FUEL SAVING FLYWHEEL TECHNOLOGY FOR RUBBER TIRED GANTRY CRANES IN WORLD PORTS

REDUCING FUEL CONSUMPTION THROUGH USE OF FLYWHEEL ENERGY STORAGE SYSTEM

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Abstract

Terminal operators in ports around the world are seeing a sharp rise in their operating cost as a result of the amount of diesel fuel needed to operate cargo handling machinery. VYCON Energy®, a Southern California company, has developed a flywheel energy storage technology that can alleviate a significant amount of the cost while also reducing harmful emissions. A three phase test was conducted with the cooperation of Yantian International Container Terminal and Hutchison Port Holdings to determine the results obtained when using flywheel energy storage technology on Rubber Tired Gantry (RTG) cranes. The test measured the reduction in fuel consumption when regenerated energy produced by the crane is stored, then discharged when needed, in a real world environment.

RTG cranes are mobile cranes designed for the movement of shipping containers once they are placed into the distribution channels from the ship. The cranes are powered by a diesel generator set (genset), which consists of a diesel engine coupled with an alternator. An RTG crane is capable of moving containers weighing up to 50 metric tons at a rate of 20 moves per hour. Typically, the hoist motor dictates the diesel genset size. The hoist motor experiences the highest power demand because the lifting, or hoist, of a container requires both a large peak power and steady state power. During the lowering of a container, the hoist motor is used to control the decent and therefore acts as a generator by creating regenerative braking energy. This energy is routed to dissipating resistor banks and wasted as heat. This paper details the operation and fuel consumption test results of VYCON's REGEN System, a flywheel energy storage technology, installed on a standard 1 over 5 ZPMC RTG crane at Hutchison's Yantian International Container Terminal (YICT) during 2007.

The tests measured the following: 1) Average fuel consumption of an RTG crane in normal day to day operations. 2) Average fuel consumption of an RTG crane when utilizing VYCON's REGEN System. 3) Fuel consumption when replacing the existing diesel genset with a reduced power output diesel genset combined with the REGEN flywheel energy storage system. The final results indicate overall fuel savings up to 38% based on operational handling rates.

Introduction

A significant percentage of the operating costs for terminal operators is the diesel fuel consumed on cargo handling equipment. As the price of oil/fuel continues to rise, finding ways to reduce fuel consumption is critical. At the current time, the cost of a barrel of oil is over $100 USD, which is the highest price to date.

Large cargo handling cranes, such as the RTG shown in Figure 1, are ideal candidates for a flywheel energy recovery system. RTG cranes consume a large amount of fuel, are highly utilized on an hourly basis and actually create new energy during normal operation. A conventional diesel genset provides electrical power for the hoist, trolley, and gantry motors, as well as for the routine demands of the crane. One of the advantages of utilizing this type of power system on a RTG is that it allows the crane to move freely throughout the container terminal as is required by daily port operation.

Figure 1
Typical Rubber Tired Gantry (RTG) Crane

The diesel genset is sized for the hoist motor, because the hoist requires the highest amount of electrical power (both peak and steady state). Although the hoisting period lasts only a few seconds, the genset must be able to support the peak power need. The resulting effect is excessive fuel consumption during peak power and also in idle mode. The diesel genset meets peak power demands by consuming a large amount of fuel during each lift event. However, when a container is lowered, the regenerated energy created by controlling the hoist motor is directed to resistor banks and dissipated as heat. With the addition of a flywheel energy storage system, a RTG crane can capture the regenerated energy and deliver it back during the hoisting of a container. More importantly, the addition of a flywheel energy storage system lowers the peak power demand of the crane and enables the reduction of the diesel genset output power. In this scenario, a smaller output power genset reduces fuel consumption during idle period. Together, the two technologies work to complement each other in providing overall fuel savings.

Testing was conducted in three phases: 1) determining the average fuel consumption for the RTG cranes at the YICT container terminal, 2) adding the REGEN System and measuring fuel consumption with the conventional diesel genset, and 3) replacing the conventional diesel genset with a reduced output power diesel genset to determine the fuel savings of the combined technologies.

Theory of Operation

The VYCON REGEN flywheel energy system can be installed on any RTG crane, either retrofitted or as an option in manufacturing, to create a hybrid power system. It works by capturing the regenerated energy from the hoist motor and making that energy available during the lift cycle.

A simplified power diagram for an RTG is shown in Figure 2. The REGEN flywheel energy storage system integrates only with the hoist motor because the trolley and gantry motors afford reduced regeneration opportunities.

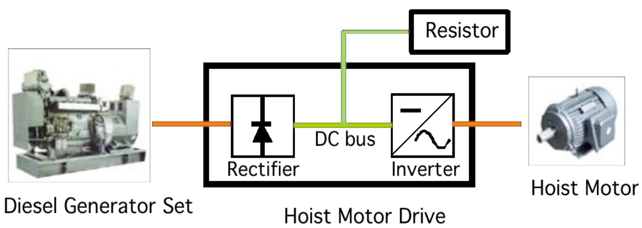

Figure 2
RTG crane hoist motor drive.

An RTG crane uses a diesel engine in the range of 350 to 675 kW and is typically paired with a 3-phase alternator. The output of the alternator is connected to an independent motor drive, which powers an isolated 3-phase winding in the hoist motor. The 3-phase rectifier is composed of passive diodes; each resistor bank is controlled by a transistor chopper.

When the REGEN System is not being used, the diesel engine must supply all of the hoist power. During the time the hoist power is ramping towards its peak, the load, which is made up of the spreader and container, is accelerating. When the desired lifting speed has been reached, the power demand is reduced and the load is lifted at constant speed with constant power. This process requires a surge in the amount of fuel used.

When VYCON'S REGEN System is installed, the output is connected to the DC bus as shown in Figure 3. During a lift event, the system controller measures the engine power at the DC bus and attempts to hold the engine power to 50 kW during acceleration. After the peak power demanded by the hoist has been supplied by the REGEN System, the system controller gently reduces the maximum REGEN output power to 60 kW (total of 120 kW from the two flywheels combined) to allow the engine to ramp up in power slowly. This process uses significantly less fuel.

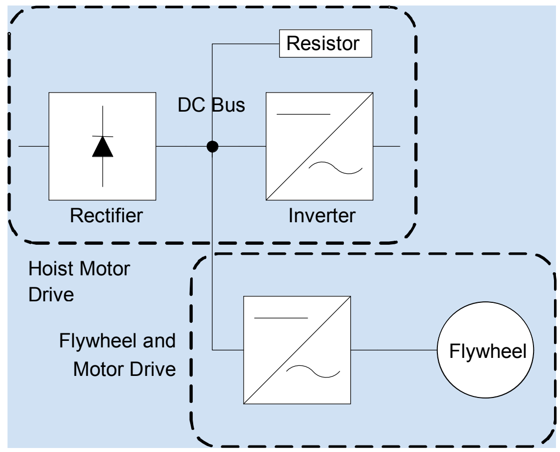

Figure 3
REGEN system connections to the DC bus of the Hoist Motor Drive

Figure 4 illustrates a simplified RTG crane system diagram with the VYCON REGEN system.

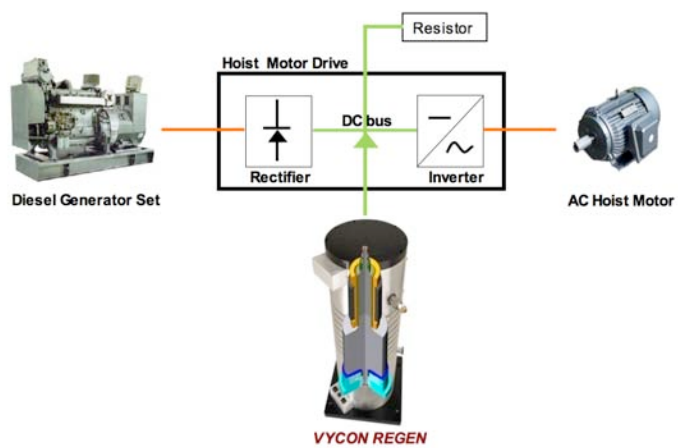

Figure 4
RTG Crane Diagram with the VYCON REGEN System

The flywheel consists of a 3-phase permanent magnet synchronous motor-generator connected to a 3-phase inverter. The flywheel spins in a vacuum, is levitated on active magnetic bearings, and stores 2.1 MJ (0.58 kWh) at 18 kRPM.

During a typical lowering event the energy regenerated via the hoist motor is dissipated as heat in the resistors. When VYCON'S REGEN System is installed, the system controller permits up to 80 kW to be absorbed by each flywheel and is available for reuse during the next lift. If the regenerated power from the hoist on an individual DC bus is greater than 80 kW, or if a given flywheel has been fully charged, excess power will be dissipated in the hoist motor drive resistor bank. When the energy can be reused, the demand for fuel is greatly reduced.

Test Plan

The Yantian International Container Terminal (YICT) and VYCON worked together to develop a testing plan to determine the fuel savings that can be realized by implementing flywheel energy storage on their RTG cranes. In the final phase of the plan, the conventional diesel genset was replaced with a reduced size diesel genset working in conjunction with the REGEN System. All testing was conducted at YICT. To measure the impact of each phase of testing, only one variable was introduced for each phase. The testing consisted of three distinct phases:

- Phase 1: Determine the fuel consumption of an RTG with the conventional diesel genset.
- Phase 2: Determine the fuel savings by combining the REGEN System with the conventional diesel genset.
- Phase 3: Determine the fuel savings with a reduced size diesel genset and the REGEN System.

During Phase 1, two RTG cranes (YC83 and YC99) were selected to measure their fuel consumption with the existing diesel genset during normal day to day operations at YICT. The measurement was recorded for comparison to the results found in Phase 2 and Phase 3.

During Phase 2, crane YC99 was selected to be retrofitted with the REGEN System. Crane YC83 served as the control. As in Phase 1, YC83 was operated with the existing diesel genset under normal conditions at YICT. YC99 was operated with the REGEN System. It was found that on the YC99, the peak power requirements on the diesel genset were reduced, thereby providing fuel savings.

During the final phase of testing, the conventional diesel genset on crane YC99 was replaced with a reduced output power diesel genset. As in previous phases, YC83 was operated as per normal. With the replacement of the diesel genset and the addition of the REGEN System, fuel consumption on the YC99 was further reduced. The REGEN System reduced the peak power requirements on the diesel genset and the reduced size engine allowed for higher fuel savings at the lower kW loads.

The correct selection of a reduced output genset is crucial in maximizing fuel savings. It must be designed to consume minimal fuel during idle, while providing sufficient power to hoist a full container when the REGEN System is not online. Genset manufacturers stock systems with a range of power outputs, however use the same engine to drive the alternator. With these gensets, there will be little to no fuel savings as the engine size is the same. A key feature in the selection of the appropriate genset is to identify a system with the correct power output combined with the smallest engine size available. This will produce the best fuel savings results. For the purpose of this test (Phase 3), a 288 kW genset driven by a 12 liter engine was used. Calculations show that gensets in this power range are available with engines of 11 and 9 liters, which would improve on the results obtained.

Phase 1 – 3 Test Plan Details

1. Fill up, measure, and record the starting point of the fuel level.
2. Record the following parameters before utilizing the RTG crane:
    a. Engine Run Time (Hours)
    b. Handled Box Number (Quantity)
    c. Hoist Run Time (Hours)
    d. Trolley Run Time (Hours)
    e. Gantry Run Time (Hours)
    f. Fuel Consumption (Liters)
    g. Average of Fuel Consumption per Move (Liters/Move)
    h. Average of Fuel Consumption per Running Hour (Liters/Hour)
    i. Real Energy (kWh)
    j. Reactive Energy (Kvar)
    k. Total Load Lifted (Tons)
    l. Energy per Lift (kWH/Move)
    m. Energy per Ton Lift (kWH/Ton)
    n. Average Handled Boxes per Hour (Moves/Hour)
3. Operate the RTG crane as normal for a pre-determined time.
4. During the test period, fill up, measure, and record the fuel consumed. Ensure that each fill up is to the same level as when the test was started and record all items listed in Step 2.
5. Upon completion of the test period, fill up, measure, and record the amount of fuel consumed. Ensure that each fill up is to the same level as when the test was started and record all items listed in Step 2.

Test Results

Phase 1 of the testing showed that baseline fuel consumption of the cranes at YICT was in the range of 2.2 – 2.4 liters per move while operating at an average rate of 10 moves per hour. The fuel consumption was calculated taking into account the various modes of operation such as idle, hoist, trolley and gantry times. Table 1 provides the results of the Phase 1 testing.

Item	Description	Units	YC83	YC99	YC99 (retrial)
1	Engine Run Time	hours	210.59	221.15	289.78
2	Number of Moves		1948	2243	3185
3	Hoist Run Time	hours	63.51	70.7	100.54
4	Trolley Run Time	hours	28.85	36.5	47.9
5	Gantry Run Time	hours	19.06	22.96	28.45
6	Fuel Consumption	liters	4688	5359	7086
7	Average Fuel Consumption per Move	l/move	2.407	2.389	2.225
8	Average Fuel Consumption per Running Hour	l/hour	22.261	24.232	24.453
9	Average Moves per Hour	moves/hr	9.25	10.14	10.99

Table 1
Phase 1 testing with the existing diesel generator set without energy recovery

Phase 2 of the testing measured the fuel consumption of crane YC99 with the addition of VYCON'S REGEN flywheel energy system. Average fuel consumption was reduced to 2.0 liters per move with a handling rate of 12 moves per hour. Table 2 summarizes the results of this test phase.

Item	Description	Units	YC99
1	Engine Run Time	hours	332.46
2	Number of Moves		4037
3	Hoist Run Time	hours	128.51
4	Trolley Run Time	hours	63.93
5	Gantry Run Time	hours	40.13
6	Fuel Consumption	liters	8234
7	Average Fuel Consumption per Move	l/move	2.04
8	Average Fuel Consumption per Running Hour	l/hour	24.767
9	Average Moves per Hour	moves/hr	12.14

Table 2
Phase 2 Test Results with Existing Diesel Generator Set and REGEN

In Phase 3, the original diesel genset was replaced with a reduced output power diesel genset. Specifically, the 410 $kW_{mechanical}$ (380 $kW_{electrical}$) diesel genset driven by a 14 liter diesel engine (Detroit Diesel Model 6063HK35) was replaced with a 322 $kW_{mechanical}$ (288 $kW_{electrical}$) diesel genset driven by a 12 liter (MAN Model D2866LE201). The test results indicated that fuel consumption was further reduced to 1.50 liters per move, handling containers at a rate of 13.3 moves per hour. This configuration was also tested to verify that the MAN engine was capable of lifting a full container. The results show that the lift was accomplished at a lower speed than the original specification. This variation is acceptable to the customer based on the fuel savings potential. Table 3 captures the test results for Phase 3 of the testing.

Item	Description	Units	YC99
1	Engine Run Time	hours	137
2	Number of Moves		1809
3	Hoist Run Time	hours	56.94
4	Trolley Run Time	hours	27.42
5	Gantry Run Time	hours	16.12
6	Fuel Consumption	liters	2713
7	Average Fuel Consumption per Move	l/move	1.5
8	Average Fuel Consumption per Running Hour	l/hour	19.803
9	Average Moves per Hour	moves/hr	13.2

Table 3
Phase 3 Test Results with Reduced Size Diesel Generator Set and REGEN

In summary, the testing showed a fuel savings ranging from 8% to 15% with the addition of the REGEN System to the standard RTG crane. When using a smaller diesel genset in conjunction with the REGEN System, the fuel saving increased to from 32 to 37%. Table 4 presents the summary of the testing.

Test Phase	Configuration	Genset	Fuel Consumption	Savings
		kW_{mech}	liters/move	% vs baseline
1	Standard RTG (YC99)	410 kW	2.39	-
2	Standard RTG with REGEN System	410 kW	2.04	14.61%
3	RTG with REGEN system and new genset	322 kW	1.50	37.21%

vs. Second Baseline RTG (YC83)

Test Phase	Configuration	Genset	Fuel Consumption	Savings
		kW_{mech}	liters/move	% vs baseline
1	Standard RTG (YC83)	410 kW	2.41	-
2	Standard RTG with REGEN System	410 kW	2.04	15.25%
3	RTG with REGEN system and new genset	322 kW	1.50	37.68%

vs. Third Baseline RTG (YC99 retrial)				
Test Phase	Configuration	Genset	Fuel Consumption	Savings
		kW_{mech}	liters/move	% vs baseline
1	Standard RTG (YC83)	410 kW	2.23	-
2	Standard RTG with REGEN System	410 kW	2.04	8.31%
3	RTG with REGEN system and new genset	322 kW	1.50	32.58%

Table 4
Test Results Summary

Conclusion

The results of the test clearly show that the addition of a flywheel energy storage device to a RTG crane can provide a significant reduction in fuel consumption. By augmenting the genset power with the stored energy, less demand is placed on the motor. The installation of the REGEN System provided a direct fuel savings of 8-15%.

The effect of the REGEN System alone lowers the maximum power demand for crane operation. By installing a lower output power genset in conjunction with the REGEN System, additional fuel savings are realized during the idle periods. In the case of YICT, the ZPMC RTG crane was modified by replacing a 410 kW genset with a smaller 322 kW genset. The fuel savings increased to 32-38%. The smaller genset and flywheel energy storage device had no impact on performance and handling rates.

In the current environment of increasing fuel prices, taking advantage of the free energy created by normal operation of the RTG crane can significantly reduce operating costs. If flywheel energy storage devices are designed into new RTG cranes, the genset can be installed with a lower power requirement directly from the OEM. The lower powered genset will have a lower price than the typical higher power genset and will provide a pricing offset to the cost of the flywheel energy storage device.

With port operators around the world looking for methods to reduce fuel consumption and to also reduce emissions, taking advantage of the free energy available on every RTG crane can and should become a normal practice.

Acknowledgements:
VYCON would like to acknowledge the support and dedication to this effort from the Yantian Container Terminal's maintenance department, engineering groups and management. Hutchison's strong emphasis in research of new technologies to lower port emissions was a key contributor to conducting this test