In the present container yard, container boxes are mainly handled manually with a rubber-tired gantry crane (RTG). Terminal operators have strongly requested automated handling equipment to save on labor, raise productivity with information, management and enable 24-hour operation. Orders for cutting-edge automatic rail-mounted gantry cranes (RMGCs) were accepted and high productivity, safety, and reliability delivered. Features include: (1) Automatic operation excluding container handling on the chassis. (2) Improved storage capacity over RTGs and improved productivity thanks to higher operation speed. (3) Landing variation is less than ±50 mm. (4) Safe operation due to self check function on devices and anticollision device.

1. Introduction

Automation of cranes at container terminals includes various problems caused by the outdoor environment, and its realization has been delayed compared with indoor cranes.

The first difficulty with container cranes at the dock is that the relative position of the ship to the crane cannot be surely known due to the rolling motion of the ships.

Transfer cranes in the container yards do not face the rolling motion of ships, and their automation is in a relatively easy environment; however, the automation of the rubber-tired gantry cranes (RTG) most extensively used both domestically and overseas must deal with the irregularities of the tire behavior, and actually has not been realized yet.

In this paper, attention is paid to the automation of rail-mounted gantry cranes (RMGC) uses as yard cranes, and an “automatic operation system for rail-mounted gantry cranes” capable of achieving automatic operation of all container handling operations except container handling in a truck lane was developed, and its outline is introduced below.

Twenty-four systems have been delivered to container terminals in South-East Asia, and the commercial operations were started and have been running smoothly since 1996.

2. Outline of crane

This crane is a rail-mounted gantry crane for handling containers. Table 1 shows the principal specifications, and Fig. 1 schematically illustrates the RMGC. Fig. 2 shows a comparison with a conventional

![Fig. 1 Rail mounted gantry crane (RMGC)](image)
RMGC under operation at site is shown.

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Table 1  Principal specifications

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
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<tbody>
<tr>
<td>Type</td>
<td>Rail-mounted gantry crane</td>
</tr>
<tr>
<td>Number of storage</td>
<td>12-row 6-stack (1 overpass)</td>
</tr>
<tr>
<td>Rated load</td>
<td>40.0 t</td>
</tr>
<tr>
<td>Lift</td>
<td>21.668 m</td>
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<tr>
<td>Span</td>
<td>37.03 m</td>
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<tr>
<td>Trolley travel range</td>
<td>45.43 m</td>
</tr>
<tr>
<td>Wheel base</td>
<td>15.0 m</td>
</tr>
<tr>
<td>Crane width</td>
<td>24.0 m</td>
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<tr>
<td>Speed (m/min)</td>
<td></td>
</tr>
<tr>
<td>Hoisting</td>
<td>35/96 (RTG)</td>
</tr>
<tr>
<td>Trolley travel</td>
<td>150 (70)</td>
</tr>
<tr>
<td>Gantry travel</td>
<td>120 (135)</td>
</tr>
<tr>
<td>Chassis handling</td>
<td>Both sides cantilever</td>
</tr>
<tr>
<td>Feeding</td>
<td>Cable reel</td>
</tr>
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</table>

As shown in Table 1 and Fig. 2, this crane is larger, higher in speed, and considerably higher in container storage capacity than conventional system.

3. Automatic operation

The operation commands from the planning computer in the container terminal are transmitted to the computer on the crane through an optical fiber, and automatic operation is achieved based on commands from the computer on the crane.

3.1 Range of automatic operation

This crane is a double sided cantilever type gantry crane, and the containers are manually handled from the trucks at the cantilever part on both sides.

The manual operation is limited only to the container handling part with trucks, and all other operations are within the automatic operation range. Thus, the operations between legs of the crane are fully automatic, and the automatic operation area is separated from workers except for operations below the cantilever. The container handling part with trucks is manually operated since although the crane can be accurately positioned in the container storage position in the yard, trucks are difficult to be accurately positioned with respect to the crane, and additionally, the trucks used include those exclusive to the yard and those for general roads, and their shape is not constant. Fig. 3 shows the automatic operation area.

3.2 Kinds of automatic operation

The automatic operation includes four types as described below.

1. Loading: the operation to load the containers in the yard on to trucks
2. Unloading: the operation to unload the containers on the trucks in the yard
3. Marshalling: the operation to marshal the containers in the yard within the yard
4. Move: the operation to move only the spreaders while the containers are not transferred

4. Characteristics of the high-speed automatic operation system

The objective of the automatic operation of this crane is to improve the container handling efficiency in the yard, and can be concluded to cope with natural disturbances (including solar heat, sunshine, rain, fog, and wind) specific to the outdoor environment. The concept of the automatic operation is “higher operation speed”, “accuracy” and “safety”.

Each characteristic is described below.

4.1 Higher operation speed

The moving time and the positioning time are shortened due to the greater functionality of the automation part in addition to the increase in the speed and the acceleration/deceleration of each operation including the hoisting, trolley traveling and gantry traveling compared with those of a conventional RTG system. The following technologies are applied to realize this higher operation speed.
The swing of the spreader and the hoisting load includes sway and the skew in which the hoisting load swings toward rotating direction.

Sway during the trolley travel is removed by controlling the acceleration/deceleration of the trolley, and the skew is removed by controlling the motion of the sheave car system installed on the trolley.

When the spreader and the hoisting load approach the target position in the trolley travel direction, the anti-sway with high accuracy and the position is corrected by controlling the motion of the sheave car.

Fig. 4 shows the mechanism of the sheave car, and Fig. 5 shows performance of the anti-skew of the sheave car.

Automatic operation outdoors is affected by natural disturbances caused by wind, etc., however, the anti-skew and positioning with higher operation speed and high accuracy has been realized by the action of this sheave car.

(2) Technology for automatically producing optimum pass

When a container is lowered and landed during the manual operation, landing variation is produced in the deceleration timing by the operator, and the creep time before the landing is not constant. In automatic operation, the deceleration timing is automatic so as to obtain the minimum creep time.

And, if the time for simultaneously implementing the hoisting and the trolley traveling is long, the operation time is shortened.

Manual operation is implemented keeping a safe distance so that the spreader and the hoisting load in question do not collide with other containers stacked in the yard; however, there are cases where the optimum pass can not be obtained since some operators prefer a larger safe distance.

The most important point in automatic operation is to prevent the spreader and the hoisting load from colliding with containers already stacked even when the hoisting and the trolley traveling are simultaneously implemented.

In this system, a stack height detection sensor is installed on the crane in order to automatically detect the stack height, and the shortest trajectory in which the spreader and the hoisting load do not collide with the stacked containers in the yard is calculated based on the data. The stacking information on the yard is compared with the sensor’s measured value, and safety is ensured by adopting the larger height if there is a difference between the two.

Fig. 6 shows a sample chart of automatically produced optimum passes.

4.2 Accuracy

The accurate positioning of the spreader and the hoisting load and a landing accuracy within ±50 mm is needed to be in order to realized implement container
handling operation with an interval of 400 mm of the container stack in the stack area.

**Fig. 7** shows the results of measurements when an empty container, a 20 t container and a 30 t container are landed on the ground 33 times each. The landing variation is ±20 mm on average, and the following countermeasures have been taken in order to realize this accuracy.

1. **Spreader position detection device**

   **Fig. 8** shows the constitution of the spreader position detection device.

   This detection device detects the relative position between the head block and the trolley by installing the laser beam emitters on the right and left ends of the structure, referred to as the head block, suspending the spreader as the light source, detecting the light source by cameras on the trolley, and processing the images thereof.

2. **Landing position estimation control**

   This control is a method to estimate the variation in the landing position during lowering immediately before landing, and if the variation is judged to be within the allowable value, the lowering operation is continued; if the landing variation is judged not to be within the allowable value, lowering is suspended until the landing variation is within the allowable value, and the container is then landed within the allowable value. A series of these operations are automatically implemented by using the spreader position detection device in (1) above. A function is also included within this system so that the landing operation is automatically repeated again if after the landing, the system side judges the landing to be unacceptable.

3. **Structural corrective function**

   In the crane, deviations are produced in the recognized position of the spreader position detection device with respect to the absolute position on the ground due to changes in the inclination of the legs, changes in structural distortions such as the deformation of the girders, and the changes in the clearance between the traveling wheel and the gantry rail which are caused by the movement of the trolley and the hoisting load. Corrective functions to these deviations are provided.

   Light sources moved together with the crane are provided on the gantry rail, the cameras to detect this light source and the clinometer are installed on the girder of the crane, and the movement and the inclination of the girder with respect to the center of the gantry rail are detected on a real time basis. The recognition position on the crane side with respect to the absolute position on the ground is corrected using these detected values.

   A container suspended by wire ropes is landed on to the ground surface within a variation of ±50 mm by controlling the trolley and the sheave at the height of about 30 m from the ground level through the combination of the above-described spreader position detection device, landing position prediction control, the structural corrective function and the anti-sway and positioning control.

**4.3 Safety**

In addition to the self check function of each device, monitoring functions are included to prevent collisions of the hoisting load, realizing safe operation.

Each function is described below.

1. **Consideration of suspended container position when an abnormality occurs**

   Since the hoisting load is suspended by ropes, the hoisting load might oscillated greatly when an abnormality occurs during movement and trolley travel is stopped. The automatic optimum pass takes this into consideration so as to produce an optimum pass free from collision of the hoisting load with stacked
containers even in such a case.

(2) Real time pass trace
Operation is constantly monitored to guarantee sure control along the automatically produced optimum pass. The system is automatically stopped for safety's sake when the difference between the monitored result of the actual operation and the automatically produced pass exceeds the allowable value.

Another function is included exclusively when lowering, in which the falling speed is automatically accelerated/decelerated according to the variation of the position of the suspended container with respect to the target position in order to avoid a collision in a compatible manner between the higher operation speed and the safety. This is realized by constantly implementing the anti-skew and positioning control by the sheave on the trolley in order to cope with problems such as wind even during lowering.

(3) Stack anti-collision sensor
In order to prevent collisions with adjacent containers at the target position in the lowering operation, the adjacent container is detected by the sensors fitted to the spreader.

Collisions with the adjacent containers are prevented by the above-described real time pass trace function in a normal lowering operation; however, the stack anti-collision sensor is provided as the final back-up safety device to cope with any deviation in the adjacent container's position, mistakes of various detectors, and unavoidable disturbances such as the gusts.

(4) Abundant self check function
The safety is further heightened by providing various self check functions to fulfill safety interlocks in addition to the above-described items.

5. Conclusion
The automatic operation of the rail-mounted gantry crane is introduced, in which automatic operation has been realized with outdoor large cranes in container yards with over 3 years of commercial operation experience. The characteristics of the concept of automation, "higher operation speed," "accuracy" and "safety" are described. Individual detailed technologies are omitted for want of space; however, a part thereof are introduced in this Special Issue.

These technologies can be utilized in both future container yards and also in the automation of outdoor cranes. Effort will be made on the study of the automated handling with chassis, and realization of complete automatic operation.

References
(1) Miyata, Semi-Automatic Operation System of Rail-Mounted Gantry Cranes, Study Announcement of the Special Lecture at the 20th All-Japan Crane Safety Meeting of the Japan Crane Association (1999)