of choice”
- Saves Money
THANK YOU!

Questions?
Comments!