Carbon Brush Performance on Slip Rings

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Mining Electrical Maintenance and Safety Association

September 9, 2010    Clearwater, FL
Machines that use Carbon Brushes on Slip Rings
Synchronous Motor or Generator

Carbon Brushes

Slip Rings

Synchronous Motor or Generator
Synchronous Motor

- Constant speed
- Very efficient
- Three phase windings in stator (rotating magnetic field)
- DC fields on rotor
- DC excitation supplied through carbon brushes on two slip rings (collector rings)
Synchronous Motor

- Typical brush current density – 75 Amps/in² (11.6 Amps/cm²) or less
- Collector rings are generally carbon steel or bronze
Sync Motor Collector Rings
Wound Rotor Induction Motor

- Variable speed
- Three phase windings in stator (rotating magnetic field)
- Three phase windings in rotor
- Three phase (variable frequency) current induced in rotor
- Rotor current brought out to variable resistance/electronic controls through brushes on three slip rings to control speed
Wound Rotor Induction Motor

- Typical brush current density varies widely depending on motor design and application from about 75 Amps/in$^2$ (11.6 Amps/cm$^2$) to 125 Amps/in$^2$ (19.4 Amps/cm$^2$)

- Collector rings are most often bronze or stainless steel
Wound Rotor Motor – Three Slip Rings
Turbine generator brush rigging with “change on the fly” removable brush holders
Turbine Generator

- Synchronous generator
- Extremely efficient
- Converts mechanical energy to AC electrical energy with steam or gas turbine as prime mover
- Three phase windings in stator (rotating magnetic field)
- DC Fields on rotor
- DC excitation supplied through carbon brushes on two slip rings (collector rings)
Steam Turbine Generator

- Typical brush current density 40 Amps/in² (6.2 Amps/cm²) to 65 Amps/in² (10 Amps/cm²)

- Collectors rings are almost always steel or sometimes stainless steel

- Surface speeds up to 16,000 Feet per minute (182 MPH, 81 mps)
Brush Selection and Collector Ring Filming
Brush Material Selection

- Brushes and collectors form a sliding electrical contact
- Brushes are selected based on the current density, ring material and surface speed
- The original equipment supplier (OEM) will have selected grades, but grade changes may be made if the machine operates at conditions different than rated
Airborne Contaminants 5%
Carbon Graphite from the brush 15 - 20%
Grains of Moisture
Metal Oxide 75%

Carbon Brush
Collector Ring (Steel or Bronze)
Collector Ring Film Makeup
## Typical Brush Materials Used

<table>
<thead>
<tr>
<th>Brush Material</th>
<th>Rated Current</th>
<th>Metal Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Density</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>Amp/in²</td>
<td>Amp/cm²</td>
</tr>
<tr>
<td>Graphite</td>
<td>65</td>
<td>10.0</td>
</tr>
<tr>
<td>Electrographite</td>
<td>80</td>
<td>12.5</td>
</tr>
<tr>
<td>Copper Graphite</td>
<td>100</td>
<td>15.5</td>
</tr>
<tr>
<td>Copper Graphite</td>
<td>125</td>
<td>19.4</td>
</tr>
</tbody>
</table>
Brush Wear

- Mechanical – Frictional wear
- Electrical – Material removed with the flow of current
- Thermal – With heat some carbon oxidizes into CO$_2$
- Film provides a low friction surface
Common Collector Ring
Materials

• Bronze – Resistance to chemical reactions. Limited speed capability. Good friction characteristics.

• Steel – Good mechanical strength. Can oxidize under brush at standstill or rust

• Stainless steel – Contamination resistance. May have higher brush contact drop and selectivity
Brush Holders

- Brushes must be held in contact with the ring for good performance.
- The holders must be supported so they do not vibrate.
- Clock spring holders are a poor selection where there is vibration and must be adjusted as brushes wear.
- Constant pressure holders are common on newer machines or retrofits.
Adjustable Clock Spring

Clock Spring Holders
A Different Style Adjustable Spring Ladder Back Holder
Short Style Brush Holder – Not Preferred
Full Length
Brush Holder
Preferred
Brush Holder
Alignment and
Design Concerns
"Constant Pressure" (Non-Adjustable) Spring
Brush holders set too high
Brush holder clearance to the rings should be set to manufacturer’s recommendation. This is typically about 0.125” (1/8”) maximum.
A longer holder would be better for brush stability.
Brush Holder alignment OK, exactly perpendicular to the slip ring surface or commutator surface.
Brush Holder alignment, not the best, but 1 or 2 degrees trailing is OK.
Brush Holder alignment needs adjustment. This is called leading or stubbing and can cause fast wear or friction chatter. Just 1 or 2 degrees makes a big difference.
Not Good – One brush trailing, one leading
Normal Performance

Uniform film appearance with no burn marks

No signs of excessive ring wear

No visible sparking

Brush faces uniform with no sign of burning

Minimal “side polish” from brush movement

Good brush life
Two excellent tools for accessing rings

- Feeler Stick
- Strobe Light
### Collector condition for good performance

<table>
<thead>
<tr>
<th></th>
<th>Total Indicator Runout</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inches</td>
</tr>
<tr>
<td><strong>Preferred</strong></td>
<td>0.001</td>
</tr>
<tr>
<td><strong>Allowable</strong></td>
<td>0.003</td>
</tr>
</tbody>
</table>

Surface speed and type of TIR affects brush performance.
.00044” TIR
3600 RPM
Slip Ring
0.0044” TIR
3600 RPM
Slip Ring
Small BUMP on slip ring OD may cause problems

.00044” TIR
3600 RPM
Slip Ring
3 Ring Slip Ring Assembly

Each ring has a different Profile

See next 2 slides
Collector Ring
Conditions
Foot Printing (photo Imaging/ghosting)

- Images appear on the ring that initially reflect the size of the brush face and brush spacing
- Erosion from arcing makes “low spots”
- The marks may spread out over time and make the ring surface not round
- Sometimes the ring looks like the brush is bouncing or “skipping”
Foot Printing – Turbine Generator
Photo Imaging - Advanced
Foot Printing

- Simultaneous loss of contact
- The initial trigger is a mechanical disturbance
- The damage to the ring is from subsequent electrical erosion
- Eventually, the initial marks may spread out and not be visible, but the ring will go out of round
- Damage is progressive and gets worse at an increasing rate
Foot Printing

- Mechanical triggers
  - Out of balance rotor
  - High friction area on ring
  - Brush instability
  - Contamination
  - High friction in brush holders, slow to respond springs
  - Corrosion under brushes from moisture when brushes left in contact with the ring at standstill
Foot Printing

• The strobe light is an excellent tool for spotting foot printing early so corrective action can be taken before damage progresses too far
Foot Printing – Corrective Action

- Increase brush pressure to shorten periods of bounce
- Eliminate contamination/high friction areas on rings
- Do not allow machines to remain idle for long periods with the brushes down
- Increase the number of brushes per ring to increase the chance at least one brush will be in contact
- Reposition brushes to increase the arc of contact
Foot Printing _ Corrective Action

- Make sure rotors are properly balanced
- Have brush holders properly aligned for brush stability
- Do not sandblast brush holders and eliminate burrs so brushes can move freely
Foot Printing Removed – Turbine Generator Ring After Machining
Threading

- Under normal conditions some metal is removed from the rings and is vaporized.
- Sometimes the metal does not completely vaporize and transfers into the brush face.
- These small particles work harden, becoming harder than the ring surface.
- They then cut into the ring making what look like fine pitch “threads.”
Threading
Brush Face – Threading
Microscopic View of Copper in Brush Face
Threading

- Low brush current decreases metal vaporization and can increase threading
- Sulfur containing gases (SO₂, H₂S) increase metal transfer and threading
- Low brush pressure increases metal transfer and threading
Total Brush Wear

Wear Rate

Brush Pressure

Optimum Range

Total Brush Wear

Mechanical Wear

Electrical Wear
## Typical Proper Brush Pressures

<table>
<thead>
<tr>
<th>Application</th>
<th>Brush Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PSI</strong></td>
<td><strong>(Kg/cm²)</strong></td>
</tr>
<tr>
<td>Industrial</td>
<td>2 – 4</td>
</tr>
<tr>
<td>Turbine Gen.</td>
<td>2 – 2.75</td>
</tr>
<tr>
<td>Low speed or</td>
<td>3.5 – 4</td>
</tr>
<tr>
<td>Higher Vibration</td>
<td></td>
</tr>
</tbody>
</table>
Threading – Corrective Action

- Reduce atmospheric contamination (not easy)
- Make sure brush pressure is adequate
- Check brush current density and use a graphite grade for low current density
- Use caution in removing brushes to increase brush current density as foot printing may become a problem
Grooving

- Grooving is uniform wear around the circumference of the rings
- There will always be some mechanical and electrical wear of the rings
- However, the rate should not be high enough to require frequent ring maintenance
- Excessive mechanical wear can be caused by abrasive brush grades
- Low brush pressure can increase electrical wear
Grooving

- Steel and stainless steel rings are more resistant to mechanical wear than bronze rings
Ring Grooving
Ring Grooving
<table>
<thead>
<tr>
<th>Recording</th>
<th>Plot</th>
<th>Rec#</th>
<th>Recording start</th>
<th>Size</th>
<th>TIR</th>
<th>Max STS</th>
<th>Mean STS</th>
<th>Std dev</th>
<th>Suspect</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABB Path #2</td>
<td>16</td>
<td>16</td>
<td>18 Nov 2009 (4:02:34 am)</td>
<td>106 Segments</td>
<td>26.34 mil : 24-10</td>
<td>3.58 : 19-20</td>
<td>1.059</td>
<td>0.862</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Polarity Wear

- One ring may wear more than the other, especially on synchronous motors or generators where the polarities are separate.
- Proper brush pressure reduces the wear.
- Reversing polarities periodically can make the wear more even. This is like rotating the tires on a car.
Grooving – Corrective Action

- Make sure brush pressure is adequate
- Do not use brush grades that have more “polishing action” (abrasiveness) than is required
- Brushes with some polishing action may be required on steel rings or in contaminated environments
- To reduce polarity wear reverse leads to brush holders periodically
Selectivity

- The brushes on collector rings operate in electrical parallel with each other.
- The brushes never wear at the same rate.
- Uneven currents in the parallel paths will affect brush wear rates.
- The brushes with higher current and temperature generally wear faster.
- Mechanical friction restricting movement of the brush in the brush holder.
Selectivity - Typical Voltage Drops at 100 Amperes in the Brush

- Brush rigging to cable: 1 mV
- Brush box to support: 1 mV
- Brush terminal to holder: 1 mV
- Terminal to shunt wire: 1 mV
- Shunt to carbon (2 shunts): 150 mV
- Carbon material: 120 mV
- Contact drop (brush to ring): 1000 mV
Selectivity

• The largest resistance in the parallel paths is the contact drop between the brush and the ring.

• The contact drop has the largest influence on selectivity.
Selectivity – Corrective Action

• To minimize selectivity, the resistances in the parallel paths must be as consistent as possible

• Brush manufacturer’s responsibility
  – Resistivity of the carbon tightly controlled
  – Terminals applied correctly
  – Tamped or riveted connections to the carbon should have equal and low resistance
Dirty brush holders and springs will affect performance
Selectivity – Corrective Action

• Maintenance personnel responsibility
  – Electrical connections clean and tight
  – Brush box to rigging clean and tight
  – Ensure brush moves freely in the brush holder
Selectivity – Corrective Action

- Adjustable brush springs must be adjusted for equal brush pressure.
- Constant pressure springs “age” from heat and vibration and should be replaced periodically (e.g. 5 years).
- Do not mix brush grades in a machine.
- Minimize contamination on the rings.
- Minimize brush and machine vibration.
Selectivity – Corrective Action

- Use a collector ring material suitable for the application
- Use a brush with the proper current density rating
Selectivity Corrective Action - Helical grooves in rings force current to move around in brush faces preventing localized hot spots
Selectivity – Corrective Action

- A diagonal slot in brush can help reduce selectivity
Loss of Brush Contact

- Arcing between the brush and ring can deteriorate brush life and damage the ring surface
  - Weak brush springs
  - Brushes hung up in holders
  - Vibration
  - Brushes allowed to wear too short
Brush Worn Too Short
Badly Pitted Stainless Steel Ring – Short Brushes
Metal Transfer to Brush – Brushes Run Too Short
Loss of Brush Contact – Corrective Action

- Maintain brush springs to keep good brush pressure
- Make sure brushes can move freely in the holders
- Minimize machine vibration
- Replace brushes in a timely fashion – brushes are inexpensive compared to downtime and machine repair!
Ring Corrosion

- Steel rings can rust if exposed to moisture in the air or liquid water.
- Copper bearing metals like bronze can react with sulfur compounds in the air (SO$_2$, H$_2$S) or acids.
Rusty Steel Collector Rings – Emergency Generator
Rusty Steel Slip Rings – Temporarily Out of Service
Ring Corrosion – Corrective Action

- Choose collector rings of the proper material for the environment

- Minimize corrosives in the atmosphere

- Use space heaters to minimize moisture condensation in idled equipment

- Use rust preventative on steel rings of equipment that is out of service or spares
Conclusions

- There are a variety of issues that can adversely affect collector ring and carbon brush performance
- Understanding the root causes can help the operator apply carbon brushes and collector ring materials
- Auxiliary components such as brush holders and springs must be of good design and properly maintained
Conclusions

- Good maintenance practices and troubleshooting will result in good brush life and reduce downtime and collector ring expenses
Questions ?