An Investigation into a new method to repair motor cores and improve Efficiency

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Introduction

• A South African based petrochemical company with a large installed base of Medium Voltage (MV) electric motors have encountered challenging repair decisions on numerous motors with inter-laminar insulation deterioration of the stator and/or rotor cores.

• A recently introduced repair technology which entails the re-introduction of new inter-laminar insulation of electric motor cores, have resulted in reductions in core repair cost, as well as reductions in repair time.
Damage to Cores

- Typically stator and/or rotor cores are damaged by:
  - Bearing failure resulting in a stator to rotor core rub.
  - Winding failure burning a hole in the core.
  - Degradation of inter-laminar insulation due to age, vibration and temperature cycling.
  - Incorrect burn-out process.
  - Rotor bar failure.
  - Incorrect material usage by OEM.
Damage to Cores

10 MW, 11kV Stator: Winding failure
Damage to Cores

350 kW Rotor: Bar failure

6.4 MW, 1430kV Stationary Rotor: Core rub
Damage to Cores

1500kW, stator core rub

3000 hp Lamination degradation
Damage to Cores

1050 kW, Rotor bar failure

3500kW rotor winding failure

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Damage to Cores

2.5 MW Lamination degradation

4.8 MW, Stator winding failure

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Historical Core Repair Practices

- Previous core repairs consisted of assembled core repair procedures which included:
  - Acid etching of damaged laminations;
  - Separation of the individual laminations in the affected areas and;
  - Introduction of insulating liquids to re-insulate the laminations
  - Core skim / line boar

- Disassembled core repair procedures including:
  - Restacking;
  - Re-insulation and;
  - Part replacement of laminations
Historical Core Repair Practices

13.7 MW rotor core restack

3.5 MW rotor core replacement

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New Core Repair Method

• A new method, called the InsulCore™ process, which introduces new inter-laminar insulation has been proven to substantially reduce the losses of stator cores

• This method entails using the InsulCore™ Solution: An aqueous solution of phosphoric acid with certain elements in suspension

• Proper application of the InsulCore™ Solution clears the inter-laminar shorts in stator and/or rotor cores

• The InsulCore™ Solution etches the shorted laminations, and then converts the steel surface to form a durable core coating
The InsulCore™ Process

- The core needs to be cleaned to expose bare steel.
- The core and solution in heated to 95 °C.
- The solution is applied for 20 minutes.
- Allow core to cool down naturally.
- Perform core test.
The InsulCore™ Process

1. [Image 1: Insulated core]
2. [Image 2: Insulation application]
3. [Image 3: Insulated core after treatment]
4. [Image 4: Insulated core after treatment, close-up]

450 kW rotor core InsulCore™ Treatment

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Effectiveness of New Method

• International results found that the new process reduced static core losses to approximately 4 watts/kg in most repairs, even in cases where the initial static core loss approached 26 watts/kg (Research done by EASA in the USA).

• This repair method has now been successfully implemented in the South African repair environment.

• The petrochemical company in conjunction with a repair company adopted the method to repair rotor and stator cores and is investigating the utilization of the repair process to reduce the core losses and improve motor efficiency.
Repair of a Rotor Core

- A 13.7MW Compressor Motor was sent for repairs after a bearing failed during operation.
- The repair company conducted a general overhaul on the motor, and during final testing, found that the motor vibration exceeded the limits specified by the customer.
- This problem entailed that during initial no-load operation, the vibration levels were within the limits set by the customer, but the levels then increase over a period of about one hour until it exceeded the vibration limit.
13.7MW Motor Vibration

Vibration readings of the motor during no-load test

<table>
<thead>
<tr>
<th>Time</th>
<th>Drive End</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Non Drive End</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horizontal</td>
<td>Vertical</td>
<td>Axial</td>
<td>Horizontal</td>
<td>Vertical</td>
<td>Axial</td>
<td>Horizontal</td>
<td>Vertical</td>
<td>Axial</td>
</tr>
<tr>
<td></td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
</tr>
<tr>
<td>Start</td>
<td>1.154</td>
<td>1.078</td>
<td>0.642</td>
<td>0.960</td>
<td>0.693</td>
<td>0.829</td>
<td>0.960</td>
<td>0.693</td>
<td>0.829</td>
</tr>
<tr>
<td>1 hour</td>
<td>4.434</td>
<td>3.872</td>
<td>1.827</td>
<td>3.885</td>
<td>3.663</td>
<td>2.899</td>
<td>3.885</td>
<td>3.663</td>
<td>2.899</td>
</tr>
</tbody>
</table>

* Overall vibration levels in mm/s RMS
Vibration Spectrum

Vibration spectrum after start-up

Vibration spectrum after one hour operation
Vibration Analysis

- Continual no-load operation of the motor caused a sharp increase in vibration levels linked to the rotational speed of the rotor, with some higher order harmonics.
- Initial conclusion was that the problem was caused by unbalanced magnetic circuits in the rotor core, leading to deformation of the rotor body (thermal bow).
- **BUT:** Reduction in terminal voltage caused an immediate reduction in vibration levels (non typical of a thermal bow).
- Subsequent increase of the stator terminal voltage did not immediately result in an increase in vibration levels.
Vibration Analysis cont.

• Levels thereafter again slowly increased in a similar manner as initially.
• The final conclusion was that the problem was caused by unbalanced magnetic circuits in the rotor core.
• Which was not temperature dependant, but time dependant.
• However, the phenomena of the immediate reduction in vibration severity when the terminal voltage was removed, is not yet clearly understood.
• An EL CID test was done in an attempt to quantify the problem.
EL CID Results

- Numerous slots experienced inter-laminar leakage currents with values above 100mA.
- Considered to be cause for some concern by the manufacturer.
- As a final confirmation of the origin of the vibration problem, the rotor and stator of the motor was switched with those of a similar motor.
- Which resulted in the vibration problem following the rotor exactly.
EL CID Results

Current [mA]

Slot no

NDE
MIDDLE
DE

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Problem Resolution

- The owner was left with the decision to either replace the rotor core, or to attempt a repair of the core.
- A core replacement was considered very costly and would cause a considerable delay in the repair of the motor.
- It was decided to import the InsulCore™ Solution technology described in the introduction and attempt to repair the core.
Repair and Resting Process

- The core was submitted to repeated immersions into the core repair solution as indicated by the manufacturer of the InsulCore™ solution.
- The repair process resulted in an overall reduction in inter-laminar currents.
- The EL CID test indicated that some areas still exceeded the limits prescribed by the manufacturer.
- The motor was assembled and a vibration test was conducted.
- Final vibration levels were substantially lower than previously experienced and changed very little after a period on no load test.
The InsulCore™ Process: 13.7 MW

13.7 MW rotor core InsulCore™ treatment

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## Rotor El Cid Core Test Comparison Summary

### Original Results

<table>
<thead>
<tr>
<th>Slot #</th>
<th>NDE [mA]</th>
<th>Centre [mA]</th>
<th>DE [mA]</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>160</td>
<td>32</td>
<td>100</td>
<td>Fail</td>
</tr>
<tr>
<td>Min</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Pass</td>
</tr>
<tr>
<td>Avg</td>
<td>32</td>
<td>10</td>
<td>23</td>
<td>Pass</td>
</tr>
<tr>
<td>Overall Average</td>
<td>21.1</td>
<td>Pass</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### After InsuCore Treatment

<table>
<thead>
<tr>
<th>Slot #</th>
<th>NDE [mA]</th>
<th>Centre [mA]</th>
<th>DE [mA]</th>
<th>Result</th>
<th>NDE [%]</th>
<th>Centre [%]</th>
<th>DE [%]</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max</td>
<td>120</td>
<td>25</td>
<td>170</td>
<td>Fail</td>
<td>-25.0%</td>
<td>-21.9%</td>
<td>70.0%</td>
<td>-22.2%</td>
</tr>
<tr>
<td>Min</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>Pass</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Avg</td>
<td>18</td>
<td>8</td>
<td>25</td>
<td>Pass</td>
<td>-43.8%</td>
<td>-20.0%</td>
<td>8.7%</td>
<td></td>
</tr>
<tr>
<td>Overall Average</td>
<td>16.4</td>
<td>Pass</td>
<td></td>
<td></td>
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<td></td>
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</table>
## 13.7MW Motor Vibration

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<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
<td>Plane</td>
</tr>
<tr>
<td>Start</td>
<td>0.802</td>
<td>0.483</td>
<td>0.909</td>
<td>1.130</td>
</tr>
<tr>
<td>2 hours</td>
<td>1.035</td>
<td>0.892</td>
<td>0.991</td>
<td>1.143</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Previously</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour</td>
</tr>
<tr>
<td>Reduction</td>
</tr>
</tbody>
</table>

* Overall vibration levels in mm/s RMS
Vibration Spectrum After Repair

Vibration spectrum after start-up

O/All 0.802 mm/s RMS

Vibration spectrum after 2 hours of operation

O/All 1.035 mm/s RMS
Comments on the Vibration

- The core repair process has reduced the vibration severity to within acceptable limits.
- However, the final test would be conducted under load, once the motor is installed in its area of operation.
- In comparison to a previous repair on a similar motor, which entailed a partial core replacement.
- There was a ninety percent improvement in cost and time.
Improvement

90% Cost & Time Reduction

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Energy Efficiency Improvement

• The petrochemical company is busy investigating the effect of InsulCore™ Solutions repair processes on the efficiency values of its medium voltage motor population.

• This entails conducting efficiency tests after repair to ascertain whether the repair process has deteriorated or improved the efficiency values when compared to the design value.

• A focus area of the investigation is to measure the effect of reducing the stator and rotor core losses, on the efficiency values of the motors.

• The InsulCore™ Solutions method was utilized to treat the rotor and stator cores of a 600HP, 3300V, 6-Pole motor, with the intent of determining the effect of the treatment on the losses and efficiency of the motor.
The InsulCore™ Process: 600 hp

600 hp and stator core InsulCore™ treatment
The InsulCore™ Process: 600 hp

600 hp rotor core InsulCore™ treatment
Stator Core Loss Comparisons

Stator Core Loss Comparison

Loss [W/kg]

Flux [T]

Original

Treatment 1
Efficiency Curve Comparison

Efficiency vs Load

Load

Eff

55%
55.0%
65%
65.0%
75%
75.0%
85%
85.0%
105%
105.0%
Discussion on Results

• The comparative graphs indicate that the treatment had very little effect on the core losses and the efficiency.

• Although there is an unexplained increase in the core losses above 1.3T, it falls above the operating levels of the motor.

• It would probably have been better if a motor with a “bad” core could have been selected, but the condition of the motor cores cannot be determined before the initial efficiency test, and once the process had started, it was decided that it should be completed.
Core Loss vs. Efficiency

- There is a theory that the measured core losses (from the Watt loss test) should have a direct correlation with the full load efficiency of the motor.

- However there is no research that have confirmed this theory.

- Because of the petrochemical company’s drive to conduct efficiency tests on all motors (< 1 MW) we have recorded some remarkable results.
Core Loss

<table>
<thead>
<tr>
<th>Results</th>
<th>Motor # 1</th>
<th>Motor # 2</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Watt Loss</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>@ 1.3 T</td>
<td>5.930</td>
<td>5.158</td>
<td>W/kg</td>
</tr>
<tr>
<td>@ 1.5 T</td>
<td>9.454</td>
<td>8.275</td>
<td>W/kg</td>
</tr>
<tr>
<td>F &amp; W @ Vn</td>
<td>6.327</td>
<td>6.928</td>
<td>kW</td>
</tr>
<tr>
<td>Iron losses @ Vn</td>
<td>8.152</td>
<td>6.475</td>
<td>kW</td>
</tr>
</tbody>
</table>

Watt Loss Comparison

Flux Density [T] vs Watt Loss [W/kg]
A reduction in core Watt Loss thus has a direct correlation with an improvement in Efficiency and Power Factor.
A reduction in core Watt Loss thus has a **direct** correlation with an improvement in Efficiency and Power Factor.

- This is a very significant observation.

- On very large motors, it is not possible/practical to perform efficiency testing.

- If proven this result can be used to *prove* efficiency improvements on motors without performing load testing.
Conclusion

• The newly introduced InsulCore™ core repair process has proven to be very successful.
• Reducing repair time and cost considerably.
• The repair process has reduced the vibration levels of the 13.7MW motor to acceptable limits.
• The failure mechanism is still to be further investigated.
• Although the reduction in core losses was dramatic, the effect of the new core repair process on motor efficiency must still be proven.
• Ongoing testing of additional motors is currently under way.