Successful Brush Performance on Excavator Motors and Generators

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National Electrical Carbon Products

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Main Purpose of a Brush

To conduct electrical current from it, to a rotating Commutator or Slip Ring

In the case of a DC Motor with a Commutator, it needs to conduct current to each and every commutator segment.

It needs to have intimate contact with the comm. segments to conduct current without arcing.

(Arcing or sparking is current going through air.)
Brush Life Components

Brush grade, treatment, construction
Roughness of commutator - TIR
Speed of commutator - FPM
Brush Pressure - PSI
Brush Current Density - APSI
Climate / humidity
Chemical vapor contamination
Amount of Sparking
Vibration / shock
Temperature / ventilation
Single rotation or reversing
Duty Cycle of the machine

= Total Brush Wear Rate
Having the brush perform properly is a **team effort** by the brush, commutator, brush holder and springs. It takes proper mechanical adjustment of these parts. Uniform air gap settings of the poles is also very important. Electrical settings like neutral and interpole strength also need to be correct for good operation of DC Motors & Generators.
Commutation / Brush Demands Since The Beginning (e.g. 1045 KW)

Rotational Speed – 1200 RPM

- 20 Rev per Second!
Bars Pass each brush at a rate of 3000 commutator bars per second!

And the brushes need to contact every one of them to prevent arcing.
Sliding Speed – 70 Miles per Hour
6,123 ft / minute

Commutation / Brush Demands
Since The Beginning (e.g. 1045 KW)
Revolutions per day - 1,728,000

( 630,720,000 / year )
Distance a brush slides in 6 months-

305,000 miles

(only 274,000 miles at 90% running time)
Commutation Cycles (current reversals) –

120 per second

(6 per revolution)

Commutation / Brush Demands
Since The Beginning (e.g. 1045 KW)
Commutation / Brush Demands
Since The Beginning (e.g. 1045 KW)

Current Switched Per Commutation Cycle

733 Amperes at Rated Current

1466 Amperes at Stall Current
Commutation / Brush Demands
Since The Beginning (e.g. 1045 KW)

Time to Switch the Current

0.00084 seconds

0.84 milli seconds
Most Draglines in The USA Have Been Doing This For 25 to 30 Years

No Small Accomplishment!!
What Has Been Done Since The Machines Were New?

Larger Buckets Added
- Higher RMS Loads
- More Heat
- Switching Higher Currents Greater % of the Time
What Has Been Done Since The Machines Were New?

Static Motor Field Exciters

- Higher Rope Speeds
- Increased RMS Current
- Faster Average Motor Speeds
New Controls

- Faster Response
- Higher Rate Of Current Change
  \( \frac{di}{dt} \)
What Has Been Done Since The Machines Were New?

- Many Draglines Have Greatly Increased Productivity Since New
- Often With Less Maintenance People
- And More Pressure for Less Down Time for Maintenance
Commutation

This is called Reactance Voltage

\[ V = -L \frac{dI_A}{dt} = -L \frac{\Delta I_A}{\Delta t} \]

This is called Reactance Voltage
Commutating Pole or Interpole

\[ \phi_{\text{Flux}} \propto N \times I_A \]

Backgap \( g_b \)

Armature

Frame

Shims

Frontgap \( g \)
Brush Neutral Position

Frame

Commutation Zone

Brush

Commutation Zone
Machine Adjustments

1. Brush Position (neutral)

2. Commutating Field Strength
Factory Method

vs

Field Method
Methods to Set Electrical Neutral

- DC Kick
- AC Null
- Reversability (Speed & Voltage)
- Black Band
- Brush Potential
- Pencil Volt Neutral
Commutating Pole & Shims

Order of shims is very important!
Adjustable .015” Commutating Pole Shim

Fixed .125” Thick Commutating Pole Shim

GE uses non-Magnetic comm Pole bolts
DC voltage drops on stator coils

DC Drops ........... Easy to Measure
AC voltage drops on stator coils

AC Drops ............ More Sensitive
To Shorted Turns
Main Field AC Drop Test

120 VAC

Voltages Should Agree Within 15%

Volts

Volts

Volts
<table>
<thead>
<tr>
<th>Pole</th>
<th>Good Coil Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00</td>
<td>20.5</td>
</tr>
<tr>
<td>2:00</td>
<td>19.5</td>
</tr>
<tr>
<td>4:00</td>
<td>19.3</td>
</tr>
<tr>
<td>6:00</td>
<td>20.2</td>
</tr>
<tr>
<td>8:00</td>
<td>19.8</td>
</tr>
<tr>
<td>10:00</td>
<td>20.7</td>
</tr>
</tbody>
</table>
# AC Drops - Main Field

<table>
<thead>
<tr>
<th>Pole</th>
<th>Good Coil Volts</th>
<th>120 Volts total</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00</td>
<td>20.5</td>
<td></td>
</tr>
<tr>
<td>2:00</td>
<td>19.5</td>
<td></td>
</tr>
<tr>
<td>4:00</td>
<td>19.3</td>
<td></td>
</tr>
<tr>
<td>6:00</td>
<td>20.2</td>
<td></td>
</tr>
<tr>
<td>8:00</td>
<td>19.8</td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td>20.7</td>
<td></td>
</tr>
</tbody>
</table>

**Typical Data**
## AC Drops - Main Field

<table>
<thead>
<tr>
<th>Pole</th>
<th>Good Coil Volts</th>
<th>Shorted Coils Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>12:00</td>
<td>20.5</td>
<td>24.3</td>
</tr>
<tr>
<td>2:00</td>
<td>19.5</td>
<td>17.9</td>
</tr>
<tr>
<td>4:00</td>
<td>19.3</td>
<td>12.1</td>
</tr>
<tr>
<td>6:00</td>
<td>20.2</td>
<td>18.3</td>
</tr>
<tr>
<td>8:00</td>
<td>19.8</td>
<td>23.8</td>
</tr>
<tr>
<td>10:00</td>
<td>20.7</td>
<td>23.6</td>
</tr>
</tbody>
</table>

Typical Data
Commutating Coil AC Drop Test
## AC Drops - Commutating Field

<table>
<thead>
<tr>
<th>Pole</th>
<th>Good Coil Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:00</td>
<td>0.87</td>
</tr>
<tr>
<td>3:00</td>
<td>0.92</td>
</tr>
<tr>
<td>5:00</td>
<td>0.85</td>
</tr>
<tr>
<td>7:00</td>
<td>0.88</td>
</tr>
<tr>
<td>9:00</td>
<td>0.93</td>
</tr>
<tr>
<td>11:00</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Typical Data
AC Voltage Drops

If Voltage Drops Vary More Than 15% Between Coils, Replace Coil With Low Voltage Drop
Brush Spacing

All measurements should be the same within .050” or 1.2 mm
Brush Arm
Brush Box Height

.070 - 080”
This gap between brush holder and commutator is usually between .070” and .093” for most industrial motors. Only on rather small or very large motors is the recommended gap beyond this range. This gap is not always adjustable on newer motor designs. Readjusting this gap should only be necessary after turning or stoning a substantial amount off the commutator or slip ring diameter. Slip ring motors typically have a .125” maximum gap. Too large of a brush holder setting is unstable and can promote a friction chatter condition.
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.
Pole Tip Spacing

Difference Between A and B is 1/8” Maximum
Uneven And Tapered Airgaps

Diagram showing:
- Frame
- Pole
- Armature
- Airgap
Airgap Taper Gauge
Airgap Measurement
All This Mechanical & Electrical
Symmetry Was Important When
The Machines Were New

With The Upgrades and Productivity Improvements, it is Even MORE SO!!
Circulating currents within single wafer Brush

\[ V_R = i_c \times R_A + V_{CD} + i_c \times R_B + V_{CD} \]

\[ i_c = \frac{V_R - 2V_{CD}}{R_A + R_B} \]

- \( i_c \) becomes less as \( R_B \) increases

- Use high resistivity grade brush for difficult to commutate machines.
Reducing circulating currents with more wafers

$I_A$ Load Amps

\[ V_R = i_c \times R_A + V_{CD} + i_c \times R_B + V_{CD} + i_c \times R_W \]

\[ i_c = \frac{V_R - 2V_{CD}}{R_A + R_B + R_W} \]

- $i_c$ Becomes less as $R_B$ increases

- Use a 2 or 3 wafer brush construction for difficult to commutate machines.
### Commutator Repair Indicators

<table>
<thead>
<tr>
<th>Situation</th>
<th>Runout (TIR)</th>
<th>Bar to Bar Variance</th>
<th>Undercut Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NEW</strong></td>
<td>Less than .0015</td>
<td>Less than .0002</td>
<td>.050 or more</td>
</tr>
<tr>
<td><strong>IN SERVICE</strong></td>
<td>Less than .003</td>
<td>Less than .0003</td>
<td>.020 or more</td>
</tr>
<tr>
<td><strong>NEEDS REPAIR</strong></td>
<td>More than .003</td>
<td>More than .0003</td>
<td>.010 or less</td>
</tr>
</tbody>
</table>
These brushes have an easy job of conducting current to each Commutator segment with 1.18 mils TIR.
These brushes will have a harder job trying to contact each Commutator segment with 3.39 mils TIR & .44 Max. BTB
These brushes have an impossible task of trying to contact each commutator segment with 3.94 mils TIR & 2.32 MBTB
You can hear brush clatter and see sparking when comm. TIR is excessive. Poor brush life is also realized.
These brushes are from a motor with a very rough comm. Brush wear is different since TIR of each brush path is different.
Commutator Undercutting

Mica thickness + .002" to .009"
for saw width

.010" x 30° to 45°
chamfers

Depth equals .9 to 1.5 times
the mica thick.

Copper commutator bar

Mica thickness

Enlarged view of chamfers
How Much Brush Pressure?

The proper amount of brush pressure against the commutator or slip ring depends on the application and/or the brush grade.

To calculate the brush pressure; you need to know or measure the spring force and the brush thickness and width. Brush $T \times W = \text{the cross sectional area}$. Brushes that contact the commutator at an angle do have more contact area that the product of their $T \times W$, but it is usually not a significant difference so the easier to calculate cross sectional area is used.

<table>
<thead>
<tr>
<th>Recommended Brush PSI Range</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 to 6</td>
<td>General Industrial Motors</td>
</tr>
<tr>
<td>3 to 8</td>
<td>Fractional HP Motors</td>
</tr>
<tr>
<td>5 to 10</td>
<td>Traction Motors</td>
</tr>
<tr>
<td>3 to 4</td>
<td>Slip Rings – Low Speed, Graphite Grade</td>
</tr>
<tr>
<td>2 to 2.75</td>
<td>Slip Rings – High Speed, Graphite Grade</td>
</tr>
<tr>
<td>3 to 5</td>
<td>Metal Graphite Grades</td>
</tr>
</tbody>
</table>
Total Brush Wear

Wear Rate

Brush Pressure (PSI)

Optimum Range

Total Brush Wear

Mechanical Wear

Electrical Wear
Brush Pressure (In PSI) = \frac{\text{Measured spring force in pounds}}{\text{Brush cross sectional area in sq. inches}}

**Example:** 7 Lb. 4 oz. Spring Force = 7.25 Lbs

Brush T x W = 1” x 1 1/2 = 1.00 x 1.50

Brush Pressure (In PSI) = \frac{7.25}{1.00 \times 1.50} = \frac{7.25}{1.50} = 4.83 \text{ PSI}

Note: All dimensions are in inches.
Do not sandblast springs or brush holders!
Solvent clean
Do not mix brush grades or brush springs.
WARNING

Do Not Mix Brush Grades

It is highly recommended that you do not mix brush grades in your motor or generator. Grades may look similar but could have 10 to 1 difference in resistance. To avoid selectivity or filming problems, make sure all the brushes in any machine are all the same grade. This may mean that you will need to change all brushes instead of just a few short ones.

Whenever changing brush grades, it is also recommended that the existing film on the commutator be removed with brush seater and let the new grade develop its own distinct film. Brush seater stones, when properly used, do not cut, scratch or remove copper from the commutator. One widely used seating stone size is .625 x 1.125 x 4.75. These are available from Ideal Industries as Catalog number 23-008M, Brush Seater No. 9 from Martindale Electric Co., or #64000063 from National.
**Example:** 1050 Kw DC Gen. rated 450 Volts, 2210 Amps

and has 36 brushes 1.125 Thick x 1.75 Wide

\[
\text{Current Density} = \frac{2210}{1/2 \times 36 \times 1.125 \times 1.75} = 62.4 \text{ APSI}
\]

Note: All dimensions are in inches.
Commutator Film Makeup

- Carbon
- Brush
- Carbon Graphite from the brush 15 - 20%
- Copper Oxide 75%
- Airborne Contaminants 5%
- Grains of Moisture

Copper Commutator
Relative Humidity - The amount of water vapor in the air as a percentage of what the air could hold at that temperature.

This is what the weather man reports.
Humidity

**Absolute Humidity**- The mass of water vapor per mass of dry air.

Absolute humidity is independent of temperature (until you fall below the dew point).

Absolute humidity is what brushes care about.
Humidity

Units

Relative Humidity - %

Absolute Humidity – grains / lb dry air

1 grain = 0.000143 lbs
Humidity

**Dew Point** - Temperature at which relative humidity is 100% (saturated). If temperature decreases further moisture will condense out of the air. (dew)
Psychrometric Chart

-40 F to +40 F
-40 C to +4 C

% Relative Humidity

Grain / lb Dry Air

Temperature (Degrees F)
### Absolute Humidity

<table>
<thead>
<tr>
<th>Where</th>
<th>When</th>
<th>Temp.</th>
<th>R.H.</th>
<th>Abs. H</th>
</tr>
</thead>
<tbody>
<tr>
<td>LA</td>
<td>Summer</td>
<td>90 F (32C)</td>
<td>90%</td>
<td>178 gr/lb</td>
</tr>
<tr>
<td>AZ</td>
<td>Summer</td>
<td>100F (38C)</td>
<td>10%</td>
<td>28 gr/lb</td>
</tr>
<tr>
<td>TX</td>
<td>Winter</td>
<td>32F (0C)</td>
<td>100%</td>
<td>24 gr/lb</td>
</tr>
<tr>
<td>WY</td>
<td>Winter</td>
<td>- 20F (-26C)</td>
<td>100%</td>
<td>1.8 gr/lb</td>
</tr>
<tr>
<td>AB</td>
<td>Winter</td>
<td>- 40F (-40C)</td>
<td>100%</td>
<td>0.5 gr/lb</td>
</tr>
</tbody>
</table>
Electrographitic Brush Materials and treatments

Treatment can lubricate (reduce friction)

Treatment increases Mechanical Strength

Some Treatments Improve Commutation which Lowers Temperature And Increases Life

Treatment help brushes survive harsh environments
Electrographitics

Wear Rate vs. Humidity

- Untreated
- Treated

Wear Rate decreases with decreasing Humidity.
Contaminants

Silicone

Gear Lubricants
Silicone

Silicone vapors, even in very small concentrations, can cause extremely rapid brush wear

Not much of a problem in highly ventilated excavator motors and generators, but can be a problem in enclosed machines, machines with unit coolers, or in confined spaces
Contaminants

Silicone – Sources

- RTV Silicone
- Silicone containing lubricants
- Silicone insulation
- Mold release agents
- Defoaming agents (paper industry)
- Others
Do not use silicone as a sealant around DC Motors!
Vapors or mist can contribute to copper drag, insulation degradation and brush wear.
Blower Inlet

Grease splash drawn into Motor and on commutator
Copper Drag
Blower Operation

Correct arrangement of blower housing, impeller blades and direction of rotation to obtain proper pressure and air flow.

View looking at air inlet side of blower housing. Blower motor is on far side.
### DC Motors

Current Density = \( \frac{\text{AMPS}}{\frac{1}{2} \times \# \text{ Br} \times T \times W} \)

### Slip Ring Motors

Current Density = \( \frac{\text{AMPS}}{\# \text{ Br} \times T \times W} \)

**Example:** 100 HP DC Motor rated 500 Volts, 163 Amps

and has 8 brushes .625 Thick x 1.25 Wide

Current Density = \( \frac{163}{\frac{1}{2} \times 8 \times .625 \times 1.25} \) = 52.16 APSI

Note: All dimensions are in inches.
Without axial brush stagger, there are areas of the commutator that do not form a film but instead may oxidize as a reaction to the surrounding environment. Some designs must stay like this since the brush holders are non-adjustable in the axial direction.
Proper Axial Stagger can prevent grooving or ridging
Axial brush stagger is very important on newly resurfaced Commutators so uneven wear and grooving will be minimized. This is especially important on Armatures that see axial movement during operation like excavator draglines.
Proper axial stagger of brushes
No grooves, no ridges
Short Brush Life?

The main function of a carbon brush is to conduct current to the revolving motor commutator. In order for the brush to be able to do its job, it needs the help of other associated components in the brush rigging, commutator surface and surrounding environment. Brushes need to have good intimate contact with this moving commutator in order to give adequate life and spark free performance.

Questions that need to be answered when resolving Short Brush Life

What is the current density
   Nameplate vs Actual
What is the commutator runout
What is the speed in RPM, FPM
What is the comm. temperature
What is the humidity
What is the measured brush PSI
What is the amount of sparking
What is the duty cycle, reversing
What is the vibration during operation
What does the comm film look like
What is the brush orientation; radial, trailing, stubbing (leading)
What is the brushholder spacing
Is silicone used nearby
What was actual brush life history
Selectivity

Caused by variations in resistance between the brush / commutator interface

Selectivity usually shows up as film stripping with grooving, higher currents in stripped paths, higher temperatures in stripped paths. Selectivity, once started usually gets worse quickly. This is because carbon is the only material where its resistance decreases as temperature increases. A snowball effect occurs as higher currents lead to higher brush temperatures which leads to lower brush resistance which leads to higher currents etc. Remember electrical current takes the path of the least resistance.

To expect UNIFORM electrical resistance between the brush and the commutator then we must have UNIFORM contributing factors.

| Uniform current distribution | Uniform brush temperatures |
| Uniform electrical connections | Uniform comm smoothness in each path |
| Uniform spring force | Uniform brush friction & spacing |
| Uniform brush seating | Uniform arcing, although NONE is best |
| Uniform brush materials | Uniform filming |
| Uniform Electrical adjustments | Uniform mechanical & magnetic adjustments |
Troubleshooting a Commutation (Sparking) Problem

1. **Check outside contributing factors**
   - Excessive vibration of complete machine; unbalance or alignment
   - Overloaded or too light of a load for extended periods of operation
   - Motor too hot - insufficient cooling air - blower motor running backwards
   - Contaminated air supply - chemical vapors paint spray or oil mist
   - Proper operation of the SCR or static power supply
   - Full shunt field amps on motors running at base speed or less.

2. **Check condition of commutator and film appearance**
   - Compare film to commutator check charts to narrow down possible causes
   - TIR maximum = .004" with comm. speed below 5000 FPM; .003" max. above 5000 FPM
   - .0003" maximum bar-to-bar difference (shouldn't span more than 10 consecutive bars)
   - No mica fins, high mica, excessive dirt buildup in undercuts, etching or burning.
Troubleshooting a Commutation (Sparking) Problem

3. **Check brushes**
   - All the same grade, fully seated, not burned, cracked or too short
   - Electrical neutral properly adjusted -- Slight "off neutral" may be better.
   - Free to move within the brushholder, not sticking, no loose shunts or loose terminals
   - Minimal brush vibration (check with strobe light or insulated Feeler Stick)
   - Proper and equal spring force (brush pressure usually 3.5 to 6 pounds per sq. inch)
   - Equally spaced circumferentially around the commutator within .050".
   - Brushholders properly spaced .070" to .090" above the commutator
   - No frayed shunts or evidence of current being passed thru the spring or brushholder.
   - Proper current density for that brush grade
   - No sluggish action of brushes from sandblasted brush holders or springs
Troubleshooting a Commutation (Sparking) Problem

4. **Check stator coils and poles**
   - Connected properly according to the connection diagram
   - Air gaps equal within .010" total
   - Tip to tip spacing equal within .125"
   - Equal resistances within 10%

**Commutating coils**
- Check for shorted turns by AC drops (A 260 watt soldering gun with the tips removed produces the required low voltage, high current AC supply). Voltage drop across each coil should be equal within 15% (Armature must be out of the stator totally or located by the bearing brackets for uniform air gap - also best to check while coils are still mounted in the stator and connected in one circuit)
- Same number of magnetic & non-magnetic shims under each pole and proper order and location of magnetic and non-magnetic shims.
- Non-magnetic comm. pole bolts on many large GE DC machines.
Troubleshooting a Commutation (Sparking) Problem

Main Coils

- Check for shorted turns by AC drops. Can usually use 110 VAC and readings should be equal within 15%.
- Magnetic steel shims and pole bolts only

5. Check insulation resistance (500 or 1000 VDC)

If below 1.5 megohms (corrected to 40 C), blow unit out and make sure windings are dry. Separate stator windings from armature circuit by lifting the brushes. Oil presence will cause tracking which may be difficult to blow out. May need steam cleaning, bake and varnish dip.

6. Motor repair shops may have to make additional checks for faults in armature
Brush Life Performance Components

- Brush grade, treatment, construction
- Roughness of commutator - TIR
- Speed of commutator - FPM
- Brush Pressure - PSI
- Brush Current Density - APSI
- Climate / humidity
- Chemical vapor contamination
- Amount of Sparking
- Vibration / shock
- Temperature / ventilation
- Single rotation or reversing
- Duty Cycle of the machine

+ 

= Total Brush Wear Rate