AC Dragline Electrics Update

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Introduction - Barriers to AC

- Draglines with M-G set drives have been in operation for nearly one century

- Evolutionary upgrades with analog and digital controls

- Reliable operation but limited with respect to
  - efficiency,
  - productivity,
  - maintenance and
  - operating costs

- Strict utilities requirements on allowable voltage fluctuation, power factor at the PCC and levels of harmonic injection
  - This can be overcome with Active Front Ends (AFEs) in place of normal rectifiers. This makes static AC drives a superior alternative to M-G set drives.
Bucyrus - History of Innovation

A Tradition of Proven Performance

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AC Gearless Dragline

Introduction - Configuration

- Replace multiple Hoist / Drag gears and DC motors with single, synchronous gearless motor connected directly to the drum
- All M-G sets and gears for Hoist and Drag are eliminated
- Use geared static AC drives for Swing and Propel
- All M-G sets for the Swing are eliminated
## AC Gearless Dragline

### Benefits

## 8750 AC Gearless and DC Machine Comparison

<table>
<thead>
<tr>
<th>Description</th>
<th>8750 DC Machine</th>
<th>Zhungeer 8750 AC Gearless Machine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boom Length</td>
<td>360 ft</td>
<td>360 ft</td>
</tr>
<tr>
<td>Boom Angle</td>
<td>39 deg</td>
<td>34 deg</td>
</tr>
<tr>
<td>Hoist Drum Diameter</td>
<td>125 in</td>
<td>128 in</td>
</tr>
<tr>
<td>Drag Drum Diameter</td>
<td>125 in</td>
<td>128 in</td>
</tr>
<tr>
<td>Bucket Size</td>
<td>143 cu yd</td>
<td>118 cu yd</td>
</tr>
<tr>
<td>Average Production Rate</td>
<td>3,845</td>
<td>4,380</td>
</tr>
</tbody>
</table>
AC Gearless Dragline

Benefits

Increased Productivity
Typically 20% more with gearless hoist and drag

- Reduced Bucket Filling Times
- Higher Hoisting Speeds
- Matched Lowering / Payout Speeds

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### AC Gearless Dragline

#### Benefits

<table>
<thead>
<tr>
<th>Existing Geared DC Drives</th>
<th>AC Gearless Drive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Transformer 0.98</td>
<td>Input Transformer 0.98</td>
</tr>
<tr>
<td>MG Set Motor 0.93</td>
<td>AFE / Inverter 0.98</td>
</tr>
<tr>
<td>DC Generator 0.92</td>
<td>AC Integral Motor 0.93</td>
</tr>
<tr>
<td>DC Motor 0.92</td>
<td></td>
</tr>
<tr>
<td>Existing Gearing 0.96</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL Efficiency 0.74</strong></td>
<td><strong>TOTAL Efficiency 0.89</strong></td>
</tr>
</tbody>
</table>

20 % Higher Efficiency for AC Gearless, 20 % Lower Energy Cost
AC Gearless Dragline

Benefits

Reduced Maintenance and Operating Costs (up to $1m/a)
More Uptime
More Productivity

- Elimination of Hoist / Drag Gearing & Lubrication
- Elimination of Hoist / Drag DC Motors & Generators
  - No Commutators / Brushes
  - Less Maintenance
- Reliable Digital Electronics
AC Gearless Dragline

Benefits – Production Performance

- The dragline was commissioned and walked into mine and commenced production in November of 2007.
- Production test was completed in March 2008.
  - The overall availability has been 94%.
  - The electrical downtime has been 24% of the total 6%.
  - Accepted by Zhungeer Energy on November 12, 2008.
- Record achieved in August 2009:
  - Weekly BCM’s: 530,175.
  - Monthly BCM’s total: 2,137,273
  - Shift production record: 43,938 BCM’s
  - Monthly working hours: 516.35
- Hot off the Press
  - Daily Production record 80,315 BCM’s Sept 1st
  - Daily Production record 92,702 BCM’s Sept 2nd

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Replace multiple Hoist / Drag DC motors with AC induction motors.

Replace multiple Swing / Propel DC motors with AC induction motors

All M-G sets are eliminated
AC Conventional Dragline

Benefits – Inverter Cabinets
AC Conventional Dragline

Benefits – Customer Question # 1 - PF

- Q1: A key performance requirement of each of these configurations is that the machine must be able to obtain 0.80 leading power factor at the high voltage slip rings on the machine at the machines nominated peak power level. It is important to verify that the AC drive will be capable of sustaining a minimum VAR capability to achieve 0.80 leading power factor at the 22 kV incomer terminals of the machine on a consistent repeatable basis for the duration of the machine life with a modulation index of less than 1.00.

- A: Modulation Index is defined as: \[
\frac{\sqrt{6}}{\pi} \times V_{DC} = m \times V_{AFE}
\]
- The drive systems can provide up to 0.8 leading pf at peak load at slip rings
- Auxiliary load is typically 3.0 MVA with 0.8 lag pf
- The peak load of the drives is 24.5 MW
- 7/7/8 uses 30 AFEs with a modulation index of 0.89 to achieve 0.8 leading power factor.
AC Conventional Dragline

Benefits – Customer Question # 1 – Single Line

7 Hoist, 7 Drag, 8 Swing, 4 Propel, 30 AFEs, 3.0MVA@0.8pf aux.
Drive Power Transformer (DPT)

- Q2.1: Explain choice of impedance
- Q2.2: How is impedance level achieved
- Q2.3: Is there a danger of saturation
**Impedance Choice**

- The impedance must be high enough for the AFE requirements
- The impedance must be high enough to limit the current rise in case of a short circuit and give the switchgear enough time to open
- The impedance must be low enough to allow sufficient regenerative VAr flow back to the line

**Impedance Level**

- A gap greater than 50mm is inserted between the primary and secondary windings and this results in a loosely coupled system
- Not all the flux from the secondary winding links the primary windings.
- Most of the secondary flux closes through the gap between the primary and secondary. Hence the high impedance is concentrated on the secondary.
- This secondary leakage flux is proportional to the impedance of the transformer and creates an inductive voltage drop under load.
The secondary is wound first, a suitable gap is inserted and then the primary is wound on top.

Secondary Winding. CTC wire in special geometric arrangement

Gap > 50mm

Primary Winding

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Motor Load and System Control

- Q3.1: Was Load testing of BI 348 Motor completed

- Q3.2: Was SiBAS 32S System operational testing completed
AC Conventional Dragline

Benefits – Customer Question # 3 - Control

BI348 Motor Stall Torque Proving Test in Norwood, April 2008

- Stall Test
  - Torque verified by a direct measurement with an overhead crane scale
  - Direct measurement resulted in a torque value within 4.3% accuracy

- Indirect Torque Measurement
  - Tests at varying speeds were performed
  - Torque verified by an indirect measurement using power and speed.
  - Results show that torque produced has a -1.47% error compared to the torque reference
SiBAS32S Control Test in Germany, June 2008

- Two identical motors mounted back to back.
- Seven tests were performed
  - Speed reference step response
  - Torque reference step response
  - Plugging response
  - Full speed reversals response
  - AFE power factor control
  - AFE VAR compensation control
  - AFE staggering
  - Optimal Flux tracking
  - Confirmation of load sharing
AC Conventional Dragline
Benefits – Customer Question # 3 - Control

- Confirmation of Load sharing between the coupled drives
Motor RTD recordings including speeds, currents and torques

- Q4.1: Recordings of the RTD temperatures of the “real world” motors for a heavy digging and high hoisting duty cycle, along with motor speeds, currents, and torques for all motions.

- Q4.2: All motion RTDs, (Hoist has the highest duty)

- Q4.3: RTD comparison of all Hoist motors, 2 days

- Q4.4: Drive monitoring recordings of all motions
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Benefits – Customer Question # 4 – RTD’s

- RTD data Swing stator

![Actual Swing Recordings](image)

January 30-31, 2009

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Benefits – Customer Question # 4 – RTD’s

- RTD data Drag stator – zoomed in

Actual Drag Recordings
January 30-31, 2009

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Benefits – Customer Question # 4 – RTD’s

- RTD data Hoist stator – zoomed in
AC Conventional Dragline

Benefits – Customer Question # 4 – RTD’s

- RTD data Hoist stator – 2 day observation
AC Conventional Dragline

Benefits – Customer Question # 4 – Control

- Hoist Motion
Power Quality Recordings (Input VARS, Watts and Voltage)

- Q5.1: Recordings of total input VArS, Watts and voltage from a real world machine when operating on a heavy hoisting and swinging duty cycle, and whether they would be prepared to set the peak VArS to demonstrate the leading power factor capabilities of the machine.

- Q5.2: Motion and Total Machine Power

- Q5.3: Watt / VAR / Power Factor

- Q5.4: Harmonic Measurements
AC Conventional Dragline

Benefits – Customer Question # 5 – Power

- All Motion and total machine power data – zoomed in
Power Factor at Machine Terminals

During commissioning, the power quality of the auxiliary load is measured. The values recorded for the machine in the previous recordings are

- 1.00 MW
- 0.67 MVAR (lagging)
- 1.19 MVA

Therefore, the drive must always provide 0.67 MVAR to compensate for the auxiliary load.

This is programmed as an offset to the VAR / Watt curve.

The VAR/Watt curve is shown on the following slide.
AC Conventional Dragline

Benefits – Customer Question # 5 – Power

- VAR / Watt Curve – reference and actual
**AC Conventional Dragline**

**Benefits – Customer Question # 5 – Power**

- **Drive Power Factor (motoring)**

![Graph showing power factor and related data](image)

<table>
<thead>
<tr>
<th>Signal/Name</th>
<th>X1</th>
<th>X2</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
<th>Std dev</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motion Power</td>
<td>00 01 00 00</td>
<td>00 10 31 31</td>
<td>2.760</td>
<td>10.816</td>
<td>0.3159</td>
<td>2.05E6</td>
<td>MW</td>
</tr>
<tr>
<td>Drive Active Power</td>
<td>00 01 00 00</td>
<td>00 10 31 31</td>
<td>4.132</td>
<td>11.564</td>
<td>0.8045</td>
<td>2.02E1</td>
<td>MW</td>
</tr>
<tr>
<td>Drive Reactive Power</td>
<td>00 01 00 00</td>
<td>00 10 31 31</td>
<td>-0.853</td>
<td>-1.553</td>
<td>-1.461E0</td>
<td>0.6487</td>
<td>MW/Var</td>
</tr>
<tr>
<td>Drive Apparent Power</td>
<td>00 01 00 00</td>
<td>00 10 31 31</td>
<td>5.011</td>
<td>12.341</td>
<td>0.7288</td>
<td>2.08E0</td>
<td>MW</td>
</tr>
<tr>
<td>AFE 1 Phase R Current rms</td>
<td>00 01 00 00</td>
<td>00 10 31 31</td>
<td>878.48</td>
<td>879.78</td>
<td>879.38</td>
<td>3.07E4</td>
<td>A</td>
</tr>
<tr>
<td>Power Factor</td>
<td>00 01 00 00</td>
<td>00 10 31 31</td>
<td>0.9307</td>
<td>0.9766</td>
<td>0.9301</td>
<td>0.02E0</td>
<td>-</td>
</tr>
</tbody>
</table>

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Benefits – Customer Question # 5 – Power

- Drive Power Factor (regenerating)
Power Factor at Machine Terminals

In the previous recordings, the following power factors were recorded from the drive.

- 0.932 leading in motoring
- 0.973 leading in regeneration

The machine power factor is then calculated by including the lagging VARs from the auxiliary power to result in

- 0.956 leading in motoring (0.96 leading reference)
- 0.998 leading in regeneration (1.0 unity reference)

This is confirmed by the next slide, where the power quality was measured at the dragline terminals
AC Conventional Dragline

Benefits – Customer Question # 5 – Power

- Power Factor at Machine Terminals
AC Conventional Dragline

Benefits – Customer Question # 5 – Power

- Harmonic current measurement – Machine terminals

- Phase A current at the sliprings
- RMS Value: 570.1 A
- Machine Power: 21.72 MVA
- THD: 1.35 % (computed up to 63rd harmonic)
AC Conventional Dragline
Benefits – Customer Question # 5 – Power

- Harmonic current measurement – AFE terminals
  - Phase A current for AFE1 at the AFE terminals
  - RMS Value: 454.4 A
  - THD: 8.45 % (computed up to 63rd harmonic)
Introduction

AC Helper Drive Dragline Configuration

- Add multiple Hoist / Drag or Swing AC induction motors to compliment existing DC motors
- Add AC Skid to supply AC Helper motors (Deck Extension)
- Set AFE at Unity PF – doesn’t overload synchronous motor capability
AC Helper Drives

Benefits – No MG Set Modifications
AC Helper Drives

Benefits – Planetary to Drag Drum

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AC Helper Drives

Benefits – Easy Maintenance
AC Helper Drives

Benefits – Plug into Conventional Gearcase
AC Helper Drives

Benefits – Productivity Goals Achieved

- Integration of new DC Digital Drives with the AC Helper Drive was the key to the success for the productivity gains being sought
Summary

- The technology for an all static AC dragline is here **NOW**
  - More Productivity ; Higher Efficiency
  - Less Maintenance

- Gearless Dragline in operation since November 2007

- AC Conventional Dragline in operation since November 2008
  (another under construction – commissioning Dec 2009)

- AC Helper Drives (hoist & drag) in operation since April 2009

- Video
- **Slide Show**