Power Demand and Energy Usage of Container Crane – Comparison between AC and DC Drives

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***Abstract*-The electrical data of two quay cranes, one has a DC drive system and the other has an AC drive system, in actual working conditions at a container terminal are measured and presented in this paper. Peak demand, energy usage, power factor and power quality are examined and compared.**

I. INTRODUCTION

Since the introduction of IGBT based AC drive products in the late 1980s, there has been much debate on which technology – AC or DC drive – should be used by the crane industry for new container cranes. The AC technology appears to win the debate as today almost all container cranes are AC.

However, the electrical power demand and energy usage of container cranes have not been mentioned in any debate. With the new "bigger and faster" container cranes being built, the high electrical cost of running these container cranes must now be closely analyzed. This paper will contribute to the AC versus DC debate with information on the power demand and usage of the quay cranes.

The test was carried out at a container terminal in Australia. Two very similar quay cranes have been selected to produce a meaningful result. Schneider circuit monitor CM3250 is used at the high voltage supply end of each quay crane to capture the electrical data, these CM3250 have on board memory to log data every second.

The electrical data of the quay cranes in actual working conditions, that is actual loading/unloading containers to ship, are recorded. The data is then examined, compared and conclusion can be drawn for the comparison of AC vs DC based on power demand and energy usage.

II. AC AND DC QUAY CRANES UNDER TEST

As there are no exactly match pair of quay cranes at the container terminal, two very similar quay cranes (physical size, mechanical arrangement, year of manufactured,…) have to be selected to produce comparable results.

Almost only Hoist and Cross Travel motions are used in loading/unloading containers to/from container ship. These motions produce the peak demand and around 99% of the energy usage. Therefore, this study concentrates mainly on these two motions. The main electrical data of these quay cranes is listed in Table 1.

TABLE I
MAIN DATA OF QUAY CRANES UNDER TEST

Quay crane with	AC Drive	DC Drive
Safe Working Load	60T	50T
Main Transformer	2.2 MVA	1.25 MVA
Hoist motor	2 x 373kW	2 x 300kW
Hoist Speed - No Load	150 m/min	150 m/min
Hoist Speed - Full Load	75 m/min	75 m/min
Acceleration time	4.16 seconds	4.20 seconds
Cross travel Motor	2 x 100 kW	1 x 150 kW
Cross Travel Speed - No Load	210 m/min	180 m/min
Cross Travel Speed - Full Load	210 m/min	180 m/min
Acceleration time	5 seconds	5 seconds

The AC quay crane uses AC drive system with Active Front End technology, that is full compensation can be made for power factor and harmonics. Fig. 1 shows the "as commisioned" single line diagram of this crane with location of the CM3250 meter.

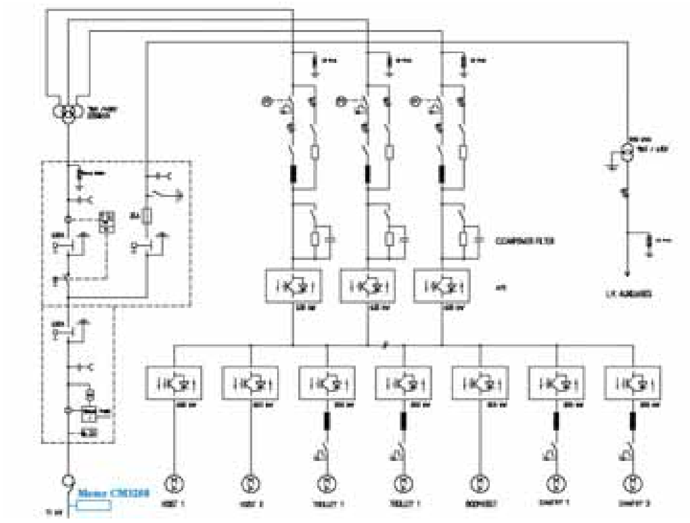

Fig. 1. AC quay crane – Singleline diagram showing meter CM3250 location.

The DC quay crane uses DC drive technology with harmonic filter to compensate the generated harmonics. Fig. 2 and Fig.3 show the "as commissioned" single line diagram of this DC quay crane with location of the meter CM3250.

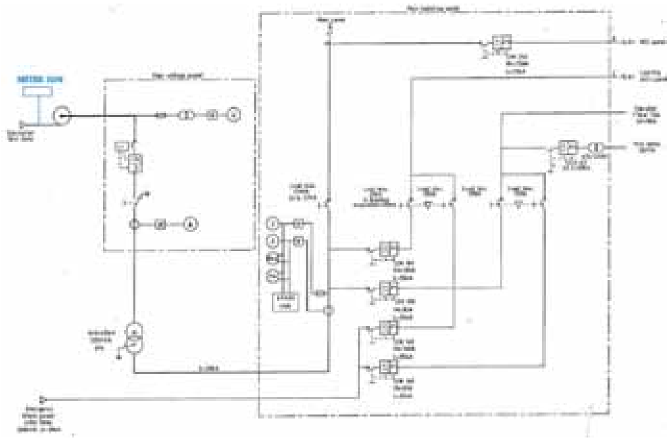

Fig. 2. DC quay crane – Singleline diagram – HV section showing meter CM3250 location.

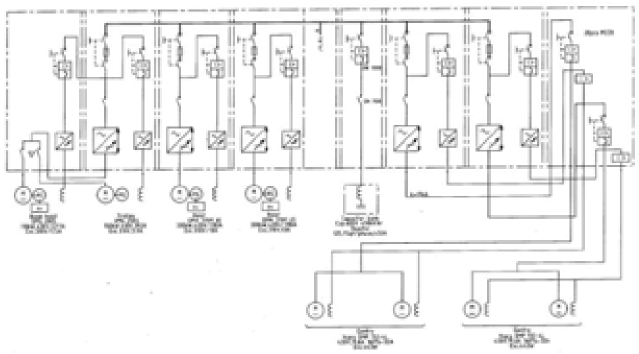

Fig. 3. DC quay crane – Singleline diagram – LV section

Schneider circuit monitor CM3350 with on-board memory was used at the high voltage supply connection to the quay cranes to record the electrical data every second. These meters are part of a complete power monitoring system installed at this container terminal for monitoring the whole terminal.

III. RESULTS

A. Expected Results

Peak Power Demand

It is expected the peak demand would be larger for AC drive technology due to:

Motor size: AC motors are larger in size to produce the same torque and overload capability. This means larger rotational inertial, cooling systems.

Supply arrangement**:** AC drives technology requres two steps, conversion and inversion while DC drive technology needs only conversion. This means extra power requirement, larger cooling devices as more heat would be generated for the AC drives.

Energy Usage

As with the peak demand, it is expected that AC quay crane would use more energy than DC quay crane.

Power Factor and Power Quality

Equipped with Active Frond End, the AC quay crane would produce a better overall power factor and power quality. DC quay crane would have acceptable harmonic level and very poor power factor.

B. Measured Results

Peak Power Demand and Energy Usage

Electrical data were captured during actual working conditions: loading containers to container ship. At the same time, loading sequence and container weight are also recorded. Fig. 4 and Fig. 5 show graph of Real Power (kW), Reactive Power (kVAr) and Apparent Power (kVA) of the quay cranes working on the same ship hold, ie. minimum usage of gantry motion.

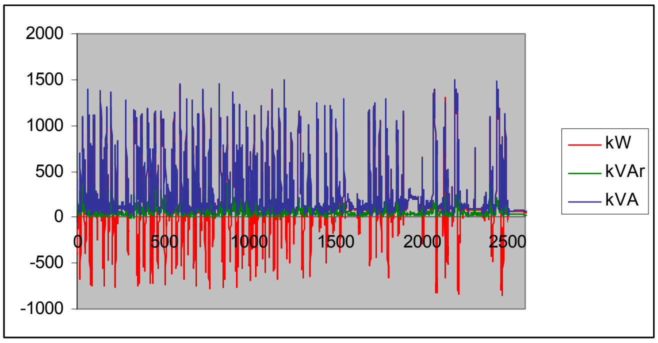

Fig. 4. AC quay crane – Captured 1 second data – Graph of powers vs time.

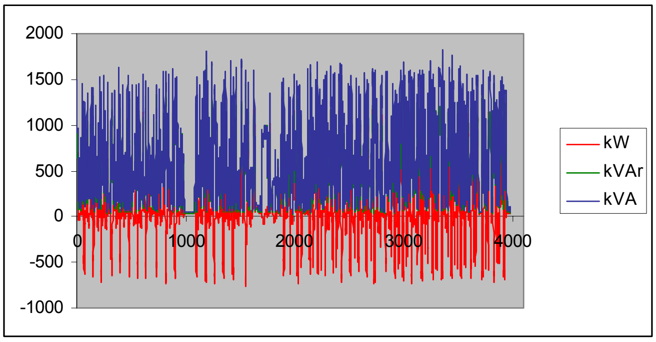

Fig. 5. DC quay crane – Captured 1 second data – Graph of powers vs time.

The first impression is that DC quay crane handled more containers, there are regenerative Real Power (-ve kW), DC quay crane requires larger kVA demand. This data is used to calculate the energy usage of the quay crane for handling each container.

To make comparison, a loading cycle with the similar container weight is used. Fig. 6 and Fig. 7 show the Power graphs of the AC and DC quay cranes when handling container weight 26.1T and 26T respectively.

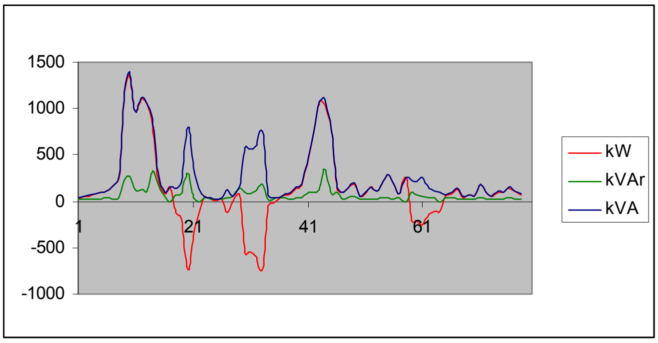

Fig. 6. AC quay crane – Captured 1 second data – Graph of powers vs time for one loading cycle: Lock container - Hoist – Hoist & Cross travel – Lower – Unlock container – Hoist – Hoist & Cross Travel – Lower & land on top of next container.

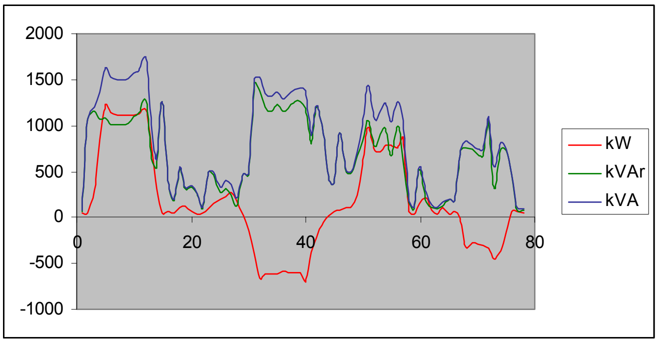

Fig. 7. DC quay crane – Captured 1 second data – Graph of powers vs time for one loading cycle: Lock container - Hoist – Hoist & Cross travel – Lower – Unlock container – Hoist – Hoist & Cross Travel – Lower & land on top of next container.

A loading cycle comprises of::
Lock the container to the spreader for a safe move,
Hoist the container up, start cross travel (while hoisting) to sea side when clear of all obstacles,
Lower the container to its final position and unlock,
Hoist the empty spreader up, start cross travel (while hoisting) to land side when clear of all obstacles,
Lower the empty spreader on top of the next container.

Therefore a graph of Power versus Time of a complete load cycle is expected to have four peaks values. The Real Power should have two negative peaks (regenerative when lowering). Fig. 6 and Fig. 7 confirmed these expectations. The slightly differences in shape and duration are due to the techniques of the quay crane drivers.

The results are summarized in Table 2. Theoretical average power demands are calculated and also shown in the table for reference only. The formula and actual mechanical data used in calculation of the average demand is not shown.

TABLE 2
TEST RESULTS – POWER DEMAND & ENERGY USAGE

Quay Crane with	AC Drive	DC Drive
Loads (including Hatch lids – 20T)	29	47
Load Weights	from 7T to 48.4T	from 7T to 48T
Peak Demand (kW) – 26T load	1476.00	1211.00
Average Demand (kW) – 26T Load	147.76	105.26
Theoretical Average Demand (kW) – 26T	152.01	126.83
Net used energy (kWHr)	113.50	115.20
Average used energy per container (kWHr)	3.91	2.45

To make a true comparison between AC and DC quay cranes, the electrical conditions have to be the same. It is assumed that the issue of poor power factor of DC drive quay crane has been solved (in the later section), comparison is now based on the peak kW demand rather than the peak kVA demand.

As shown in Table 2, peak demand from AC quay crane is 21.9% higher than DC quay crane. When taking the Safe Working Load of the quay cranes into account, the differences is still expected to be higher than 15%.

In real life, the Electrical Distribution Company (the Utility) does not look at this instantaneous peak demand. The peak demand is normally calculated from the "remotely read" energy kWHr and kVArHr every 15 or 30 minutes. That means the peak kW demand shown in the electrical bill is actual the average kW demand.

Comparison using average kW demand shows a 40% difference. Taking into account the driver's techniques, the final position of the container and other containers on the ship, the difference is still expected to be in the low 20%.

With higher peak and average demand, the energy usage has to be higher for AC drive quay crane. Values in Table 2 shows that an average of 60% more energy is required to handle a container for this test. AC drive quay crane uses 100% more energy than DC drive quay crane has been observed to use at any other time.

The real peak demand is important for protection settings, a high setting may not fully protect the quay crane and with a low setting the quay crane may not function with heavy load . Line current values are also captured in this test. This data would help the protection study. However, it is out of scope of this paper.

The real peak demand is also important for a weak supply network, light flickering, voltage drop. can cause serious problems during Hoisting. Studying the captured data would help finding the solution and select appropriate equipment for a container terminal with weak supply. For example, sizing an "energy storage" device or a "peak lopping" device. These devices are capable of supplying energy during hoisting. Again, this is out of scope of this paper.

Power Factor

Fig. 8 and Fig. 9 show gragh of Power Factor vs Time of AC and DC drive quay cranes when handling 26T container.

An average Power Factor is also shown in the graghs. This average Power Factor (as seen by the Utility) is the ratio of kWHr and kVAHr.

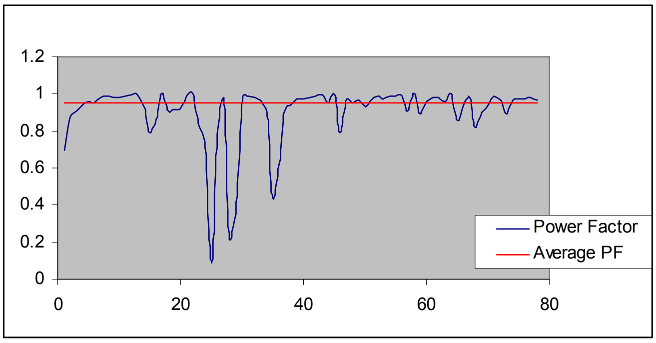

Fig. 8. AC quay crane – Captured 1 second data – Graph of power factor vs time for one loading cycle. Average power factor (as seen by the Utility) is calculated from kWHr/kVAHr

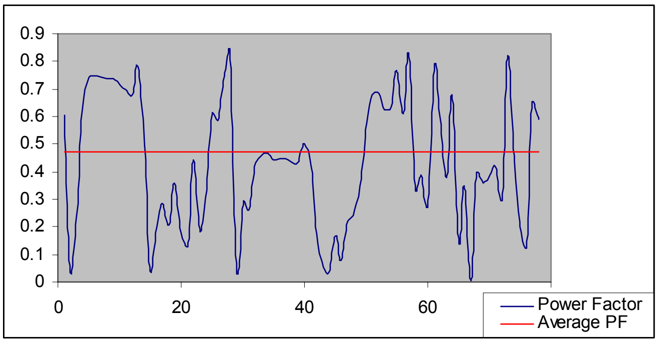

Fig. 9. DC quay crane – Captured 1 second data – Graph of power factor vs time for one loading cycle. Average power factor (as seen by the Utility) is calculated from kWHr/kVAHr.

TABLE 3
TEST REULSTS – POWER FACTOR

Quay Crane with	AC Drive	DC Drive
Power Factor - Real time	0.087 - 1	0.006 - 0.838
Power Factor – charged (= kWHr/kVAHr)	0.952	0.475

Results are summarized in Table 3. As expected, DC drive quay crane has a very poor power factor. However, it is possible to solve this problem by using a dynamic power factor correction unit.

A dynamic power factor correction unit consists of capacitor banks and power electronic switches. A microprocessor is used to control the switching to connect an appropriate amount of corrective capacitance on the "per-cycle" basic (50 cycles per second for 50Hz system). The desired power factor can easily be achieved. "Crane Factor" from TM GE Automation system or "Pure wave AVC" from S and C Electric Company are two examples of such unit.

Two Australian container terminals use a Pure Wave AVC unit with a very good result. For better utilization, the power factor correction unit was connected at the main 11kV bus bar, which supplies to three (3) DC drive quay cranes, two (2) AC drive quay cranes and 500 outlets for refrigerated containers. Overall power factor is always greater than 0.9.

So that with the right selection of equipment, poor power factor of DC drive quay crane is no longer an issue.

Total Harmonic Distortion (TDH)

The following is the extract from the Schneider meter CM3250 user manual. It shows how the THD is calculated.

- **THD.** Total Harmonic Distortion (THD) is a quick measure of the total distortion present in a waveform and is the ratio of harmonic content to the fundamental. It provides a general indication of the "quality" of a waveform. THD is calculated for both voltage and current. The circuit monitor uses the following equation to calculate THD where H is the harmonic distortion:

$$\mathrm{THD} = \frac{\sqrt{H_2^2 + H_3^2 + H_4^2 + \cdots}}{H_1} \times 100\%$$

Measured TDHs of live voltage and current for AC and DC drive quay cranes during the 26T loading cycle are plotted against time (second) as shown in Fig. 10 and Fig. 11. Different scales are used for voltages and currents.

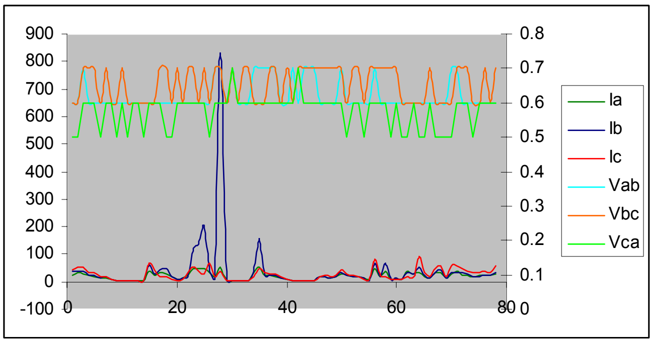

Fig. 10. AC quay crane – Captured 1 second data – Graph of THD vs time for one loading cycle. Different scales are used for clarification

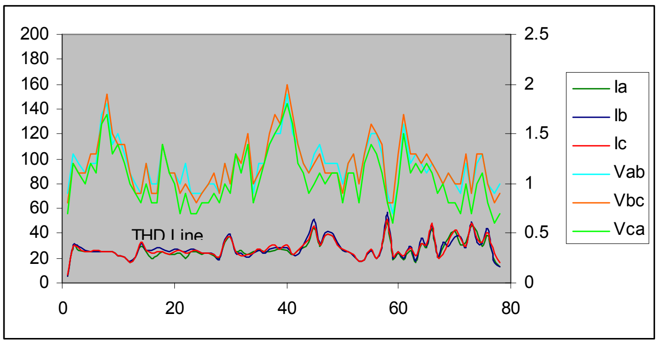

Fig. 11. DC quay crane – Captured 1 second data – Graph of THD vs time for one loading cycle. Different scales are used for clarification.

And the results are summarized in Table 4.

TABLE 4
TEST REULSTS – THD

Quay Crane with Total Harmonics Distortion (THD)	AC Drive	DC Drive
Line Currents		
Ia (%)	1.9 - 51.9	5.6 - 49.7
Ib (%)	1.6 - 830.3	5.3 - 56.9
Ic (%)	1.6 - 93.1	63. -50.9
Line Voltage		
Vab (%)	0.9 - 1.2	0.7 - 1.9
Vbc (%)	0.9 - 1.2	0.8 - 2.0
Vca (%)	0.9 - 1.2	0.6 - 1.8

The measurement shows an abnormal THD value of 830.3% of current on phase b. AC drive quay crane achieves smaller variation of THDs of voltages and currents. However, the measurement shows that THD of both AC and DC drive quay cranes are comparable.

IV. CONCLUSION

With actual measured electrical data presented for comparison and discussion, it can be concluded that if proper power factor correction and harmonic compensation are provided, a quay crane with DC drive technology is a better choice as it produce lower Peak Demand and Energy Usage.

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