The Effect of DC Machine Adjustment on Loop Unbalance

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Rich Hall – Morgan AM&T
Jim Shackelford – Peabody Energy
Technical Contributor

Jason Conrad – GE Canada

Peterborough, Ontario, Canada
Dragline Loops Contain

• Direct Current Generators
• Direct Current Motors
• Ammeter Shunts
• Cables
• Connections
Dragline Generator Loops
Design Benefits

• Multiple units in each loop “average out” some of the variation in individual generators and motors, cabling, etc.

• Multiple motors and generators “average out” the effect of temperature variations around the house

• Multiple loops give some degree of control of the machine if one loop is lost
Loop Balance

Ideally, the loops behave exactly the same as each other under all conditions.

Visually, they would look like a well-choreographed synchronized swim team.
Loop Balance

cont.

- This means each generator behaves like every other generator
- Each motor behaves like every other motor
- Each loop’s cables and connections have the same resistance as each other loop
These loops act electrically in parallel

- If the generators in one loop produce more Voltage than the generators in other loops, that loop will draw more current.

- If the motors in one loop “try” to run faster than the motors in other loops, they cannot because they are geared together, but that loop will draw more current.
These loops act electrically in parallel

- If the resistances of the cables and connections are lower in one loop than the other loops, that loop will draw more current
So what??

- Unbalanced loop currents may cause excessive torque in some loops, cause increased mechanical wear and take life out of couplings, gears, and structural parts of the machine.

- Unbalanced loop currents may result in too little torque in some loops and reduce the productivity of the dragline.
• Unbalanced loop currents may result in increased brush and commutator wear
• Unbalanced loop currents may result in flashovers
• Unbalanced loop currents may trip the loop overcurrent
• Unbalanced loop currents may cause the generator field overcurrent to trip
Bigger Problems!!!

- Unbalanced loop currents may result in overheating some generators or motors.
- Badly unbalanced loop currents may cause the sync motors to pull out of synchronization, especially on weak power systems.
Results

• This may cause damage to equipment, loss of productivity, increased downtime and increased repair costs

• Rule of thumb in the business loss insurance industry: the cost of the repair is 10% of the business loss
How much voltage does it take to drive rated current?

- The rating of a GE 1045 KW generator is 475 Volts and 2200 Amperes.

- It does not take 475 Volts to drive rated current in the loop, however.
How much voltage does it take to drive rated current?

• The answer – about 20 Volts per generator!!!
How much voltage does it take to drive rated current?

- When the machines are in a “motoring” quadrant, the generators are generating an electro motive force (EMF), but the motors are also generating an electromotive force that opposes the generator EMF and it is called a counter EMF (CEMF).
How much voltage does it take to drive rated current?

- It is the sum of the generator Voltages minus the sum of the motor Voltages in the loop that drives loop current.

- This Voltage divided by the loop resistance gives the loop current.
How much voltage does it take to drive rated current?

- The loop resistance is most easily determined at stall when the motors are not rotating or generating any CEMF.

- For a 1045 KW generator, about 40 Volts per generator drives stall current (2X rated current or 4400 Amperes).

- Loop Resistance = \(\frac{(40V + 40V - 0V - 0V)}{4400 \text{ Amperes}}\) ≈ 0.0181 Ohm
How much voltage does it take to drive rated current?

• It does not take a large Voltage imbalance to drive a lot of current when you divide it by 0.0181!!!
Standards for Loop Balance

- 5% of stall current at stall conditions
- 5% of stall current while running steady (even at peak power)
- 10% of stall current during transient load changes
How much voltage difference does it take to be at the recommended limits?

- 5% of 4400 Amperes = 220 Amperes
- \( V = IR = 220 \text{ Amperes} \times 0.0181 \text{ Ohms} \)
  \[ V = 3.9 \text{ Volts} \]
- So a 4 Volt difference between loops is all it takes to be at 5% of stall current!
Four Quadrant Operation

1. Positive Volts (+ Volts)
2. Negative Amps (- Amps)
3. Negative Volts (- Volts)
4. Positive Amps (+ Amps)
Loop Balance

- Loop 1 is the control loop and is inside the commutation limits, so it is OK.

- Loop 2 is the slave loop and is inside the commutation limits, so the equipment is OK. It is “loafing”, however, so the dragline is working at less than capacity.
Loop Balance

- Loop 1 is the control loop and is inside the commutation limits, so it is OK.

- Loop 2 is the slave loop and is outside the commutation limits. This may lead to commutation distress, flashovers, excessive wear of couplings and gears, tripping of the machine, etc.
Assembling DC Machines

• To work properly together and to commutate well, machines must be built or rebuilt properly.

• Following are GE factory tolerances provided by GE Canada, Peterborough, Ontario.
Generators

- Pole centerline to pole centerline chord
  - measured at both ends of machine
  - minimum to maximum values must not differ by more than 0.125” (3.2 mm)
Pole Tip Spacing

Difference Between A and B is 1/8" (3.2 mm) Maximum
Generators

• Brush Holder Assembly
  – holders to be set 0.070” to 0.080” from commutator surface (1.8 to 2.0 mm)
  – axial skew must not exceed one mica thickness over the length of the commutator
Brush Box Height

0.070 – 0.080”
(1.8 – 2.0 mm)
BRUSHHOLDER SPACER GAUGE

Brushholder

THICKNESS OF THIS GAUGE

Commutator Surface

Brushholder

THICKNESS OF THIS GAUGE

Commutator or Slip Ring Surface
Generators

• Circumferential brush spacing (paper tape on commutator)
  – arcs measured from one brush toe to the next must be within 3/64” (0.047” or 1.2 mm) (MAXIMUM)
Brush Spacing

A = ______
B = ______
C = ______
D = ______
E = ______
F = ______

Max. Spacing Diff. = ______

Target is .030”
On Westinghouse Equipment

Max. Spacing diff = .050” on GE equip.
Generators

• Air Gaps
  – all air gaps to be within +/-0.007” (0.18 mm)
  – commutating pole air gaps may be different than main pole air gaps
Uneven And Tapered Air Gaps
Air Gap Taper Gauge
Air Gap Measurement
Motors

• Pole centerline to pole centerline chord
  – measured at both ends of machine
  – minimum to maximum values must not differ by more than 0.125” (3.2 mm)
Motors

• **Brush Holder Assembly**
  - holders to be set 0.070” to 0.080” from commutator surface (1.8 to 2.0 mm)
  - axial skew must not exceed one mica thickness over the length of the commutator
Motors

• Circumferential brush spacing (paper tape on commutator)
  – arcs measured from one brush toe to the next must be within 3/64” (0.047” or 1.2 mm)
• **Air Gaps**
  
  – all air gaps to be within +/-0.007” (0.18 mm)
  – commutating pole air gaps may be different than main pole air gaps
N = Number of Turns

g = Air Gap
$\phi \propto N \times i$
SATURATION CURVE

Flux $\phi$ in Air Gap

Iron Saturation Region

Air Gap Region

$N \times I_F$ (Ampere Turns)
Volts = E. M. F. = B x L x V

where

\[ B = \text{Flux Density (}\ \frac{\phi}{\text{area}}\text{)} \]
\[ L = \text{Length of the conductor} \]
\[ V = \text{Velocity of the conductor} \]
Generator

\[ V \propto B \times L \times V \]

\[ V \text{ (EMF)} \propto B \propto I_{\text{Field}} \]
**Motor**

**Speed**

\[ V = B \times L \times V \]

\[ V \propto B \times \text{RPM} \]

\[ \text{RPM} \propto \frac{\text{Volts}}{B} \]

\[ \text{Volts} \propto \frac{\text{Volts}}{I_{\text{Field}}} \]

**Torque**

\[ F \propto B \times I_A \times L \]

Torque = Force \times Radius

Torque \propto B \times I_A
Motor

\[ V \propto B \times L \times V \]

\[ V \propto B \times L \times \text{RPM} \]

\[ V \text{ (CEMF)} \propto B \times \text{RPM} \]

\[ \propto I_{\text{Field}} \times \text{RPM} \]
MCF866B, 836 KW, 475 Volt, 1760 Ampere, 1200 RPM
### Load Curve – 836 KW Gen.

<table>
<thead>
<tr>
<th>Armature Volts</th>
<th>Arm. Amps</th>
<th>Field Amps</th>
</tr>
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<tbody>
<tr>
<td>600</td>
<td>0</td>
<td>18.9</td>
</tr>
<tr>
<td>575</td>
<td>1120</td>
<td>18.6</td>
</tr>
<tr>
<td>550</td>
<td>2230</td>
<td>18.6</td>
</tr>
<tr>
<td>450</td>
<td>2500</td>
<td>13.5</td>
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<tr>
<td>350</td>
<td>2770</td>
<td>11.2</td>
</tr>
<tr>
<td>250</td>
<td>3030</td>
<td>9.4</td>
</tr>
<tr>
<td>40</td>
<td>3600</td>
<td>6.2</td>
</tr>
</tbody>
</table>
Adjusting DC Machines - Factory

- Black Band Method

- See the paper “NECP – Tuning DC Motors and Generators – Jun 07” on the WMEA web site wmea.net for other methods of tuning DC machines.
Buck Boost Curve

Buck Amps

Boost Amps

Load Amps (%)

No Load Band
Center on Buck Side (Strong)

Corrective action – shift brush rigging with rotation (motor) or against rotation (generator)
Buck Boost Curve

No Load Band
Center on Boost Side (Weak)

Corrective action – shift brush rigging against rotation (motor) or with rotation (generator)
Buck Boost Curve

Band Center on Boost Side (Weak)

No sparking in black area, sparking outside black area

Corrective Action – Remove nonmagnetic shims, add magnetic shims

Band Center

Load Amps (%)

Buck Amps

Boost Amps
Corrective Action – Remove magnetic shims, add non magnetic shims

Sparking with no buck or boost

Band Center

Band Center on Buck Side (Strong)
Voltage or RPM Regulation Defined

- Increased Voltage or RPM Regulation
- Decreased Voltage or RPM Regulation

Volts or RPM

Armature Amps
Generator – increased main pole air gap

Saturation Curve

Regulation

Before

After

Regulation decreases
Generator – decreased main pole air gap

Saturation Curve

Regulation

Regulation increases

Before

After
Generator – increased comm pole air gap
or add nonmagnetic shims

Saturation Curve

No Effect

Regulation

Regulation increases

Before

After

Volts

Field Amps

Volts

Armature Amps
Generator – decreased comm pole air gap or remove nonmagnetic shims

Saturation Curve

No Effect

Regulation

Before

After

Regulation decreases

Volts

Field Amps

Volts

Armature Amps
Generator – brush shift with rotation

Saturation Curve

Volts vs. Field Amps

No Effect

Regulation

Volts vs. Armature Amps

Before

After

Regulation increases
Generator – brush shift against rotation

Saturation Curve

No Effect

Regulation

Volts

Field Amps

Volts

Armature Amps

Regulation decreases

Before

After

No Effect

Regulation decreases
Motor – increased main pole air gap

Saturation Curve

Volts / RPM

Field Amps

RPM

Armature Amps

Regulation

Before

After

Regulation increases
Motor – decreased main pole air gap

Saturation Curve

Volts / RPM vs. Field Amps

Regulation

RPM vs. Armature Amps

Regulation decreases

Before

After
Motor – increased comm pole air gap or add nonmagnetic shims

Saturation Curve

Volts / RPM

Field Amps

No Effect

RPM

Armature Amps

Regulation

Regulation increases

Before

After

Motor – increased comm pole air gap or add nonmagnetic shims

Saturation Curve

Volts / RPM

Field Amps

No Effect

RPM

Armature Amps

Regulation

Regulation increases

Before

After
Motor – decreased comm pole air gap or remove nonmagnetic shims

Saturation Curve

Volts / RPM

No Effect

RPM

Field Amps

Regulation

Armature Amps

Regulation decreases

Before

After
Motor – Brush shift with rotation

Saturation Curve

Volts / RPM

No Effect

Regulation

RPM

Regulation increases

Before

After

Field Amps

Armature Amps
Motor – Brush shift against rotation

Saturation Curve

Volts / RPM

No Effect

RPM

Regulation

Regulation decreases

Before

After

Field Amps

Armature Amps
Voltage Regulation – Shunt Generator

Low Voltage Regulation

Volts vs. Armature Amps
Voltage Regulation – Shunt Generator

Delta Volts

Low Voltage Regulation

Delta Amps

Armature Amps

Volts
Voltage Regulation – Differential Compound Generator

Volts

Delta Volts

Armature Amps

Delta Amps

Higher Voltage Regulation
Differentially Compound Generators

- Differentially compound generators limit loop current unbalances, as generators that are more heavily loaded (loop unbalance) will drop in voltage and shed some load.

- This helps, of course, but does not “cure” loop unbalance.
Machine Adjustments and Loop Balance Summary

- DC machines must be built to accepted tolerances of air gaps, brush spacing, brush box heights, pole spacing, comm pole bolt material, etc. to be as much alike as possible for the machines to commutate well and share load.

- Connections within the machines must be tight to minimize variation in excitation currents and loop resistance.
Machine Adjustments and Loop Balance Summary cont.

- When machines are disassembled and reassembled, it is important to keep track of shims, especially commutating pole shims. Both the thickness and order of shims are important! There is not an easy way to correct interpole shimming in the field, so care with the machines when working on them in shops is critical.
There are many things that can contribute to commutation issues: rough commutators, symmetry of assembly, brush grades and construction, faulty machine components and electrical connections. Sometimes people try to “fix” machines by tuning them up with neutral adjustments. Remember – this affects machine output and loop balance, and you cannot “adjust out” these underlying causes of commutation distress.
Field Process to Address Loop Unbalances

• Take Time versus: Drive Reference, Armature Volts and Amps, and Motor Field Current
• Make Stud to Stud Spacing Correct
• Set Neutral (on GE Generator 1/8” with Rotation)
• Adjust Generator Air Gaps to Ensure that the Sum of the Volts in Each Loop are Equal within 2.5 Volts per Generator in the Loop (4 Generators in the Loop – 10 Volts)
• Trim Motor Fields “As Necessary”
• Adjust Motor Neutral As “Last Resort” (Should be at Neutral – Not with or Against Rotation)
• If Possible Re-wire the Motion to Two Loops
Oversize Hole
Use ½” Thin Wall Conduit to Center Stud on Yoke
Lot 8 2570W
Hoist Unbalance “As Found”
485 Amps – 12.2%
Lot 8 2570W
Drag Unbalance “As Found”
988 Amps – 24.9%
Lot 8 2570W
Hoist and Drag Unbalances “As Left”
After Adjustments and Making Both Motions into Two Loops
Hoist Unbalance 53 Amps – 1.3% Drag Unbalance 95 Amps – 2.4%
Key 2 8750
Drag Unbalance “As Found”
1800 Amps – 50%
Key 2 8750
Drag Unbalance “As Left”
59 Amps – 1.6%
Key 2 8750
Hoist Unbalance “As Found”
616 Amps -15.6%
Key 2 8750
Hoist Loop Unbalance “As Left”
139 Amps – 3.5%
Related WMEA Papers – available on wmea.net

- National Carbon – Successful Brush Performance – Jun 05
- NECP – Tuning DC Motors and Generators – Jun 07
Reference Materials

- “Loop Unbalance Guidelines” – GE Benchmark, January 1997, Steve Baade

- “Loop Unbalance Guidelines” – GE Benchmark, April 1997, Steve Baade

- GE “DC Machine Adjustments and Operating Characteristics”
Reference Web Sites

- Morgan AM&T – National Electrical Carbon – [www.morganAMT.com](http://www.morganAMT.com)
- GE Motors - [www.GEMotors.com](http://www.GEMotors.com)