A DESIGN OF HIGH EFFICIENT GANTRY CRANE FOR ULTRA LARGE CONTAINER SHIP

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Abstract: This article presents the design system for high efficiency gantry crane system using elevator and conveyor system. The basic concept for the proposed gantry crane system can be used with modification of the classical gantry crane instead of changing lots of them. However, the proposed crane system can reduce the cycle time more than the classical gantry crane. The high efficiency gantry crane can also improve the productivity of the container transportation job because of reducing cycle time. In order to achieve the effectiveness of the proposed design system, the loading and unloading capabilities are compared with the classical crane, and then these results show that the proposed crane system has better performances than the classical type. *Copyright © 2005 IFAC*

Keywords: Transportation, Automatic Operation, Time Optimal, Mechanism, Efficiency enhancement

1. INTRODUCTION

Recently, the amount of container transportation through harbor is increasing worldwide and the size container is also getting larger, so that there comes need of new handling equipment system to handle many containers at short time in harbor with ultra large container ship (Song, *et. al.*, 2001; Lou and Goh, 2003). It means when harbor's equipment is insufficient against amount of transporting cargo, there comes increase of distribution expense, harmful effects to international competitive power and obstacle of importation/exportation trade those are serious harmful factors at development of actual-economy.

[1] Research supported by the National Research Laboratory Program of the Korea Ministry of Science & Technology (MOST).

Automation of crane is the most representative equipment applicable to ULCS which consists of quay crane directly handling cargos at both sides from ships and transfer crane being operated at Yard area of harbor. Specially, a quay crane of Gantry type influences greatly to productivity of container terminal. The speed of cranes currently used at worldwide is about 40 moves/hr but 100 moves/hr is needed to adjust new large container ship (6,000~8,000 TEU size). So developing automation and high–speedy of crane is currently under research in the country as well as worldwide level (Song, *et. al.*, 2001).

So, we proposed a new type of crane which is named by TTEC(Two-Trolley Elevator Conveyor) to improve the performance of conventional crane. It is applied to new mechanism which can improve productivity of crane without reorganizing wharfs alongside an anti-sway method to prevent crane swaying so that improve productivity more. We compared capability of cargo working of gantry crane designed by results of this research to existing cranes used at ships of 6,000~8,000 TEU size using experimental simulation.

2. DESIGN OF GANTRY CRANE WITH HIGH PERFORMANCE

A new crane system suggested in this article consists mainly of sea side part, land side part and buffer part. Sea side part and land side part have trolley structure movable vertically /horizontally so that prevent sway. Buffer part consists of elevator system and conveyor system, and composition of each system is as follows (Kim, 1999; Kim and Kwon, 2000).

2.1 Trolley system having anti-sway equipment (sea side part and land side part)

Existing trolley system installed at container crane and tier type crane for use at Yard get containers settled with spreader descended by rope. After spreader ascends for certain section, trolley moves horizontally and descend to load cargo to portable vehicle or at loading area, then spreader ascends again toward next cargo. Loading and unloading of cargos or containers performed by repeating above process.

Therefore in this type of transporting using rope, there occurs a sway at spreader connected with ropes by horizontal force from inertia when trolley moves horizontally and stops after spreader ascends for certain section after settling container. A sway is also created by strong wind from Oceanside making it harder to load container at accurate site and workers should wait until sway stops, which means delay of overall work. Recently, active development of equipment controlling sway by operative control program or other structures installed, and more development of equipments is needed to suppress and absorb horizontal force comes from weight of container and spreader. In this research, in order to overcome the problems stated above, new equipment that can prevent sway of spreader by installing prop with multi-grade cylinder that moves elastically according to upward and downward moving between trolley and spreader, arm and damper, and absorbing sway and shock of spreader was developed. Fig.1 shows picture of anti-sway equipment developed in this research (Kim and Kwon, 2000).

This equipment has following features as shown in Fig. 1. First, a smooth movement is possible by air cushion formed inside of each cylinder when trolley makes spreader connected by ropes ascend/descend. Second, the installed prop between spreader and trolley can suppress sway of spreader elastically by supporting multi-grade cylinder at both side in case of horizontal force occurs from inertia that is formed when trolley moves settled spreader to proper site after ascending and then stops. Third, installed damper in this prop absorbs shock or vibration so to prevent sway of spreader. Therefore, using this anti-sway system installed at Main/sub trolley make it possible to move/load cargo of container to proper site stably by minimizing sway of spreader, and it is also possible to raise ratio of service of harbor affairs by reducing needed work time and to decrease fatigue of workers with semi-automation of spreader at ship side. It also fixed existing problem of vibration coming from inter-operation of 2 trolleys by separating trolley of land side without attaching it existing trolley.

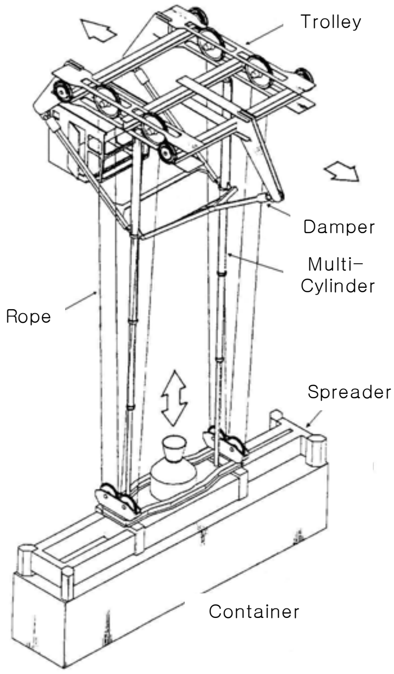

Fig. 1. Anti-sway system

2.2 Buffer part

2.2.1 Elevator system

It is a part that sending or receiving container transported from sea side or supposed to be transported to sea side, toward trolley of sea side. It is designed to increase working performance at sea side by sharing vertical hoisting duty of sea side trolley. Elevator system is designed as a structure that can change height of elevator adjusting to height of loaded container at container ship and also can perform providing information to customhouse by comparing weight of container to recorded data of document and checking black list.

2.2.2 Mounting/demounting equipment for connecting instrument of container

Structure of elevator system also allows automation of Mounting/demounting equipment for connecting instrument of container used in loading container on hatch of container ship. There needed time to stop other machine for mounting/demounting equipment for connecting instrument of container in the past, but with this method, performing it with up/down movement of elevator increased performance of cargo working by removing additional work time. This way also prevents connecting instrument of container from being damaged.

2.2.3 Conveyor system

Conveyor system improves entire cycle time by keeping several containers on conveyor all the time and loading continuously at land side in order to prevent undesired stop of work previously which is caused from the discordance of cargo-working of sea side and land side. Schematic configuration of High efficiency Gantry crane system designed as above is shown in Fig. 2. As it shown in Fig. 2, The Crane system designed at this research features below items.

① Minimize waiting time by applying buffer function with Elevator and Conveyor system.
② Prevent sway of container by anti-sway equipment.
③ No additional construction required in installing at existing crane and harbor.
④ Remove inter-disturbing factors caused from vibration when Trolley and Spreader moves by separating buffer part from main body of crane unlikely suggested in former research (Kim, *et al.*, 200).

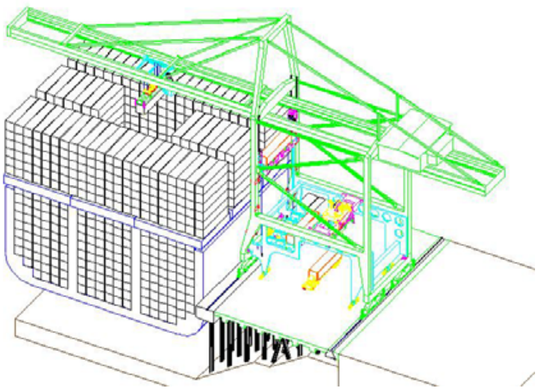

Fig. 2. Schematic configuration of high efficiency gantry crane system.

3. OPERATING METHOD OF PROPOSED CRANE

In this research, the operating method of the designed high performance gantry crane included both that are the general single cycle has only one direction of the container movement and the dual cycle is available bidirectional loading and unloading simultaneously.

3.1. Single cycle operation

The single cycle operating method selects the only one direction of two, that are from the sea side to the land side or its reverse direction. In this case, the proposed system can reduces a reciprocating range for each trolley and spreader than the general crane by dividing the work between two trolleys and elevators. Fig. 3 shows the operating structure by single cycle method.

In Fig. 3, the operation flow of the proposed system for the single cycle can be described as follows:
① **A↔B**: Transportation between ship and elevator by trolley on sea side
② **B↔C**: Vertical transportation by elevator
③ **C↔D**: Longitudinal transportation and buffering by conveyor
④ **D↔E**: Container loading and unloading by the other trolley on land side

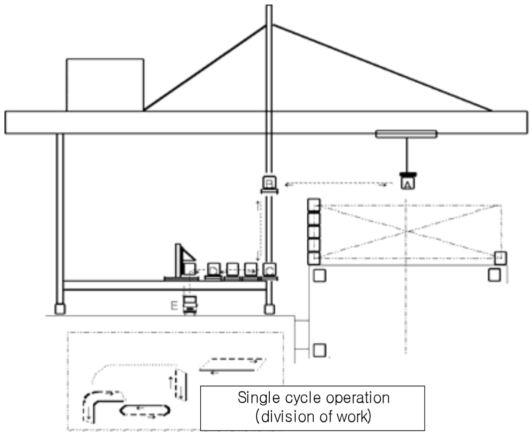

Fig. 3. Operation structure of single cycle crane system.

At first, a container is transported to the elevator horizontally by the main trolley, and the empty trolley returns again to the side of ship. Secondly, the elevator does it vertically to the conveyor. Finally, the container is unloaded to a trailer by the sub-trolley of the land side. Also, the system has the flexibility by the conveyor has the ability of buffer. In case a trailer did not arrive yet under the crane, the container can be stored to the conveyor. That is it can load container immediately at the trailer is arriving. The system has further advantage that is no need to wait the container is stable for the sway. Trolleys have the anti-sway device that is the shape of hard pole type and it is able to regulate the vertical length by withdrawing.

3.2 Dual cycle operation

The proposed crane system can work both single and dual cycle operation. It is able to load and unload simultaneously. In this operation, there are no empty on each work ranges of machines at the full operation. The dual cycle operation of TTEC is expected to bring the improvement of productivity of 1.5 times than the single cycle operation.

4. PERFORMANCE ANALYSIS FOR LOADING/UNLOADING

To prove Excellencies of the developed system, it is required the performance analysis with the conventional crane system. Therefore, we considered the same condition between the conventional and proposed crane for the performance of each machines, crane size, the trolley driving velocity, the hoisting velocity, and etc. Although methodology that evaluate the ability of loading and unloading had been introduced as Taylor's method of time calculation, Gilbereth-married's the research(Hwang, 1992) of detailed action, and etc. But, these are amiss in this research. So, this research applied and evaluated the performance and work times of loading and unloading by the production method for the configured distance on the system, which has been applied popular at many crane manufacture companies.

4.1. Production method for work distance

In this research, the considered work distance that is related on loading and unloading at the port equipments are calculated by the general rule(Korea Encyclopedia Research group, 1995). At first, there was the need the definition for a standard of the crane and ship. And then, we defined the following condition that included the outreach, boom, main frame, the capability of working through the designed size of the general and proposed system, and calculated the work time.

4.2 Calculation of cycle limit

4.2.1 Conventional crane system

The defined work process that was configured by using the standard distances is shows in Fig. 3. And each time of the interval of process, work distances and process can be described in the reference 5(Kim, *et al.*, 200). The performances for each part of machines are shown in the reference 5. The productivity per hour can be calculated as 35[EA/hr] by these conditions.

4.2.2 A proposed crane system (Single cycle)

A working process to apply the reference distance of Fig. 3 in the case of single cycle can be represented as shown in Fig. 4. In Fig. 4, the working processes of single cycle crane system are largely classified the quay's side and sea side, respectively. That is to say, quay's side is also divided the operation processes by ship trolley, elevator and conveyor, sea side is divided by a working process of dock trolley. At this time, the working distance and time of each interval are described in table 4.

Therefore, the velocities, acceleration time and deceleration of load and unload within a working interval of Fig. 1 are described by Table 1~4, respectively. About the velocity, acceleration and deceleration of hoist from Table 1~4, whole working time by following a working process of Fig. 4 is shown in Table 5. Here, we know that an amount for regular hour in working time is 60[EA/hr].

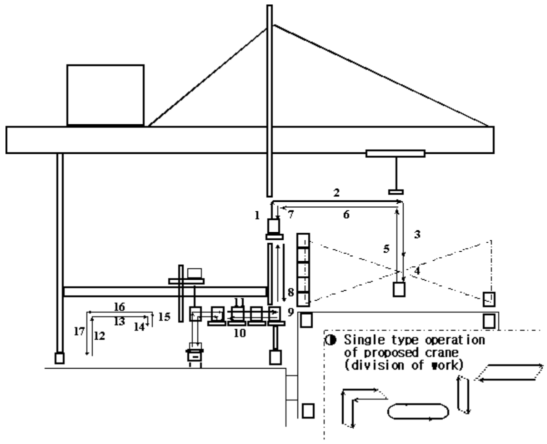

Fig. 4. An Operation process of new type crane system. (single cycle)

4.2.3 A proposed crane system(Dual cycle)

In the case of the proposed crane system, a working process to apply reference distance is represented by Fig. 5. At this time, working distance and time for each interval are described in table 6.

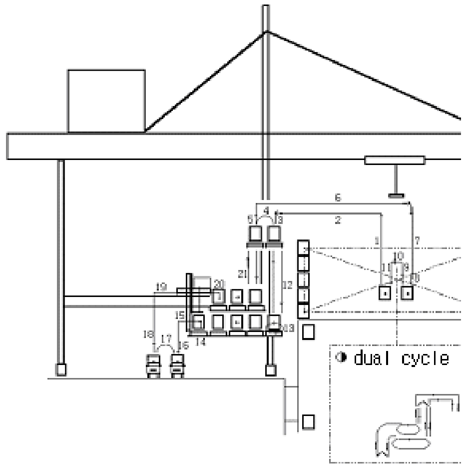

Fig. 5. Operation process of new type crane system. (dual cycle)

Table 1 Velocity and acceleration time of driving equipment for the ship trolley

Item		Velocity [$m/\min$]	Acc. time [sec]	Acc. rate [$m/\sec^2$]
Hoist	Loaded	60.00	1.50	0.667
	Empty	120.00	3.00	0.667
Lower	Loaded	60.00	1.50	0.667
	Empty	120.00	3.00	0.667
Trolley	Loaded	180.00	5.00	0.600

Table 2 Velocity and acceleration time of driving equipment for the elevator

Item		Velocity [$m/\min$]	Acc. time [sec]	Acc. rate [$m/\sec^2$]
Hoist	Loaded	50.00	1.50	0.556
	Empty	100.00	3.00	0.556
Lower	Loaded	50.00	1.50	0.556
	Empty	100.00	3.00	0.556

Table 3 Velocity and acceleration time of driving equipment for the conveyor

Item		Velocity [$m/\min$]	Acc. time [sec]	Acc. rate [$m/\sec^2$]
Transfer	Loaded	100.00	5.00	0.333

Table 4 Velocity and acceleration time of driving equipment for the dock trolley

Item		Velocity [$m/\min$]	Acc. Time [sec]	Acc. Rate [$m/\sec^2$]
Hoist	Loaded	50.00	1.50	0.556
	Empty	100.00	3.00	0.556
Lower	Loaded	50.00	1.50	0.556
	Empty	100.00	3.00	0.556
Trolley	Loaded	100.00	5.00	0.333

Table 5 Cycle time of the proposed crane system. (single cycle)

Driver	No	Motion	Dist. [m]	Moving time [sec] Acc	Run.	Dec.	Total	R/T [sec]	S/T [sec]	Total time [sec]
Ship Trolley		Rest						2.0	2.00	49.41
	1	Hs	1.00	1.23	0.00	1.23	2.45		2.45	
	2	Ts	32.06	5.00	5.89	5.00	15.68		15.69	
	3	Hs	1.00	1.34	0.00	1.34	2.69		2.68	
		Rest						2.0	2.00	
	4	Hs	0.00	0.00	0.00	0.00	0.00		0.00	
		Rest						2.0	2.00	
	5		1.00	1.23	0.00	1.23	2.45		2.45	
	6	Ts	32.06	5.00	5.69	5.00	15.68		15.69	
	7	Hs	1.00	1.23	0.00	1.23	2.45		2.45	
		Rest						2.0	2.00	
Elevator / Conveyor	8	Hel	21.35	1.50	24.12	1.50	27.12		27.12	42.93
	9	Hel	21.35	3.00	9.81	3.00	15.81		15.81	
	10	Tcv	2.60	2.79	0.00	2.80	5.59		5.59	11.18
	11	Tcv	2.60	2.79	0.00	2.80	5.59		5.59	
Dock Trolley		Rest						2.0	2.00	36.06
	12	Hs	5.60	1.50	5.22	1.50	8.22		8.22	
	13	Ts	3.00	3.00	0.00	3.00	6.00		6.00	
	14	Hs	1.00	1.34	0.00	1.34	2.68		2.88	
		Rest						2.0	2.00	
	15		1.00	1.34	0.00	1.34	2.68		2.68	
	16	Ts	3.00	3.00	0.00	3.00	6.00		6.00	
	17	Hs	5.60	3.00	0.36	3.00	6.36		6.36	
		Rest							0.00	
Total cycle time [sec]										49.18

The velocity, acceleration time and deceleration time of load and unload for a working interval of Fig. 5 also are identified with Table 1~4. In the case of the velocity, acceleration and deceleration time of hoist to be got by Table 1~4, whole working time following an operation process of Fig. 5 is represented as Table 7. We can see that an amount for regular hour in working time is 94[EA/hr].

4.3 Synthesis analysis of crane performance

As the above facts for analysis results of loading ability, we know that the developed crane system in this paper has the better performances than the conventional crane systems, such as a working interval, working time and so on. Therefore, Table 8 indicates the comparison results of loading ability for the developed crane system versus the conventional crane. In the case of a working time as shown in Table 8, the single type and dual type of proposed crane system are improved by about 36% and 51% for the conventional crane, respectively.

Moreover, in the case of loading ability for proposed crane systems, we know that single type and dual type crane systems are improved by 58% and 104% for the conventional crane system, respectively. Especially, the merits/demerits of developed crane system are compared with the conventional crane system in Table 8.

From these results, we can minimize waiting time by applying buffer function with Elevator and Conveyor system and settling time by applying anti-sway equipment respectively. Moreover, Table 6 is described the synthesized results of performances compared the developed crane systems with the conventional crane system. As shown in Table 9, for the diversified fields such as the improvement of loading volume, automation capacity, the simplification of structure, the proposed crane systems in this paper have more excellent performance and effectiveness.

Table 6 Comparison of merits/demerits for the conventional crane versus proposed crane.

Item	Conventional crane	Proposed crane
Merit /Demerit	appearance waiting time between crane and trailer necessary settling time	function of bumper : smooth working minimization of waiting time and settling time
Automation	Difficult	Easy (Semi-Auto)

Table 7 Cycle time of proposed crane system. (dual cycle)

DRIVE	No	M	D(m)	Moving Time (sec) Acc	Run	Dec	Total	R/T (sec)	S/T Time (sec)	Total Time (sec)
Ship Trolley		Rest						2.0	2.00	76.40
	1	H	1.00	1.225	0.000	1.225	2.449		2.45	
	2	T	32.06	5.000	5.887	5.000	15.68		15.69	
	3	H	1.00	1.225	0.000	1.225	2.449		2.45	
		Rest						2.0	2.00	
	4	Hs	0.00	0.000	0.000	0.000	0.000		0.00	
		Rest						2.0	2.00	
	5	H	1.00	1.225	0.000	1.225	2.449		2.45	
	6	T	32.06	5.000	5.687	5.000	15.68		15.69	
	7	H	1.00	1.342	0.000	1.342	2.683		2.68	
		Rest						20	2.00	
	8	H	3.60	1.225	0.000	1.225	4.65		4.65	
	9	T	32.06	5.000	5.887	5.000	15.68		15.69	
	10	H	3.60	1.225	0.000	1.225	4.65		4.65	
		Rest						2.0	2.00	
Elevator/ Conveyor	11	H	21.35	1.500	24.12	1.500	27.12		27.12	42.93
	12	H	21.35	3.000	9.810	3.000	15.81		15.81	
	13	T	2.60	2,793	0.000	2.793	5.586		5.59	11.18
	14	T	2.60	2,793	0.000	2.793	5.586		5.59	
Dock Trolley		Rest						2.0	2.00	44.37
	15	H	1.00	1.342	0.000	1.342	2.683		2.68	
	16	T	3.00	3.000	0.000	3.000	6.000		6.00	
	17	H	5.60	3.000	0.360	3.000	6.360		6.36	
		Rest						0.0	0.00	
		Rest						1.0	1.00	
	18	H/T	4.5				8.29		8.29	
		Rest						1.0	1.00	
	19	H	5.60	3.000	0.360	3.000	6.360		6.36	
	20	T	3.00	3.000	0.000	3.000	6.000		6.00	
	21	H	1.00	1.342	0.000	1.342	2.683		2.68	
		Rest						2.0	2.00	
Total cycle time[sec]										38.20

Table 8 Comparison of loading ability for the conventional crane versus the proposed crane

Item	Conventional crane (3550 TEU)	Proposed crane Single Cycle	Dual cycle
A working interval of spreader [m/cycle]	Loading distance 175	Loading distance 87	Loading distance 47
Cycle Time [sec]	77.34	49.18	38.20
Loading capability [EA/hr]	46	73	94

Table 9 Synthetic comparison of the conventional crane versus proposed crane.

Item	Proposed crane Single	Dual	Conventional crane
Amount of loading	70[EA/hr]	94[EA/hr]	38[EA/hr]
Automation	Possible (Semi-Auto)		difficult
manufacture, construction	Using existing crane equipment		-
Simplicity of structure	Minimization of error from simplicity		-
Emergency for fault	Change to conventional crane	Change to single type operation	Stop working
Stability of structure and wind force	Safe structure		bed
Precision of landing for trailer	excellent		Sway
Safety of container	Safe move		Impact for landing
X-Ray inspection	Possible		Complex (difficult)
Mount/demount automation	Possible		Complex (difficult)

Especially, the proposed crane system can solve anti-sway and vibration problem of the crane through separating land side trolley and crane. It is more effectiveness than the conventional crane system, which is integrated the upper part of the crane, in the problem of structural stability. Moreover, since the crane system proposed in this paper can execute buffer operation using conveyor, chain and so on, it is designed by more effective structure to be connected by land side and sea side than the conventional crane system.

5. CONCLUSION

In this paper, we proposed the design method that can improve the productivity and the performance against conventional crane system using elevator and conveyor system. Moreover, in order to sow the effectiveness for the proposed crane system, we can verify more excellent performance than conventional crane system through simulation results. It also has a good merit that we consider an economical problem and the maximum application for structures of conventional crane system. The main characteristic is summarized as follows:

① Improve the ability of loading/unloading by applying separation of the land side and sea side work with trolley and conveyor.
② Increase the efficiency of yard operation by applying buffer function with elevator and conveyor system.
③ Change the method new type and conventional type when occur some error in the land side trolley.
④ Solve anti-sway and vibration problem of the crane through separating land side trolley and crane.

In the further works, if we solve the problems of structural analysis for the designed crane system in this research, the developed crane systems can be expected to apply the actual industrial fields without civil engineering works for conventional crane system.

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