GAINING EFFICIENCY IN CONTAINER HANDLING OPERATION WITH REGENERATIVE POWER CHARGING SYSTEM

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Abstract

In the emerging development of emission cutting and energy saving technology for advanced cargo handling system in container terminal, introduction of hybrid handling equipment in recent years appears to be a potential solution. This paper presents an analysis method of operation data for hybrid straddle carrier as a common in-yard handling equipment in a container terminal that has been installed with regenerative power charging system which is designed to achieve fuel efficiency and gain regenerative energy from hoisting and traveling operation. First, the operation information database in the form of wave data is gained through electric data logging system, and then wave data is analyzed separately for hoisting and traveling operation by combination of wave data reading software and spreadsheet. Finally, gained result is plotted to show relation between measured parameter and the impact of modifying each parameter to fuel efficiency and energy regeneration.

Keywords: *container handling equipment, fuel efficiency, regenerative energy, operation data analysis*

1. Introduction

World community faces significant environmental threat in the form of climate changes. The most important system for cargo distribution in the 20th centuries; container shipping, is pushed to follow certain regulation to perform certain standard in daily operation to meet with this challenge although it's small contribution to the total volume of emission to the atmosphere (Maritime experts group - APEC, 2009). As a part of container shipping system, container terminal has an interesting characteristic. It can pursue an efficiency of cargo transportation systems as well as developing environmentally-friendly cargo transportation systems. The area of improvement touches the container handling operation in container terminal in several ways i.e.: improvement of berth allocation, optimization of handling operation, fleet management and the recent updates: introduction of environmental-friendly container handling equipment.

This study is focused on the development of emission cutting and energy saving technology for advanced cargo handling system in container terminal, with the introduction of hybrid handling equipment. Background of the study is the need of container terminal to assess the potential efficiency that can be gained by employing hybrid straddle carrier to replace conventional diesel power straddle carrier in daily operation (Shinoda and Hangga, 2011). The authors conducted further study of operation analysis in the form of fuel efficiency and energy regeneration by motions of container handling equipment. Measurement method is then applied to real operation of hybrid straddle carrier and gained data are analyzed by data log software and spreadsheet.

2. Hybrid Straddle Carrier Mechanism

Straddle carrier (S/C) is handling equipment that usually operates in combination with stacking cranes/transfer cranes (T/C) and yard chassis (C/Y) in the container yard although in some terminal it can be used for apron side movement of container to supply the container crane (C/C) (see Figure 1a). S/Cs have the ability to perform a wide range of handling operation such as transport, stacking (up to 4-tier), loading/unloading (LoLo) of trucks and rail cars.It often considered as the optimal system for medium and large terminals, when movement flexibility and high accessibility are required. However, conventional S/Cs also possesses some disadvantages: high investment cost and high energy consumption during operation. Manufacturers are trying to take care of these problems by producing hybrid type straddle carrier that carry potentials for energy saving, which however need to be proven. The type of hybrid straddle carrier that is examined in this study is diesel electric straddle carriers, which is designed for high performance and achieve low emission like Nox, HC, CO and PM together with improved fuel consumption.

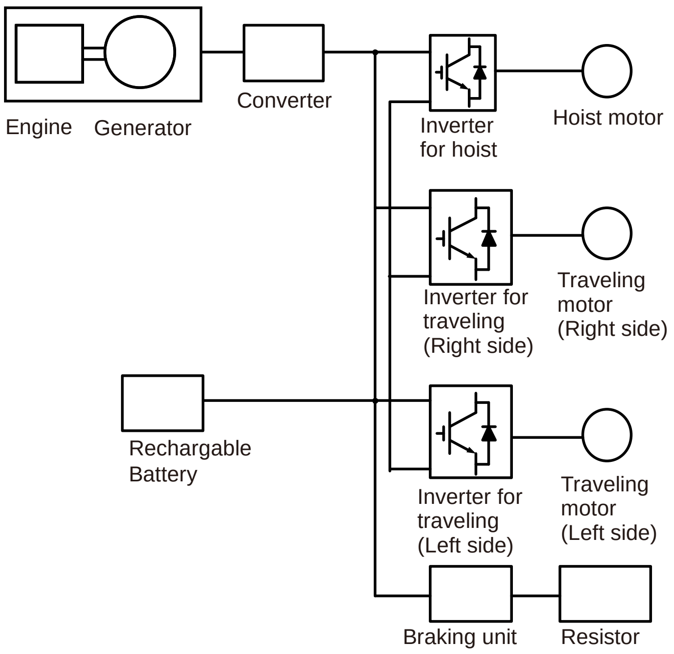


Figure 1 System diagram of diesel electric straddle carrier

The diesel electric mechanism explained as a single diesel engine that drives a single generator to produce electric power for the induction motor that drives the straddle carrier. Control of travelling speed of the straddle carrier wheel is carried by regulating the wheels with two motors and two inverters. This introduction of inverter is the difference between the hybrid-type and conventional diesel mechanical-type of straddle carrier, as depicted in Figure 1. For the purpose of this research, a real hybrid straddle carrier that is operated in Hakata Port Terminal, Fukuoka-Japan was chosen to be examined with the following characteristic.

1. Type : Diesel Electric with inverter
2. Acceleration Capability : 30 seconds to reach 20 km/h
3. Traveling capability : 23 km/h (with load), 27 km/h (without load)
4. Hoisting/Loweing speed : 280 mm/sec (with load), 400 mm/sec (without load)
5. Other characteristic : Equipped with battery to store regenerative energy by motion

One of the interesting characteristic of the examined SCs is the rechargeable battery installed in the engine room to store the energy by regenerative charging through SCs movement. This stored energy then can be converted into electric power for helping movement purpose of the generator in hoisting operation. Kinds of movement that is expected to gain regenerative energy are braking phase of travelling and lowering operation. To be sophisticate, this research is designed to measure how the impact of travelling, hoisting and lowering movement of S/C in providing energy by charging as well as the impact to fuel consumption.

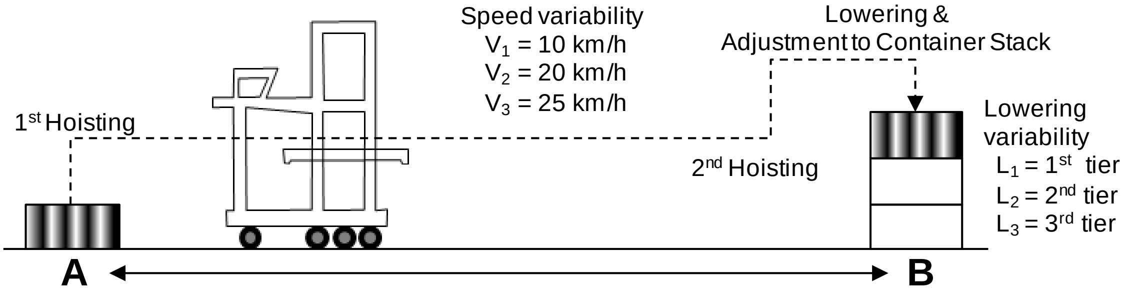


Figure 2 Designed movement pattern for S/Cs experiment

Table 1 Example list of measurement item, range and output for experiment

CH	Item	Range	Output (V)
1-1-2	output of battery	±500A	±10V
1-1-3	lifting motor speed	±500A	±10V
1-1-5	traveling motor speed	±500A	±10V
1-1-13	engine speed	0 - 2000 rpm	0 - 10V
1-2-3	fuel consumption	0 - 2000 l/h	0 - 10V

3. Methodology to Examine Hybrid S/Cs efficiency

The authors propose a methodology to measure the power output of Hybrid S/C during operation. First, movement patterns are designed for experiments, then a voltage data logger is installed in the S/C, finally recorded data in voltage is converted into real value to be analysed. Figure 2 exemplify the movement patterns for S/C that is designed for experimental purposes. Basically, S/C hoisting a container with load, then travel from point A to B. After reach point B, S/C will lowering the container and adjust it into stacking area. There are some variable that will change during the experiments i.e.: S/C traveling speed and stacking position (up to 3 tier). When stacking a container into 2nd and 3rd tier, before reaching point B, S/C will have to conduct 2nd hoisting to adjust to the stacking position. It is a standard procedure in S/C operation, as during traveling, container must be placed on designated center of gravity of S/C for stability purposes. The motions of S/C in this experiment are divided into several phases: hoisting phase, starting phase (accelerate until reach a steady RPM), cruising phase (constant acceleration at designated speed), braking phase, 2nd hoisting phase and lowering phase.

To capture the output of the engine, battery and generator of S/C, continuous and temporal mesurement of voltage output from capacitor terminal during designed movement patterns was performed. Data was recorded in a data logger of HIOKI LR8400-20 at recording speed of every 20 ms and had a voltage resolution of 0.5 mV in the 10 V range (see HIOKI product catalog for further detail). The data logger captured various loads from different parts of the S/Cs instrument and produced an isolated multi channel waveform based on 18 measurement list (example of measurement items is shown in Table 1), notably: fuel consumption/fuel economy and motor traveling speed. For measurement of fuel economy, the amount of fuel used per hour (l/h) is measured instead of distance (l/km) since S/C will need to reach several designated speed and run constantly for some time. Motor traveling speed, is measured in rpm (revolution per minute) to annotates rotational speed of mechanical component of the engine crank.

The waveforms which are gained from voltage measurement which based on the movement patterns, as exemplified in Figure 3, are then converted into real value. Recorded waveform data for each channel that represents measurement items in Table 1 in the logger is exported to spreadsheet into CSV (comma separated value) and then converted into real value using ACV (average channel value) method by the means of following numerical formulation.

$$ACV = \left(\left(\sum_{i}^{n} di \times \Delta t\right) \div n\right) \times \left(\frac{M}{O}\right) \quad (1)$$

where:

n = total number of data items
d*i* = data on channel number *i*
Δt = sampling period
M = Max measurement range
O = Max output voltage
ACV = Average Channel Value

The numerical formulation is designed to obtain the integration value of the signal waveform during a specific motion phase. When calculation of the range specified by the cursor A/B is selected as shown in Figure 4, the calculation area is constrained to the waveform between the cursors. After integration of the shaded portions, the value is divided by total number of data. Finally, the average value of integration is multiplied by convertion rate (*M/O*) to get the real value of output for each measurement item.

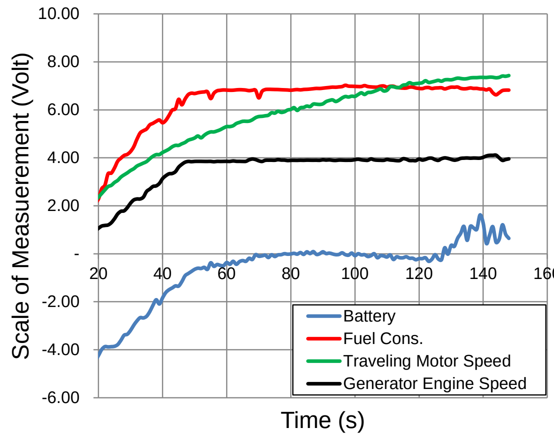


Figure 3 Example of raw waveform data for starting phase

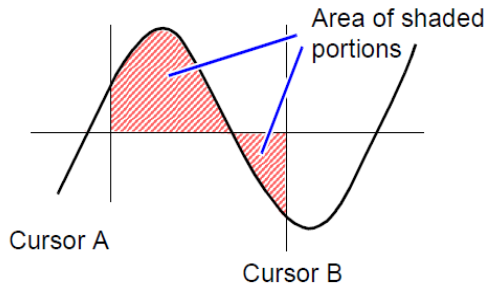


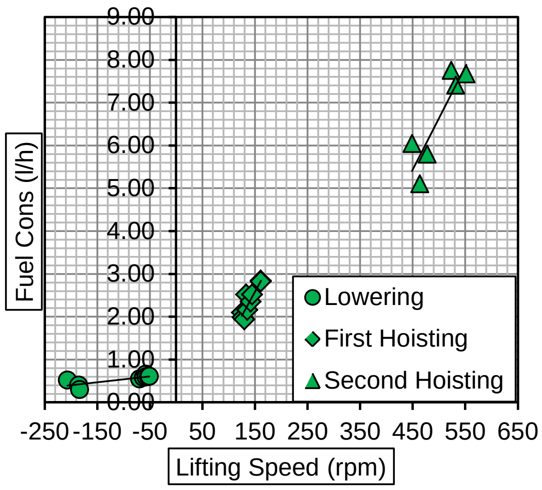
Figure 4 illustration of of ACV

4. Data Analysis

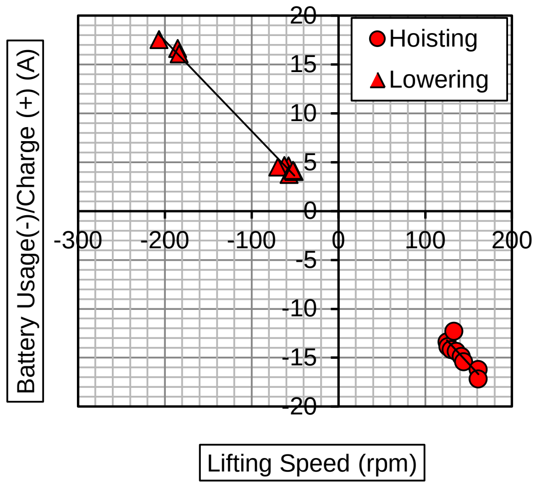
4.1. Hoisting Analysis

The hoisting analysis of operational data depicted the correlation between lifting speed and fuel consumption as well as to battery usage/charging by combining real value that is gained in each phase of hoisting/lowering, with variability in hoisting speed and stacking position of container as depicted in Figure 2.

Positive axis of Figure 5 shows that there are significance increase of fuel consumption for every marginal increase of lifting speed during hoisting operation on high rpm. A significance battery power utilization also recorded on the same stake. Relievingly, lowering operation used very less energy consumption, as shown on the negative axis of Figure 5(a), and in addition gained significance regenerative energy for every marginal increase of lowering speed as shown in negative axis of Figure 5(b). The shape of both figure show strong correlation between lifting speed and normal performance parameter of fuel consumption and alternate performance parameter of battery utilization. Conclusive explanation of this phenomena is that some energy are regenerated when lowering a container, and this energy is stored in the lithium ion rechargable battery that can be reuses to assist the engine later on for other operation.



(a) Dependance of lifting speed and fuel consumption



(b) Dependance of lifting speed and fuel consumption

Figure 5 Relation of efficiency parameter in hoisting operation

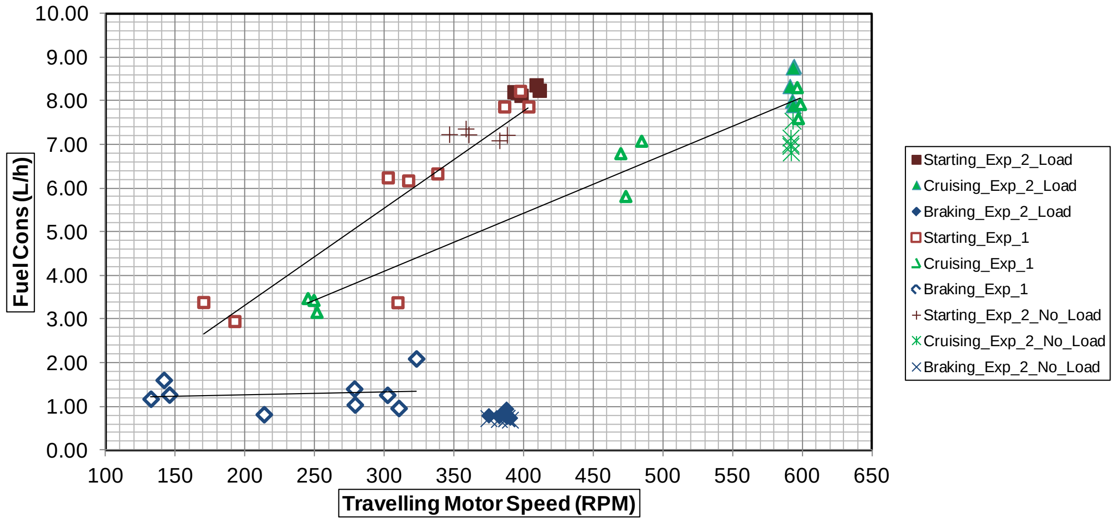


Figure 6 Dependence of traveling speed and fuel consumption

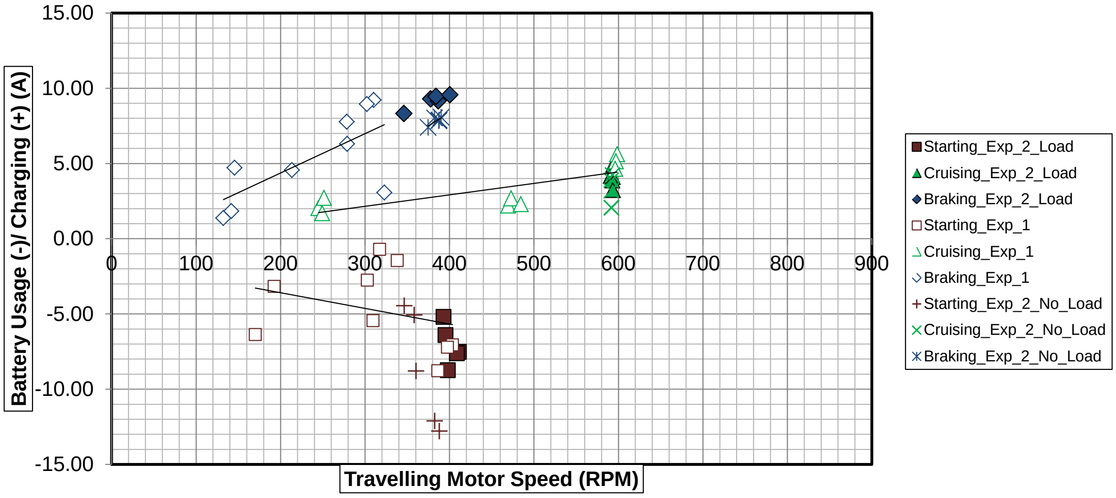


Figure 7 Dependence of traveling speed and battery usage (-)/charging (+)

4.2. Traveling Analysis

As S/C traveling operation is divided into more sophisticated phases: starting, cruising, and braking phase, it is easier to analyze the converted waveform data by considering independent characteristic of each phase. The changing variable are traveling speed, notably: 10 km/h, 20 km/h and 25 km/h respectively, and appearance/non appearance of container load during travel. Therefore, travel distance is not fixed as S/C need to reach designated travel speed and maintain it for some minutes during cruising phase before braking phase. There are three kinds of traveling experiments that is conducted for S/C. Exp_1 is for changing of travel speed which produced different average rpm for each experiments. Exp_2 is for changing acceleration but maintain traveling motor speed at high rpm with a container load to S/C, and Exp_3 is similar with Exp_2 only without a container load to S/C.

Figure 6 shows the dependence of traveling motor speed of S/C main engine and fuel consumption for each phase. Significance increases in fuel consumption (l/h) is recorded during starting phase varied with motor traveling speed (rpm) because the engine require higher energy for transmission to accelerate until reach the designated travel speed. Cruising phase also show similar trends even though S/C travel in relatively constant speed and acceleration. The reason lies in the throttle opening angle. To maintain constant speed, S/Cs driver conducted push-pull activity of the throttle, thus increase the consumption of energy. Nevertheless, braking phase shows constant energy consumption during S/C deacceleration throttle is seldomly pushed. Finally, the appearance/non appearance of container load for all traveling phases shows slight difference to the increase of fuel consumption. Noted that constant weight of loaded container was used for all the experiments.

Figure 7 shows the dependence of traveling motor speed and battery usage/charging. Starting phase consume energy from generator's battery, and during braking phase, left over of the throttle and braking activity to reduce speed gained regenerative energy which is common sense for hybrid vehicle. Focusing on braking phase, all the experiments showed positive result in annotating the relation between braking and gaining energy from battery charging, called regenerative energy. Which is an energy recovery mechanism which slows a vehicle or object down by converting its kinetic energy into electric power and the stored saved in a storage battery and used later to power the motor for another use, such as hoisting, powering air conditioner in the control room and lights.

Surprisingly, cruising phase also gained regenerative energy that is saved in the storage battery. The hyphothesis is that, while S/Cs driver conducted push-pull activity to maintain speed, S/C perform a slight horizontal vibration every second, and the load was perform a vertical vibration. These vibrations might be the reason for gaining of regenerative energy during cruising phase. Further experiments need to be conducted specifically to assess the possibility of motions that leads to regenerative charging.

Finally, Figure 8 show the correlation of battery utilization/charge to the S/C fuel consumption. The analysis resulted in a potential dependency between battery utilization/charging to the increase/decrease of fuel consumption during each traveling phase. Additional result that appeared in this research is that braking activity during braking phase shows less correlation to regenerative energy charging as different braking treatment were conducted by S/C, notably early braking and late braking. Further experiments sophisticated for braking operation is planned to be conducted to see the effect of braking to gain regenerative energy.

By this preliminary research on the methodology to assess operational efficiency of a hybrid straddle carrier in container terminal, the authors is confidence that further research to collect more reliable data based on the designed movement pattern should be conducted. This operational analysis can be used to determine the appropriate operation method of Hybrid S/C to optimalize the advantages of regenerative charging and reduction of fuel consumption. The operational data analysis shows that the current technology of regenerative charging by motions employed on Hybrid Straddle carrier possess potentials to compensate disadvantage of high investment cost.

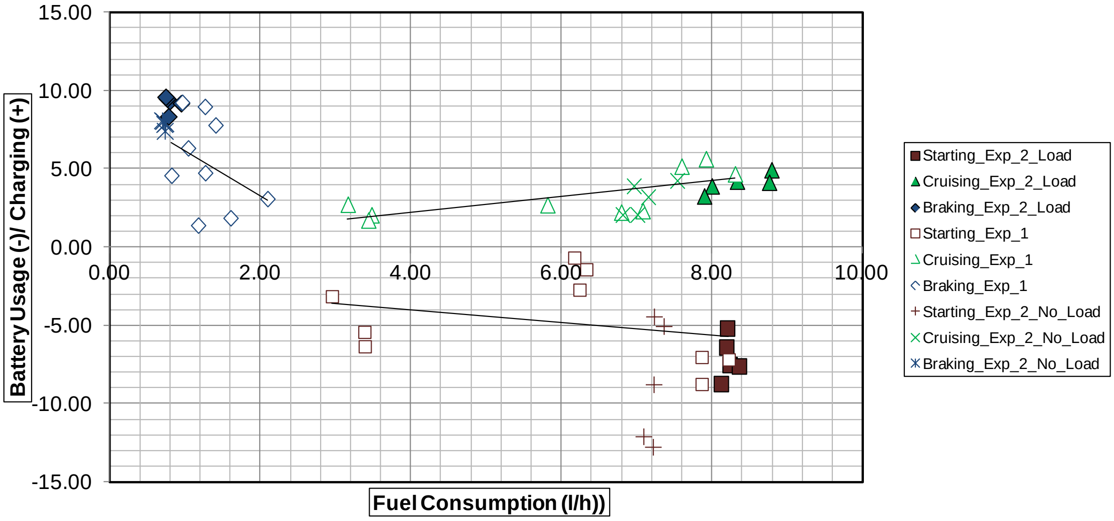


Figure 8 Dependence of battery usage (-)/charging (+) and fuel consumption

5. Conclusion

This study proposes methodology to assess and measure the efficiency of hybrid straddle carrier (Hybrid S/C) in the form of fuel consumption and gained regenerative energy by motions. Combination of data logging instrument, logger utility software and spreadsheet is used to capture and analyse the movement pattern that is designed originally. This preliminary research shows that the gained data is reliable to be analysed. The analysis result shows the potential of improvement in operation technique and method of hybrid straddle carrier to optimize its specific characteristic of environmental-friendly machine. It also shows that the regenerative energy can be gained by specific motions of hybrid S/C during traveling and hoisting/lowering operations. The result of this study can be used for assessing both functional operation of S/C in the form of driving method and movement cycle to reach optimum efficiency. Moreover, it will affect the whole operation efficiency in container terminal as S/C hold more important role in modern container terminal as it can be operated in many types of operation.

6. Future Remarks

In the future, the authors would like to perform more sophisticated traveling analysis for cruising and braking phase to measure the impact to gained regenerative energy and also perform comparative operational analysis between conventional diesel mechanical straddle carrier and hybrid (diesel electric) straddle carrier in real operation at container terminal.

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