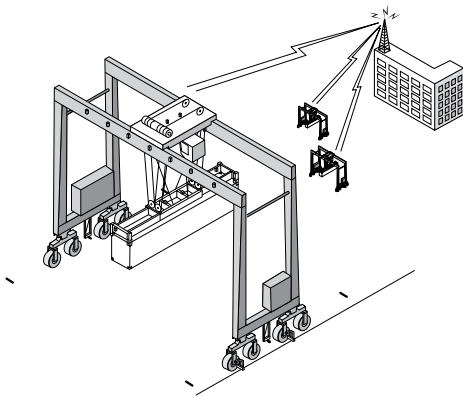


# Automated transfer Crane

Kanji Obata  
Koji Uchida  
Takashi Chikura  
Hirofumi Yoshikawa  
Tadaaki Monzen



In 1996, Mitsubishi Heavy Industries, Ltd. (MHI) succeeded in putting its large-size automated rail-mounted gantry crane (RMGC) into practical use for the first time in the world. Now, there is an urgent need for the automation of rubber-tired gantry cranes (RTGs), because they are used widely to handle containers in container yards. Because of the characteristics of rubber-tired wheels, automation of RTGs has always been considered difficult. To meet this need, MHI has developed an automated RTG through the application of (1) container stacking position deviation detection technology using CCD cameras mounted on the spreader to hold the container, (2) high-accuracy stacking control technology and (3) automatic traveling control technology for guiding the crane to the target position in the gantry direction.

## 1. Introduction

MHI has been making efforts to develop automated cranes to meet users' needs for automatic and labor-saving container handling operations in container yards.

Among various types of cranes being operated in container yards, MHI has already applied the automatic operation system to its large-size rail-mounted gantry cranes (RMGCs) which are operated in container stack areas for stacking and delivery of containers<sup>(1)</sup>.

By reason of their high mobility and flexibility to various yard layouts, rubber-tired gantry cranes (RTGs) are in widespread use all over the world, and accordingly, automation of the RTG is greatly desired. However, this had not been realized due to the structure of RTGs of which the crane body is supported by rubber-tired wheels. More specifically:

- rubber tires are apt to vibrate and deform, making it

difficult to ensure container stacking accuracy in automatic operation, and

- as this crane travels on tracks having no mechanical guide such as rails, automatic control for allowing it to travel along the given track and reach the target position is harder to achieve than in the case of RMGCs.

This report gives an outline of the new technologies developed by MHI to solve the technical problems for realization of practical operation of automated RTGs.

## 2. Outline of automated RTG

**Fig. 1** illustrates the general construction of the newly developed automated RTG and **Table 1** shows the main specifications. The automated RTG has been completed by adding sensors and a control unit to the standard type manually operated rubber-tired gantry crane.

Hence, the automated RTG can be operated automatically by giving the required operating commands either directly from an RTG operator's cab or remotely from a planning computer located in the container terminal via a radio transmitter.

### 2.1 Automatic operation zone

**Fig. 2** shows the zone in which the automated RTG is automatically operated, which is separate from the manually operated zone.

Only loading and unloading of containers on and from the chassis, which is used as a container transfer truck, is carried out manually. Automatic operation is performed in all other areas. The reason why manual operation is selected for handling containers in the chassis lane is that it is not easy for the chassis operator to maneuver the chassis by hand accurately to the working position of transfer crane, whereas the automated RTG

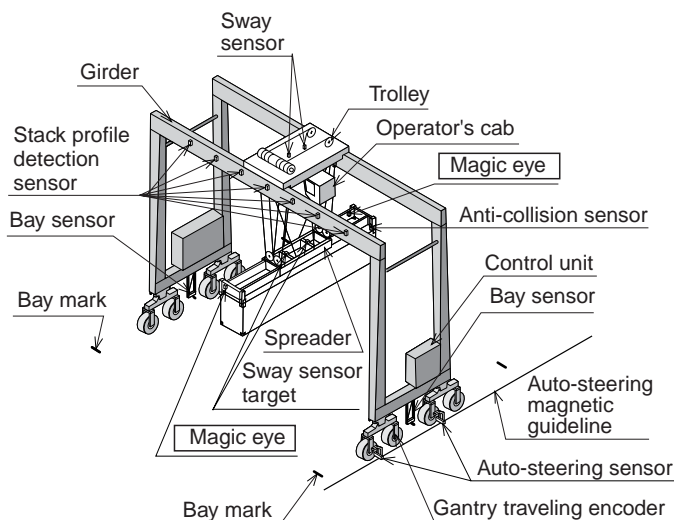


Fig. 1 Type and position of sensors mounted on the automated RTG

Table 1 Main specifications of the automated RTG

Type		6 container rows plus 1 chassis lane, 1 over 4 stacked
Container	Type (ft)	ISO 20/40/45
	Rated load (ton)	40.6
Speed	Main hoisting (m/min)	23 to 52
	Trolley traveling (m/min)	70
	Gantry traveling (m/min)	135
Yard gradient	Trolley traveling direction	Less than 1/100
	Gantry traveling direction	Zero
Sensors for automatic operation		Magic eyes, sway sensors, auto-steering sensors and bay sensors

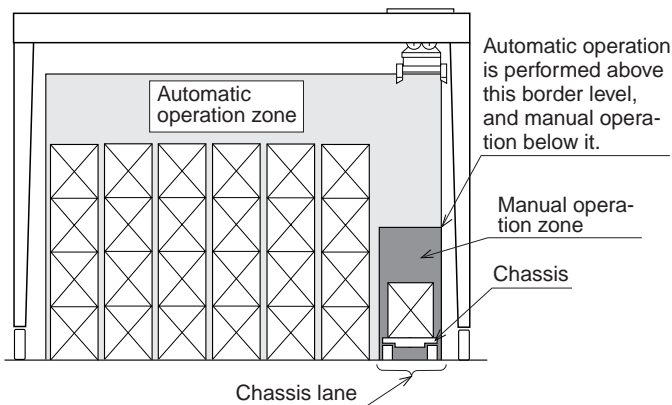


Fig. 2 Automatic operation zone and manual operation zone  
The automated RTG is operated independently in the automatic and manual modes in these zones, as shown.

can be positioned accurately in the container stack area in the yard. This manual operation is carried out carefully by the RTG operator.

When delivering a container from the stack area onto the chassis, the container being lifted by crane (lifted container) is lowered by automatic operation until it has reached the preset border level, and the operation mode then changes to manual operation. When lifting up a container from the chassis, the operator manually controls the hoisting device until the container has reached the preset border level at which automatic operation becomes valid. The position of the chassis lane is determined according to the yard layout data base which has been entered beforehand into the control unit of the automated RTG.

Furthermore, automatic operation mode changes to manual mode whenever the operator manually intervenes in the automatic operation for any reason.

### 2.2 Scope of automatic operation

- (1) Transferring containers from chassis and stacking them in the container stacking area,
- (2) Delivering containers from stacking area to chassis,
- (3) Changing the position of containers inside the container stacking area, and
- (4) Changing the position of spreaders without carrying the container.

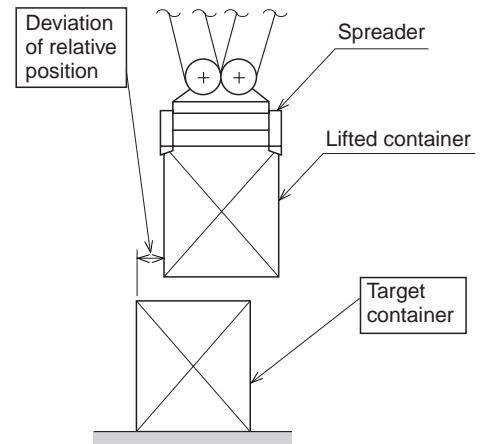


Fig. 3 Relative position deviation  
An example of the deviation of relative position of the lifted container from the target container

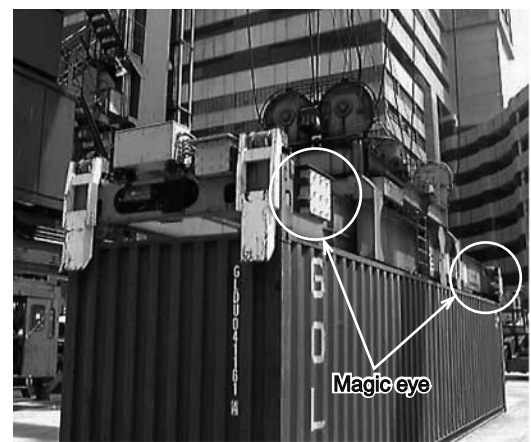


Fig. 4 General view of magic eyes mounted in place

To perform the above-mentioned automatic operations, the automated RTG has the following functions:

- Automatic control of spreaders to stack the lifted container on top of another container or on the floor of the container stacking area in the automatic operation zone
- Automatic control of hoisting and trolley traveling to the target stacking position
- Automatic steering control and automatic positioning control to the gantry target position.

### 3. RTG automation technologies

MHI has developed the following technologies for the automation of RTGs:

#### 3.1 Magic eye

To place a lifted container accurately on top of another container already stacked in the container stacking area (a target container), deviation of relative position of the lifted container from the target container must be detected as shown in **Fig. 3**. For this purpose, MHI has developed a special magic eye.

The magic eyes are mounted at the right and left corners of the front side of the spreader (**Fig. 4**). Each magic eye consists of a CCD camera and a light source. Using

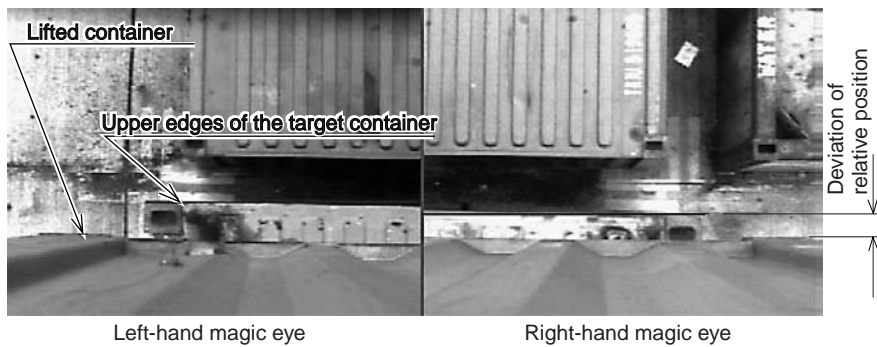


Fig. 5 Pictures taken by a pair of magic eyes  
These two pictures are taken by magic eyes and processed by an image processing device.

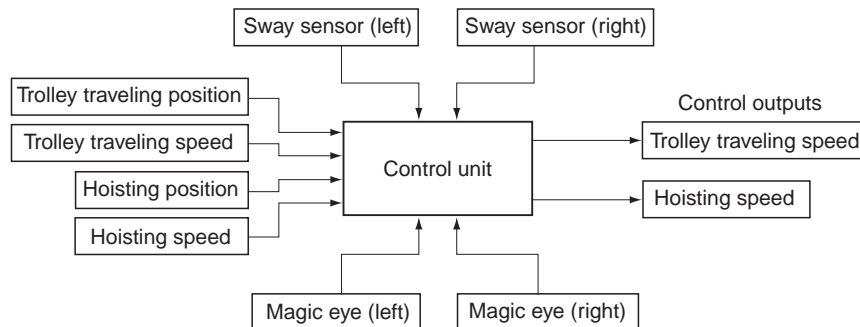


Fig. 6 Block diagram showing an outline of automatic stacking control

the picture below the spreaders taken by the CCD camera, an image processing device detects the positions of the upper edges of the target container and the lower edges of the lifted container and determines the deviation of relative position between them. **Fig. 5** shows an example of the processed pictures taken by the magic eyes.

Generally, in operating RTG, deformation and vibration occur in the rubber tires and structural members when its trolley travels or when a container is being loaded. Also, the spreader sway when the trolley travels or when the wind blows in from outside, because they are suspended from the trolley by wire ropes. Despite these disturbances, the magic eyes are capable of detecting directly the deviation of relative position of the lifted container from the target container to ensure accurate stacking control.

### 3.2 Automatic stacking control

**Fig. 6** shows a block diagram of automatic stacking control.

A lifted container position is controlled so that the deviation of relative position detected by the magic eyes is eliminated, and it is lowered toward the target container. As the upper edges of the target container become undetectable by the magic eyes when the deviation of relative position has become zero, signals from the sway sensors<sup>(2)</sup> are jointly used to correct the position of the lifted container to the end.

When the lifted container has been lowered to the level shown in Fig. 3, it is lowered further and finally placed on top of the target container if the deviation of relative

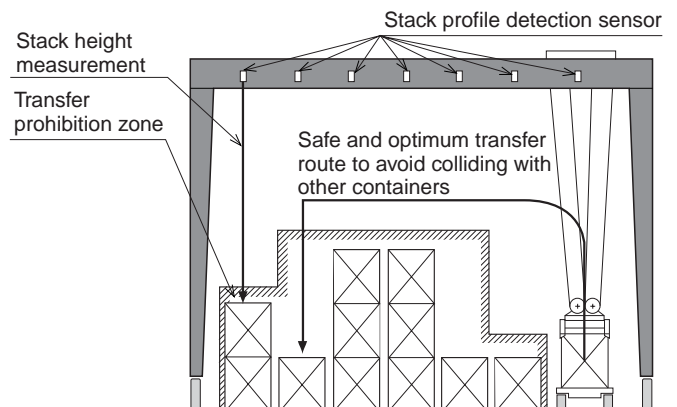


Fig. 7 Safe and optimum transfer route  
Safe hoisting and trolley traveling to avoid colliding with other containers stacked in the yard are shown.

position of the lifted container is within than the permissible value and the container is stable without any sway, or even if the container is still swaying slightly, if it is judged that the deviation of relative position will fall to within the permissible value when it is finally placed on the target container.

### 3.3 Automatic hoisting and trolley traveling control

For handling (hoisting, trolley traveling and lowering) of a lifted container, stack profile detection sensors are installed facing downward on the underside of the crane girder to detect the height of each stack, so that the lifted container can be moved safely and quickly to the target position via the optimum transfer route and without colliding against other containers stacked in the yard. **Fig. 7** shows an example of an optimum transfer route for hoisting and trolley traveling. To reduce the

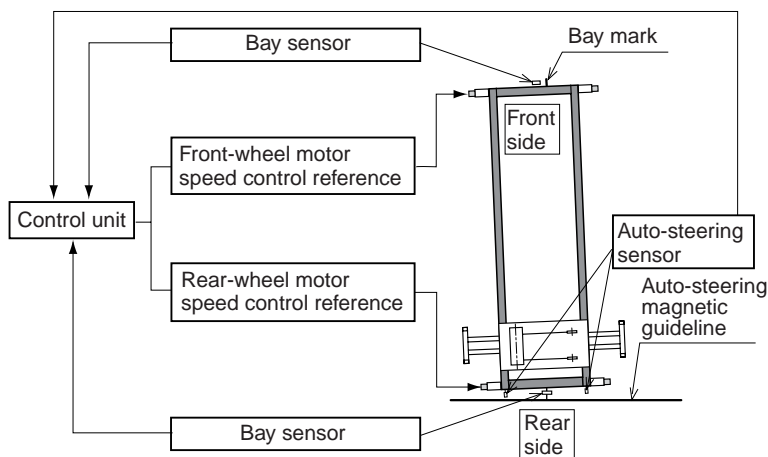


Fig. 8 Outline of automatic gantry traveling control

Table 2 Specifications of the tested automated RTG

Type		6 container rows plus 1 chassis lane, 1 over 6 stacked
Speed	Main hoisting (m/min)	26 to 60
	Trolley traveling (m/min)	70
	Gantry traveling (m/min)	120

sway of the lifted container during trolley traveling, a mechanical anti-sway control device, which is part of the standard equipment, is installed, and the sway-suppressing speed pattern on which the trolley traveling speed is accelerated or decelerated at the pitch of an integral multiple of the swaying frequency of the lifted container is used. Trolley traveling is controlled by the position signal feedback system. The trolley is stopped when the deviation of the present position from the target position becomes about zero. Ultrasonic sensors are mounted on the side face of the spreader to prevent the lifted container from colliding against a neighboring container during the hoisting and lowering operation.

### 3.4 Automatic gantry traveling control

Automatic gantry traveling control consists of automatic steering control<sup>(3)</sup> and automatic positioning control (bay positioning control).

An outline of the system of automatic gantry travel control is shown in **Fig. 8**.

Automatic steering control is implemented in such a way that the auto-steering sensors mounted on the left and right sides of the gantry rear ends detect any deviation of the actual traveling course from the reference traveling line (auto-steering magnetic guideline) installed on the floor surface, and the speeds of the front and rear traveling wheels are adjusted to reduce the detected deviation to zero.

Automatic positioning control is implemented by using the traveling encoder mounted on the traveling wheel and the bay sensors to detect the bay marks that represent the stacking position in each yard in the gantry traveling direction. The traveling speed is reduced to a



Fig. 9 General view of automated RTG under verification tests

low-speed range when the distance to the gantry target position counted by the traveling encoder becomes equal to the distance needed for deceleration of traveling speed. While the RTG is traveling at a low speed, the bay sensors mounted on its front and rear ends search for the bay marks. When the bay sensors detect the bay marks within the permissible distance ( $\pm 25$  mm), the front and rear ends of the gantry are stopped independently so that the RTG is positioned accurately and also at right angles to the yard.

## 4. Verification tests

To verify the actual performance of the automated RTG which has been developed by implementing the RTG automation technologies described above, verification tests were conducted in cooperation with the joint research partner (Modern Terminals, Hong Kong).

### 4.1 Outline of verification tests

**Fig. 9** shows a general view of the automated RTG under test, and **Table 2** summarizes its specifications.

### 4.2 Result of verification tests

An existing transfer crane modified into the automated RTG was tested in the various environments likely to be encountered in actual operation – such as sunny, rainy and cloudy days, daytime, nighttime, etc. The container stacking/delivery cycle time of automatic operation was roughly equal to that of manual operation, and 97 per cent of the containers were stacked with an accuracy of  $\pm 25$  mm from the target container by automatic operation. Automatic traveling control was proved to be capable of positioning the gantry's front and rear sides within  $\pm 25$  mm from the gantry target position almost one hundred percent of the time, and that the time needed for traveling and positioning was 20 per cent shorter than in the case of manual operation.

As the test results proved that the automated RTG showed an acceptable performance for practical operation, it was operated in the actual container yard for about one month.

### 5. Improvement of performance of automatic operation

Through examinations of the test results obtained from the verification tests conducted at the premises of Modern Terminals, Hong Kong, the following measures were taken for further improvement of the performance of automatic operation:

- (1) For reduction of cycle time:
  - Development of an anti-skew control mechanism for spreader and lifted container
  - Application of a high-response anti-sway control system<sup>(4)</sup> by means of feedforward/feedback control
- (2) For increase of stacking accuracy:
  - Development of a new type of magic eye using a laser beam to detect container edge with higher accuracy
  - Application of observer to increase significantly the anticipating accuracy for relative position deviation of spreader and lifted container

As a result of the above improvements, the automated RTG was operated at a cycle time (handling capability) of 30 containers or more per hour and with a stacking accuracy within  $\pm 25$  mm for more than 99 per cent of containers (deviation over  $\pm 25$  mm occurred only once during a three-hour operation period, which may occur even in conventional operation).

### 6. Conclusion

In this paper, the automated RTG, which is the main item of equipment used in container yards and is equipped with the specially developed “magic eye,” “automatic stacking control” and “automatic gantry traveling control,” has been introduced.

The verification tests conducted in the container yard in Hong Kong has proved that the developed automated

RTG can be used to realize automatic container handling.

In addition, further improvements of the magic eye and automatic control algorithm are expected to allow the container handling operation to proceed with a cycle time of 30 containers or more per hour and with a stacking accuracy within  $\pm 25$  mm for 99 per cent of the containers.

MHI wishes to contribute toward automation and labor saving of container yard operation by supplying its automated RTGs.

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Hiroshima Machinery Works



Kanji Obata



Koji Uchida

Hiroshima Research & Development Center,  
Technical Headquarters



Takashi Chikura



Hirofumi Yoshikawa



Tadaaki Monzen