Inspection Robot System for Hull Structure

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For ship safety, periodical inspection and maintenance in service is very important together with care during designing, building, and operation. For this reason Mitsubishi Heavy Industries, Ltd. (MHI) has developed an inspection robot system that can carry out easily, safely, and accurately tank inside construction inspections of the crude oil tanker, which has been difficult to carry out from the restriction of height, large spaces, and residual sludge. Its features are as follows: (1) Automatic setting of monorails makes scaffolding as high as 30 m unnecessary and brings labor saving and efficiency improvement. (2) By means of remote/automatic operation from the upper deck, pretreatment tools, television camera for remote visual inspection, and sensors for cracks and plate thicknesses can access to narrow construction areas and very safe and highly-accurate inspection can be achieved.

1. Introduction

For ship safety, periodical inspection and maintenance in service is very important together with care during designing, building and operation. Among these activities hull structure inspection has been promoted internationally, and expansion of the inspection range, improvement in accuracy, etc. have been aimed at for many years. In the case of very large crude oil carrier (VLCC), however, it has been difficult to carry out sufficient inspections of the internal structures of tanks because a large number of persons, a long period and dangerous work are required in preparation for inspection such as setting large scaffolding and removing residual sludge.

Therefore for inspections of the internal structures of tanks of VLCC in particular, MHI has developed a robot inspection system which is capable of automatic teleoperating from the upper deck and has verified its functions in tests on ship. An outline of this system is described below.

2. Objects of inspection and concept of robot inspection system

Fig. 1 shows objects of inspection and concept of robot inspection system.

The objects of inspection are the parts of the side shell and longitudinal bulkhead ①, the parts of upper under deck ② and the parts of transverse web frame ③ in the large tank. The parts of the side shell and longitudinal bulkhead ① are the portions where the transverse bulkhead and transverse ring intersect the stepped longitudinal frame attached to the side shell and longitudinal bulkhead. The parts of upper under deck ② are the portions where the transverse bulkhead and deck transverse web intersect the longitudinal frame attached to the underside of the upper deck. The parts of transverse web frame ③ are the portions where the bracket and web stiffener intersect the face attached to the corner of transverse web frame in the side tank. Each of these parts is a narrow area in a high position with intricate aggregates, and crack inspection is done mainly for the toes of fillet welded and plate thickness in its vicinity.

The concept of robot inspection system is that after being entered in the tank through the hatch and set at a certain position, the robot is operated by means of remote and automatic operation from a control room on the upper deck.

3. Robot inspection system

Fig. 2 shows the equipment of this system and Table 1 shows its specification.

3.1 Traveling equipment
3.1.1 Traveling equipment for side shell and longitudinal bulkhead

MHI has developed a method of automatic setting monorails from the bottom as a traveling method for the side shell and longitudinal bulkhead.

The principle of this method is as follows.
Table 1 Specification of system

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveling equipment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Side shell and longitudinal bulkhead</td>
<td>Type</td>
<td>Jacking-up monorail/Vertical movement carriage</td>
</tr>
<tr>
<td></td>
<td>Speed of vertical movement</td>
<td>2.8 m/min</td>
</tr>
<tr>
<td>Under upper deck - Transverse web frame</td>
<td>Type</td>
<td>Horizontal expanding rail/Horizontal movement carriage</td>
</tr>
<tr>
<td></td>
<td>Speed of horizontal movement</td>
<td>6 m/min</td>
</tr>
<tr>
<td>Manipulator</td>
<td>Type</td>
<td>Vertical anthropomorphic type with telescopic arm</td>
</tr>
<tr>
<td></td>
<td>Degree of freedom</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Pated load</td>
<td>50 N</td>
</tr>
<tr>
<td></td>
<td>Positioning accuracy</td>
<td>±1 mm</td>
</tr>
<tr>
<td>Teleoperating controller</td>
<td>Type</td>
<td>Personal computer</td>
</tr>
<tr>
<td></td>
<td>Power</td>
<td>DC 110V/220V, Stabilized electric power</td>
</tr>
<tr>
<td></td>
<td>Cable</td>
<td>Power/Optical composite cable : 200 m</td>
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<tr>
<td></td>
<td>Teaching</td>
<td>Automatically created from off-line hull structure data</td>
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<tr>
<td></td>
<td>Operating method</td>
<td>Automatic/Manual with joy stick</td>
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<tr>
<td></td>
<td>Monitor</td>
<td>3-dimensional graphics, Observation TV</td>
</tr>
<tr>
<td>Inspection and data processing equipment</td>
<td>Visual inspection</td>
<td>×10 zoom ITV camera, Optical disk recording</td>
</tr>
<tr>
<td></td>
<td>Crack inspection</td>
<td>Eddy-current method, Accuracy width : 0.2 mm, Depth : 1 mm or more</td>
</tr>
<tr>
<td></td>
<td>Plate thickness inspection</td>
<td>Ultrasonic method, Plate thickness : 5 mm or more, Accuracy : ±0.1 mm</td>
</tr>
<tr>
<td></td>
<td>Recording and editing</td>
<td>Personal computer</td>
</tr>
</tbody>
</table>

Fig. 2 Equipment of this system
This system is composed of traveling equipment for the under upper deck and transverse web frame, side shell and longitudinal bulkhead, manipulator for the above parts, teleoperating controller, inspection and data processing equipment, and support equipment.

As shown in Fig. 5 appearing later, the joint type FRP rails are sequentially inserted into the jacking-up equipment on the bottom and jacked up by pneumatic cylinders. The clamp built in the rail is fixed on the longitudinal frame with a proper pitch to guide the rail being jacked to prevent it from falling. As a result, the rail can be lengthened and installed as high as about 30 meters along the side wall.

The vertical movement carriage which carries the manipulator, traveling control panel, etc. travels by winding the wire rope from the top of the monorail.

3.1.2 Traveling equipment for under upper deck and transverse web frame

Fig. 3 shows the process of mock-up test with the traveling equipment for under upper deck and transverse web frame. For vertical movement to a high position, the horizontal expanding rail is winched with wire rope after setting the above-mentioned monorail on both sides or installing air winch on the upper deck.

Then, it is fixed on the side wall longitudinal frame at a certain height and the carriage of manipulator is made to travel horizontally.

3.2 Manipulator

MHI has developed the small anthropomorphic manipulator which positions the descaling tool (composed of a brush to remove sludge and a hammer to remove scale) and sensors for cracks and plate thicknesses at proper 3-dimensional angles to the objects of inspection. The rated load of end effector is 50 N and dead load 13 kg.

As shown in Fig. 5 appearing later, for the side shell and longitudinal bulkhead MHI has also developed a telescopic intermediate arm and manipulator carriage which travels on the longitudinal frame by means of this arm. The combination of these ensures a horizontal operating range of max. 3 m and makes it possible to inspect both sides by setting a monorail midway between the transverse web rings. The end effector is

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Fig. 4 Flow of system control
The inspection position data is created off-line and the robot teaching data is automatically created on the deck. After operation and recording, the data is processed off-line.

3.3 Teleoperating controller
The control computer, graphic monitor, observation TV, etc. in the control room on the upper deck are connected to the robot in the tank using power and optical fiber composite cables. MHI has developed a stabilized electric power supply to be able to use cables with a smaller diameter and also developed a multilayer printed circuit board to minimize the size of the robot's traveling control panel. Fig. 4 shows the flow of system control including automatic operation and data processing to be described in the next section. On the basis of the inspection position data created off-line from the CAD data base of hull structure designing CAD system, the teleoperating controller on the deck automatically creates the teaching data, controlling the robot, descaling tool and sensors for cracks and plate thicknesses. By means of the simplified graphic monitor, the teaching data can be checked with regard to the surroundings and the operating conditions during automatic operation can be monitored.

3.4 Inspection and data processing equipment
Crack inspection is done with the ITV camera for remote visual inspection and the eddy-current type sensor for cracks. To improve the accuracy of crack detection with remote visual inspection, the camera is capable of magnified observation with a ×10 zoom and teleoperating control of focus and iris and the lighting is made more suitable, which enables detection of cracks having a width of about 0.3 mm.

With the eddy-current type sensor for cracks, small cracks having a width of about 0.2 mm and a depth of about 1 mm can be detected. The length of cracks is determined from the sensor scanning distance.

Plate thickness inspection is performed with the ultrasonic probe without contact by pouring couplant water with a precision of ±0.1 mm.

As the result of the above-mentioned inspections, the detected information such as inspection positions, existence of cracks, length of cracks, etc. and the graduated scales are displayed, through the character generating equipment, on the remote visual inspection ITV monitor screen, output by the video printer, and recorded on the optical disk. The inspection results regarding the existence of cracks and depth and length of cracks obtained with the eddy-current type sensor for cracks are automatically recorded in the specified format. The plate thickness data is automatically recorded in the same way. This recorded data can be automatically edited to make detailed reports, damage distribution diagrams, etc., which can be printed out and retrieved.

4. Test on ship
MHI has made an operational suitability test of this system in a VLCC docked for periodical inspection. For each device to be brought into the tank, safety measures are taken such as internal pressure explosion-proofing by air, gas sensors alarms, power breakage by detection of cable cuticle. The application section was the side shell of the side tank of the 258,000 ton D/W VLCC. Fig. 5 shows the test conditions.

In this test, automatic setting of monorails, vertical movement to a high position on the longitudinal frame, setting and lengthening of the carriage of the manipulator on the longitudinal frame by the intermediate arm, and slide
removing operation on the toe of fillet welded and crack
inspection by the manipulator were performed as required.
Since there were no cracks in the side shell of the ship used for
this test, by placing a simulation test plate on the specified
position, it was verified that the ITV camera for remote visual
inspection and the eddy-current type sensor for cracks
provided the above-mentioned accuracy of crack detection.
Sludge and oil scale were removed efficiently by the air brush
and hammer. It was also verified that the sensor for plate
thicknesses has a precision of ±0.1 mm.

5. Conclusion

MHI has developed a robot inspection system which
enables more sophisticated inspections of the internal struc-
tures in tanks of VLCC and have verified its usability in tests
on a ship. This system is effective in ensuring ship safety as
will be increasingly required in future. MHI will make this
system more efficient and put it into practical use as soon as
possible.

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