DC-EXX

IGBT Exciter-Based MG Set
Excavator Drive
Overview and Field Experience

Presented to

Mining Electrical Maintenance & Safety Association

Annual Meeting
Clearwater Florida  September, 2009

TMGE Automation Systems
Dragline MG Set **DC-EXX**
IGBT System Block Diagram

- Aux AC Supply
- Main AC Supply
- Sync. Motor
- Diode Rectifier
- MG Set
- Gen Exciter
- DC Gen
- Shaft
- To other generators
- Motor Field DC Bus
- Generator Field DC Bus
- Motor Field DC Bus
- DC Motor
- Diode Rectifier
- Motor Exciter

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Shared Bus IGBT Control Design Goals

- Maximize reliability and safety.
- Protect the motor and gen fields from overvoltage insulation damage.
- Protect mechanical equipment.
- Use high response regulators and flexible control to maximize machine productivity.
- Minimize maintenance.
- Use unique advantages of IGBT technology over thyristor system.
Comparison Thyristor vs IGBT

Thyristor Family of Devices

- Easy current-controlled turn-on.
- Difficult, uncontrolled turn off.

Transistor Family of Devices

- Easy voltage-controlled turn-on.
- Easy voltage-controlled turn off.

Thyristor Reversing Exciter
- 3-ph AC in, DC Out

IGBT Reversing Exciter
- DC in, Chopped DC Out
## DC-EXX Comparison with Thyristor Exciter

### Quick Comparison of Structure & Function

<table>
<thead>
<tr>
<th>Thyristor</th>
<th>DC-EXX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Such as DC2000 / Simoreg / AVTRON</td>
<td></td>
</tr>
<tr>
<td>+ Thyristor Based</td>
<td>+ IGBT Based</td>
</tr>
<tr>
<td>+ Individual Motion Transformers</td>
<td>+ Common group transformer(s)</td>
</tr>
<tr>
<td>+ Fully integrated drive individualized by motion</td>
<td>+ Standard drive with PLC individualization</td>
</tr>
<tr>
<td>+ Integrated Isolators for most feedbacks</td>
<td>+ External Isolators for Feedbacks</td>
</tr>
<tr>
<td>+ Low Variation of cards Drive/Drive</td>
<td>+ No Variation of cards Drive/Drive</td>
</tr>
<tr>
<td>+ Low Spares requirement</td>
<td>+ Very Low Spares Requirement</td>
</tr>
<tr>
<td>+ Individual AC feeders &amp; Drive Transformers</td>
<td>+ Maximum two Common Transformers</td>
</tr>
<tr>
<td>+ Function blocks within drive</td>
<td>+ Standard drive pattern &amp; PLC master</td>
</tr>
<tr>
<td>+ Windows Control System Toolbox</td>
<td>+ Windows Toolbox</td>
</tr>
</tbody>
</table>
Technical Overview
Simplified DC-EXX One-Line
Overall Typical System One-line [Dragline]

- PLC SUPERVISORY SYSTEM
- ONBOARD SYSTEMS, SENSORS, MCC, MG SET CONTROLS
- Common Gen Exciter DC Bus
- Common Motor Exciter DC Bus

Diagram details include:
- Drive Interface Tool HMI
- Drive Level RZSI Automation Controller
- OEM Maintenance & Monitoring MMI
- MOIST
- SWING
- DRAG-PROPEL GEN EXCITERS
- DRAG & PROPEL MOTOR EXCITERS

Diagram notes:
- “** L only required if needed to provide 3Hz on converter, basic rating.
- One or two parallel units to achieve rating.
- CAN BUS
- ECE-EXX Systems Controls
- Drive Level Exciter DC Bus
- Motor Field DC Supply
- Field Coil DC-EXX
- DC Bus To SYMC Motor supply
- DC-EXX MG Dragline Control System - 2-Bus Dual Drag Dual Propel
- TM GE Automation Systems
- Salem, Virginia 24159
- ECE-EXX SPEC-RL-RIoved
- ECE-EXX SPEC-RL-RIoved
- ECE-EXX SPEC-RL-RIoved
- ECE-EXX SPEC-RL-RIoved
- ECE-EXX SPEC-RL-RIoved
- Rev C 6/1/2008
- Revision 917/2008
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- Slide 8

Driving Industry
Sync and Soft Start Excitation

**Sync and Soft Start Excitation**

**GEN EXX**
- **DC-EXX Control**
- Isolating disconnected
- **4to8 DC Gen Fields**

**Drag Loop Gen Field**
- 100 mV shunt
- **TYPICAL GEN ARMATURE LOOP IN DRAG BROWN AND USED AS STARTING MOTOR**

**M**
- **185 amp max** each circuit RMS Peaks at 1.6 PU max, < 5 sec each 60 sec

**G**
- **185 amp max** each circuit RMS Peaks at 1.6 PU max, < 5 sec each 60 sec

**PROFIBUS**
- **SELECTOR CONTACTORS**
- **600 VDC Mot fld bus**

** ServletException**
- **SET 1**
- **SET 2**
- **SET 3**
- **SET 4**

**PLC Wath VAR or PowerDrive Field Current Regulator**

**IGBT Sync Motor Excitation System (2 motors shown)**

**Soft-Start Option**
- **600 amp**
- **PROFIBUS**
- **600 VDC Mot fld bus**

**Sync Mot DC-EXX**
- **Thyristor Typical**

**Sync Mot DC-EXX**
- **Thyristor Typical**
Gen Field Supply DC Shared Bus Chopper vs SCR

### Generator Data [from published designs]

<table>
<thead>
<tr>
<th>Motion</th>
<th>Qty</th>
<th>kV</th>
<th>Data Sheet RA</th>
<th>i rms Ea</th>
<th>Individual Exciter RMS</th>
<th>Field Watts per Gen</th>
<th>Bus DC watts</th>
<th>Bus DC watts x qty gens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoist</td>
<td>8</td>
<td>1254</td>
<td>926224 RA 2</td>
<td>18.8</td>
<td>148.8</td>
<td>2245.0</td>
<td>17960</td>
<td></td>
</tr>
<tr>
<td>Drag in Drag Mode</td>
<td>8</td>
<td>1254</td>
<td>926224 RA 2</td>
<td>18.8</td>
<td>148.8</td>
<td>2245.0</td>
<td>17960</td>
<td></td>
</tr>
<tr>
<td>Drag in Propel</td>
<td>2</td>
<td>1254</td>
<td>926224 RA 2</td>
<td>18.6</td>
<td>37.2</td>
<td>2245.0</td>
<td></td>
<td>Included in Drag</td>
</tr>
<tr>
<td>Swing</td>
<td>8</td>
<td>836</td>
<td>925823 RA 6</td>
<td>16.8</td>
<td>134.4</td>
<td>3963</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Generator Watts</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>65224</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Calc kVA** | **Practical Selection**
--- | ---
92.5 | 100
92.5 | 100
23.1 | 25
83.6 | 100

**Total kVA 4 transf.** **325**

**Conservative Practical Converter Transformer KVA Size** **90**

**Nominal Primary Supply Volts** **435**

**Practical Converter transformer Feeder AC line Amps** **119.5**

**Bottom Line:**
One GF AC MCC Feed vs 4
One Transformer vs 4
**DC Chopper “Kilowatt Source” Concept**

1. Power In = total power of load / efficiency
2. DC amps = bus kw / bus volts
3. DC Amps NOT = total of DC load amps
4. Transformer load = kw at 0.95 PF, 0.98 efficiency

**Generator Data**

<table>
<thead>
<tr>
<th>Motion</th>
<th>Qty</th>
<th>kW</th>
<th>Data Sheet 36H</th>
<th>$I_{RMS, Ea}$</th>
<th>Individual Exciter RMS</th>
<th>Field Watts per Gen</th>
<th>Bus DC watts x qty gens</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hoist</td>
<td>6</td>
<td>1254</td>
<td>926224RA-SH2</td>
<td>18.9</td>
<td>113.4</td>
<td>2244.7</td>
<td>13467.9</td>
</tr>
<tr>
<td>Drag 1</td>
<td>3</td>
<td>1254</td>
<td>926224RA-SH2</td>
<td>18.9</td>
<td>56.7</td>
<td>2244.7</td>
<td>6734.0</td>
</tr>
<tr>
<td>Drag 2</td>
<td>3</td>
<td>1254</td>
<td>926224RA-SH2</td>
<td>18.9</td>
<td>56.7</td>
<td>2244.7</td>
<td>6734.0</td>
</tr>
<tr>
<td>Swing</td>
<td>6</td>
<td>836</td>
<td>925638RA-SH6</td>
<td>16.8</td>
<td>100.8</td>
<td>3663</td>
<td>21978.0</td>
</tr>
</tbody>
</table>

"SUM" = 327.6 total bus watts = 48913.8

Min DC Bus Volts = 550 exciter effic = 95% total converter load kW 51488
Motor Field Supply
DC Shared Bus
Chopper vs SCR

Large Dragline Example Sync Motors AND Motion Motor Exciters on Same Bus

**Bottom Line:**
- One AC MCC Feed vs 2
- One Transformer vs 2, total kva 400 vs 1100 kva
Crowbar Connected Gen Field DB Resistor

- No contactors = No Maintenance
- Crowbar trip set at level high enough to avoid false trips.
- Takes full advantage of new exciter capabilities – controlled DB first, crowbar is emergency backup
Three Stop Modes

1. Master switch to Neutral – normal stop
2. Motion LE stop – IGBT exciters and controller operate to bring motions to stop under full control, then LE opens
3. “Emergency” – lost power, lost fuse, or ESTOP – LE opens, Static Crowbar
   ✓ connects DBR to gen fields for fast decay
   ✓ shorts motor fields for slow decay.
Controlled Braking During LE Stop

UNCONTROLLED DBR - LE STOP

DC-EXX USES STORED FIELD ENERGY TO MAINTAIN EXCITATION WITH AC POWER REMOVED
Exciter System Drive Controller Role

- Drive Controller & Software is included in system for mode selections, tapered current limits, loop unbalance, etc.
- Excavator supervisory PLC [OEM or supplied as part of upgrade]
  - Sends references, start-stop and hard contact control signals to drives
  - Receives feedbacks over Profibus
  - Has access to global data buffer for offboard monitoring or onboard reporting
Drive Controller Functionality - General

- High speed regulation functions in drive exciter
- Outer loop and excavator functionality in HS Drive Controller like…
  - Speed and torque limits
  - Loaded bucket control
  - Swing gearing quadrant transition
- Basic Settings done with simple windows tool
- Drive Controller communicates with DL supervisory PLC over HS Profibus
### Drive Controller Example Functionality - Showing Drive Controller & Supervisory PLC Split

#### Summary - Generator and Motor Field Supplies

<table>
<thead>
<tr>
<th>New Item Ref</th>
<th>Drive Functions for Dragline &amp; Shovel Application</th>
<th>OEM or Machine Level PLC</th>
<th>Excitors</th>
<th>External Cards or Modules</th>
<th>Drive-Level PLC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>F3</td>
<td>Armature Current Regulator 100 Rad</td>
<td>P</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td></td>
<td>Mostly set as follows: 60-100 (min 60) for hoist/drag, 30 (min) for propel, approx 6 for swing.</td>
</tr>
<tr>
<td>F4</td>
<td>Voltage / Speed Regulator 3 Rad</td>
<td>P</td>
<td>IGBT Motor Field Exc</td>
<td></td>
<td></td>
<td>Speed reg about 3 for speed reg, 10 for volt reg.</td>
</tr>
<tr>
<td>F5</td>
<td>2 ea. Motor Field current regulator 36 Rad</td>
<td>P</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td></td>
<td>Can be much slower 5-10% with volt regulator.</td>
</tr>
<tr>
<td>F6</td>
<td>CEMF regulator 10 Rad must have lead (adjustable lead would be nice) to keep voltage over shoot down</td>
<td>P</td>
<td>IGBT Motor Field Exc</td>
<td></td>
<td></td>
<td>In GF2000 the lead is provided in blockware. CEMF regulator works on VFB not CEMF for excavator motors. Our published limits are based on motor terminal voltage not theoretical CEMF on the armature. There could be about 20° difference of current point current.</td>
</tr>
<tr>
<td>F8</td>
<td>Taper current limit different for each of the 4 quadrants four motor groups</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>Basic outer [max] tapered or straight current limit in drive - special override limits done in PLC and sent via Profibus.</td>
</tr>
<tr>
<td>F9</td>
<td>Lower Loaded bucket detection &amp; protection</td>
<td>P</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td></td>
<td>Simple loaded bucket is the easiest for operators to tolerate when there is a need for loaded bucket lowering EPU (drift dust suppression etc.) Exclusively PLC function to measure load when entering Q3 or Q4 and limit reference if load high.</td>
</tr>
<tr>
<td>F10</td>
<td>Rope tension (involves modifying current limit dynamically)</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>If current limit and reference are PLC functions this can be handled by the PLC.</td>
</tr>
<tr>
<td>F11</td>
<td>4th Quadrant Plugging</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>Reference and field strength control in PLC.</td>
</tr>
<tr>
<td>F12</td>
<td>Reference ramp rate can be set different based on quadrant</td>
<td>OPT</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>PLC based ramps.</td>
</tr>
<tr>
<td>F13</td>
<td>Swing Torque regulator with speed or voltage limit take over</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>Basic current [torque] regulator is in drive. Special over-rate limits in PLC to drive by Profibus. Voltage limit needs to have drop with amps. Limits need to be proportional.</td>
</tr>
<tr>
<td>F14</td>
<td>Reduced propel (walk shoe) current limit till cloth shoes on ground</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>PLC based limits allow this.</td>
</tr>
<tr>
<td>F15</td>
<td>Field loss for individual paralleled motor fields (Possible up to 8)</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>Use field regulator to hold total current, then measure one field to see if it is proper % of total. This will be a PLC function.</td>
</tr>
<tr>
<td>F16</td>
<td>Quadrant detection</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>If VFB and CFB are available in the PLC (likely), then this can be done in the PLC.</td>
</tr>
<tr>
<td>F17</td>
<td>Motor Field exciter reference output from gen field to motor field exc based on CEMF</td>
<td>X</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>CAN bus from GPDX to MPDX for MPFX levels and control. Profibus will also be connected to MPFX for monitoring.</td>
</tr>
<tr>
<td>F18</td>
<td>Ground fault detection for field circuits accommodate up to 8 paralleled fields</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>Use center-grounded resistor bridge and feed TMEIC CFP detector module, pass signals to PLC Analog I/O.</td>
</tr>
<tr>
<td>F19</td>
<td>Ground fault detection for armature circuits Accommodate up to 4 loops</td>
<td>S</td>
<td>IGBT Gen Field Exc</td>
<td></td>
<td>P</td>
<td>Already an external function with Heimann CFPs. Auxiliary can be wired to drive or PLC Analog I/O.</td>
</tr>
</tbody>
</table>
Exciter Configuration WinNew Tool

- Digitally Configurable
- Windows-based simplified PC tool
- Few basic parameters
- Outer current and upper voltage limits
- Protective limits for fields
- All other dynamic performance set by Drive Controller
WinNew Exciter Performance Testing

- Instantly shows effects of settings on operation
- Digitally configurable on PC tool for display on PC screen
- Any parameters can be displayed, scaled.
- Simple controls
Controller HMI Maintenance / Setup Screens

Range from Simple to Elaborate
Circuit & Component Details
**DC Converters**

- Three-phase, up to 600 VAC in
- Up to 600 volts DC out
- 350 or 750 amp frames for all excavator applications
- “Soft-on” for charging DC bus capacitors
- Ruggedized for excavator use.
- Built in Absorption chopper feeds remote resistors for field protection during power loss.
Installed AD / DC Converter & Control Power Supply

1. AC / DC Converter

2. 435 volt input, 600 vdc output to common bus

3. Two ratings, 350 or 750 amp.

4. 24 volt DC Power supply, 120 – 240 vac input tolerance for stability
Chopper Exciters

• Three Basic Frames: 150, 300 & 600 amps
• 300 or 600 volt DC bus feed
• Included dv/dt filter produces insulation-friendly output for motor and generator fields.
• Basic Current limits, gains, lead-lags, high speed protections, & parameter scalings all included within exciter.
• Capacitors are film-foil type, not electrolytic type.
  ✓ Not sensitive to temperature extremes
  ✓ No “wearout” or timed replacement or failures
DC-EXX Chopper
Front View & Display
DC-EXX Power Connections

- DC Bus Input: [+] and [-]
- Exciter Output: [U] and [V]
**Modules & Footprints**

- **150 A Exciter**
  - 6 W x 20 H x 12 D
  - 150 A

- **300 A Exciter**
  - 9 W x 20 H x 12 D
  - 300 A

- **600 A Converter**
  - 22 W x 43 H x 16 D
  - 600 A

- **350 A Exciter**
  - 9 W x 21 H x 9 D
  - 350 A

- **750 A Converter**
  - 12 W x 28 H x 10 D
  - 750 A

- **Crowbar**
  - 9 H x 6 W x 6 D
Output dv/dt Filter

Simple dv/dt filter limits peak voltage output to motor and generator fields to equal or less than thyristor legacy systems.

Traditional Thyristor Exciter
460 volts 3 ph AC In

IGBT Exciter
460 volts 3 ph AC In
No dv/dt filter

IGBT Exciter
460 volts 3 ph AC In
With dv/dt filter

Without dv/dt filter
Up to 200% over DC Bus

With dv/dt filter –
Limited to 130% over DC Bus
$= 1.3 \times 600 = 780$ V
Voltage & Current Isolators

1. 24 – 230 volts ac / dc powered

2. Fixed gain settings:
   - +/- 50, 100, 150 mv = +/- 10 VDC out
   - +/- 600, 750, 1200 v = +/- 10 VDC out
Dual Trigger Mode Crowbar Modules

- Discharges energy safely from generator or motor fields
- Bi-directional – for use with motor or generator exciters
- Fires either on cell voltage [>1000 v] or by drop out of fail-safe relay.
Current and Voltage Isolators

- 24 – 260 volts AC / DC powered
- 1200 volts input for loop voltage feedback
- 100 Millivolt for shunt feedback.
- DIN rail mounted
- Rugged – used in rail service
- Worldwide distribution
Rx3i Automation Controller

1. High speed [<1 millisecond scan]
2. All outer loop and excavator functions
3. Powered by stabilized 120 VAC
4. Minimal discrete I/O
5. Profibus DP communication with drives & excavator supervisory PLC
Controller I/O to Drive Interface

1. Run-Stop
2. Analog I/O
Touch Screen Setup HMI

1. Touch screen setup HMI

2. Individual motion monitor and control for test flexibility

3. Allows training as well as operational testing
Setup HMI Top Level

1. Top level monitor screen

2. Each “Button” shaped readout brings more detail as it is touched

3. Alarm and logic status
Setup HMI Special Control Modes

1. Test Modes included as needed

2. Serves as mode input to controller.
Setup HMI Special Simplified Monitor

1. Real time values displayed
2. Touching the icon allows setting of parameter.
Setup HMI Monitor and Setup

Profibus Signal Monitor

Setting Touch Screen

Setting Error Protection
Setup HMI Alarm Screen

1. Time stamped
2. First fault, first listed.
Field Installations
First Systems

1. BMA DRE-08 8050 with W Electrics Blackwater Mine
   - Mechanical refurbishment
   - New PCR, Complete Rewire
   - 45 days total lights out to boom up in June 08
2. BMA 1370W – Saraji DRE-08
3. Blair Athol 1370W, with soft start
4. Ensham 8050 Emerald Mine – dragline underwater!
5. Rix Creek 305M Crawler Dragline
6. BMA Saraji 8050 DRE-13
7. Ten new 182M shovels, 1 new 8750 DL systems plus 3 more upgrades in process
Equipment as Configured for Dragline Installation
Motor & Gen AC / DC Converter

- 435 VAC 3 Phase in 600 VDC out
- 350 amp 6-pulse diode
- 3 thyristor legs for soft on, overcurrent protection.
- Includes energy absorbing chopper
- Feeds two overhead buses at cabinet top
Motor & Gen Exciter Cabinets

- 600 VDC in
- Pulse-width DC Volts out
- Identical 150 amp rated exciters, all motions
- All commands and feedbacks by Profibus
- Includes input reactors and output filter
- Static Crowbar means no contactors except drag-propel field selection

Motor & Gen Exciter Cabinets

- 600 VDC in
- Pulse-width DC Volts out
- Identical 150 amp rated exciters, all motions
- All commands and feedbacks by Profibus
- Includes input reactors and output filter
- Static Crowbar means no contactors except drag-propel field selection
Sync Motor Cabinet

- 300 Amp Exciter [with same control as 150 amp]
- Fed from 600 volt DC source for high forcing
- Traditional three-pole application contactor
- Fed from DC bus above cabinet
Overhead DC Bus

- 600 VDC, two busses
- Independent feed for motor and gen exciters
- Feed for each exciter is dropped by cable into enclosure
- Excess energy absorbed by converter braking chopper.

Safety Provisions:
- Disconnects
- Discharge contactor
- Voltage presence lights
- Voltage held to 725 volts even when AC feed is lost
Later Panel Lineup – New PCR

- Covered DC Bus
- Complete Swing Motion
- Sync Motor Exciter
- Sync Motor Contactor
- Dragline Drop-In Power Control Room
Swing Cabinet Details

- Connections to DC Bus
- Isolation Switch
- Static Crowbar & DB Switch
- dv/dt Filter Reactor
- DC Decoupling Reactors
Sync Cabinet Details

- DC Decoupling Reactors
- Isolation Switches
- dv/dt Filter Reactors
- 300 Amp Exciters
- Field Application Contactors
DB, Sync Discharge and Absorption Resistors

- Gen field decay "dynamic brake"
- DC bus absorption, sized by duty cycle.
MG Set Shovel Control

- Ten Bucyrus 182M 10 Meter\(^3\) bucket
- Indian Market
- Cab-Mounted PLC Control
- 4 Motions, dipper trip and converter in 72 inch W x 20 inch deep enclosure!
Testing & Startup Experience
Full Onboard Installation Testing Goals

• Demonstrate equipment safety and protection of dragline & rotating gear.
• Demonstrate effectiveness of shared bus supply
• Demonstrate system regulator and exciter responses.
• Demonstrate high speed controller and communication effectiveness
  ✓ in coordinating motions
  ✓ In sync motor excitation
  ✓ In dragline digging and propel operational modes
Equipment Protection: Field Surge Voltage

DESIGN GOAL:
Limit Peak Volts on field insulation to equal or less than 780 volts, the typical peaks for a thyristor exciter.

EXAMPLE TEST RESULTS:
With Bus at 548 VDC, peak volts 688.
Shared Bus Supply Test Results

- Gen bus has surplus energy only 10-20% or so of time.
- Motor field and sync motor bus has even lower surplus power percent.
- High-speed static DB-Contactor / Crowbars are vital to this type system.
- **Conclusion**: diode converter with absorber chopper- resistor is effective.
Motion Regulator Setup & Responses

Example Current Regulator Testing

<table>
<thead>
<tr>
<th>Required Responses</th>
<th>Actual Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRAG 40 - 80 radians</td>
<td>74 radians</td>
</tr>
<tr>
<td>HOIST 40 - 80 radians</td>
<td>47 radians</td>
</tr>
</tbody>
</table>

Example Motion Stall Testing

Drag shown

Drive Controller in Boom Raise Mode

Loop 1 & 2 Amps
Loop 1 Gen Volts
Loop 2 Gen Volts
X-Y Recordings

**DRAG**
- Drag max speed 850 RPM
- Payout max speed 1105 RPM

**PROPEL**
- Normal Walk Mode
X-Y Recordings

**HOIST**
- Hoist speed 883 rpm
- Lower speed 1087 rpm
- Loop #2 outside Limits

**SWING**
- RMS & Temps Indicated Overload
- Ref Reduction Software relieved load on Motors
Experience & Lessons Learned - 1

• Minimal equipment failures related to individual hardware modules.

• Second installation:
  ✓ Found need for crowbars on sync motors
  ✓ Found need for self powered energy absorption chopper for larger systems [3 or 4 MG sets].
Lessons Learned - 2
Other Things Learned

• Aux transformers run much cooler
• Per motion controlled stop easier on gearing, etc
• Very few and common spares and fuses a “Plus”
• Moving all but 4 to 6 parameters into PLC makes exciters simple
Present Status

• Eighteen complete systems sold and in various stages of manufacture & installation.
  + 7 upgrades
  + 11 new excavators
• 6 draglines operational as of September 2009.
• One new system with IGBT armature supply soft starting.
Summary – **DC-EXX**

Excavator MG Control System

- Early results are encouraging.
- IGBT technology gives real advantages for MG control.
- Drive controller adds flexibility.
Thanks!

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