The development of the support system for tugs operation

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Abstract

Most of the work-load of ship's operator using tugboats is to execute the complex information processing such as the collection, analysis, decision making and to control tugboat separately. We developed the support system to decrease their work-load and to improve the efficiency of tugboats operation. The system is developed based on the ship maneuvering characteristics, human characteristics and man-machine interface. The effectiveness of proposed support system has been confirmed by examining the operation of tugboat using the ship-handling simulator. As a result, the efficacy of the support system that we developed has been clarified.

1. The state of the ship maneuvering using tugboats

The ship maneuvering using tugboats is one of the most difficult handling in comparison with other ship-handling. Especially, the difficulty increases when a large ship does docking by using tugboats. There are two causes of the difficulty. It is related to the docking maneuver and the operation of tugboats. The details are as following,

(1) Difficulty on the docking maneuver

First of all, the special motion such as the transverse movement without turning, the oblique movement and the rotating is necessary for docking. These motions are not required in normal navigational situation. The fluid dynamic resistance to the transverse motion is bigger than the longitudinal motion in case of general hull form, and
the interaction is complicated. So, ship operator must predict the motion of the hull separately with respect to longitudinal and transverse motion. Next, when approaching a quay and pier, the ship operator must realize extremely exact motion to prevent collision. Moreover, the growth of the motion of the large ship is quite slow and the long time is needed to stop after the motion reached constant velocity. So, the ship operator must do detection and adjustment of unexpected motion early.

(2) Difficulty on the control of tugboats:

The objects that the ship operator must control increase when a number of tugboats are used for controlling the big ship. As the number of tugboat increase, the control is becoming complicated. Besides, there is the difference in the influence that the tugboats give the hull due to the place of each tugboat and hydrodynamic reaction. Accordingly, each tugboat should be controlled as the independent system that had each different characteristic.

In the docking maneuver in comparison with usual navigation, the ship operator has to predict motion very precisely under the very small motion. In order to control the ship properly, operator must collect much information precisely and must analyze them exactly. In case of using many tugboats, the object the ship's operator must order increases indeed. It is thought that these processing give a big burden to the ship's operator.

(3) Countermeasure for the difficulty in present operation:

In the present operation, the difficulty mentioned above are treated to realize the required motion as following.

1. Increasing operating member to distribute task and to decrease the work-load.
2. Avoiding carrying out the plural operation simultaneously to decrease complicate information processing.
3. Executing the operation in the condition of slow motion to keep the time.
4. Avoiding using many tugboats simultaneously to decrease complicate information processing.

In this paper, the support system is proposed to improve the efficiency of docking maneuver under the condition of minimum number of operator.

2. Support System for Docking

2.1 Supported Functions

Supported contents must be realized based on the concept of man machine system. We have developed support system by analyzing the
issues on required functions, and the issues are solved by developed following subsystems.

(1) Easy commanding devices

The difficulty of operation of many tugboats is caused by the difference between the required motion and thecommanding items. Operator must decide the distribution of tug force corresponding to the required motion. In developed system, operator can command the desired direction and power directly by using joy-stick devises. Course direction is also ordered directly by using course dial.

(2) Control system on tugboats operation

There is a limit in the information analysis that the ship operator can execute. So it is difficult to calculate necessary power of each tugboat precisely and instantaneously in order to realize intended motion. Developed support system decides these required powers. As a result, the information analysis operator should execute can be reduced substantially.

(3) Easy understanding information display

In order to make proper command, it is necessary to get the information on present motion and actuating situation easily and exactly. Fig. 1 shows the information on the display.

2.2 Constitution of the support system

The constitution of the support system and the flow of control are shown in Fig.2. A symbol Xe shows the power for longitudinal movement. Ye shows the power for transverse movement. Ne shows the moment for turning. Xn, Yn shows the commanded thrust of each tugboat arranged along the hull.

![Fig.1 Information display](image1)

![Fig.2 The constitution of the support system and the flow of control](image2)
2.3 Information conversion system in the support system

A coordinate used in this paper is shown in Fig.3. Symbols X, Y indicate force and N indicates moment. Symbols u, v, r mean the velocity of longitudinal movement, the velocity of transverse movement and rate of turn of the hull. $\psi$ shows the course. Information conversion system is main system of support system. This system is constructed with 3 parts as following.

(1) Difference detector on the course angle

Difference detector provides the difference of course angle between present and ordered angle to the turning moment controller. At the same time, Rate of turn is detected and provided to the turning moment controller.

(2) Turning moment controller

In the turning moment controller, the required tuning angle provided by difference detector is converted to the turning moment. This conversion is carried out in consideration of the difference of courses and the rate of turn.

(3) Power controller

In the power controller, necessary force of each tugboat is decided based on the commanded longitudinal and transverse force and turning moment. Maximum power of tugboat and the place of each tugboat are taken into account. In case of present control system, the following conditions are supposed. The force due to tugboat acts on the hull normally. Tugboats are used for longitudinal and transverse motion independently. The force inducing longitudinal motion is distributed to the each tugboat equally allocated at the bow and stern. The force inducing transverse motion and turning motion are distributed to the each tugboat allocated side of hull in consideration of each tugboat's power and position.

Fig.3 Coordinate
3. Evaluation of the support system

The evaluation on the developed support system were carried out using ship-handling simulator in order to assess the safety, efficiency and operator's work-load.

3.1 Experimental condition

Experimental condition is shown in Fig.4. The experimental movements are three patterns that are often realized in actual docking maneuver. The transverse movement without turning, the oblique movement without turning and the transverse movement with turning were carried out. The objects of these handling are to start from fixed position under stopped and move on the planned line and stop at fixed position.

Principal dimension of the ship used in the experiment is shown in Table.1. Example of tugboat arrangement is shown in Fig.5. The operator can use 5 or less tugboats and decide the positions. The evaluating experiments were carried out to compare the movement using support system and not using support system. In both experiments, the positions of tugboats are same that is decided by operator.

![Fig.4 Experimental condition](image)

**Table.1 Principal dimension of the ship**

<table>
<thead>
<tr>
<th>Ship type</th>
<th>VLCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>condition</td>
<td>Full load</td>
</tr>
<tr>
<td>Gross tonnage</td>
<td>259.897 (ton)</td>
</tr>
<tr>
<td>Length overall</td>
<td>324.0 (m)</td>
</tr>
<tr>
<td>Breadth</td>
<td>56.6 (m)</td>
</tr>
<tr>
<td>draught</td>
<td>19.20 (m)</td>
</tr>
</tbody>
</table>

![Fig.5 Example of tug arrangement](image)
3.2 Result of the ship maneuvering

(1) Transverse movement without turning

The trajectories are shown in Fig.6. Although both of trajectories are similar, the contents of control show the difference. By Fig.7 showing transverse velocities, the ship maneuvering with the support system is consisting with one time's transverse movement and fine adjustment after that. In comparison with it, handling without the support system is repeating many adjustments for transverse movement. By Fig.8 showing the time-histories of generating thrust of tugboats, the control with the support system is the easy operation corresponding to required movement. On the contrary, the control without the support system changes the small thrust repeatedly. Also, there is the time zone that only one tugboat is used.

![Fig.6 Trajectories of transverse movement without turning](image1)

![Fig.7 Transverse velocity](image2)

![Fig.8 The time-histories of generating thrust of tugboats](image3)
(2) Oblique movement without turning

The trajectory of ship using support system indicates a good result shown in Fig. 9, the ship is almost moving on the planed line. But, in case of the maneuvering without the support system, the ship missed the course line just after start. The maximum deviation from planed route reach to 43 m. In order to realize the oblique motion without turning, it is necessary to estimate the progress of the motion on longitudinal and transverse. The ship maneuvering without the support system is not possible to estimate them accurately.

Fig. 9 Trajectories of oblique movement without turning

Fig. 10 The time histories of motion
The time-histories of motion are shown in Fig. 10. Course control without support system cannot keep required course due to lack of estimation on the fluid dynamic forces. In order to realize oblique motion without turning, it is necessary to keep the balanced velocity between longitudinal and transverse direction. With the support system, balanced velocity is kept. On the contrary, without the support system, it is not realized and the changing of both velocities cannot be controlled simultaneously. It is difficult to control two kinds of velocity of movement simultaneously, so the operator controls one after the other.

(3) Transverse movement with turning
The control for the transverse movement with turning by applying the force control is very difficult because the relation between the moving direction and course direction change continually due to the turning motion. As a result, in case of not keeping the balanced situation, her motion becomes a big deviation from planned route. This complex movement requires the operator over capable capacity of information processing when operator controls the force acting transverse direction that is tugboat. Nevertheless, the trajectory of ship using support system shown in Fig. 11 shows the planned movement with fluctuation that is transverse movement with turning. In case of the motion of ship without support system, she kept her position on the planned route until turning, then her motion deviated from planned one quite big after turning. This movement can be assessed that the purpose was not achieved.

The time-histories of generating thrust of tugboats are shown in Fig. 12. In case of ship using support system, the plural tugboats are operated to make coordinated movement of longitudinal and transverse forces. On the contrary, the coordinated actions are seldom seen in the case of the motion without support system. It was not possible for the operator to analyze the complicated information. So, he was not able to command appropriately with appropriate timing.

Fig. 11 Trajectories of Transverse movement with turning
3.3 Evaluation on the efficacy of developed support system

The proposed support system was developed to improve the efficiency and safety of ship handling and to decrease the operator’s work-loads. Fig. 13 shows these evaluation items that are the time consumption, number of command, the mean side deviation and the mean course deviation respectively. The time consumption for completing planned movement with the support system is shorter than one without support system. Maximum decreasing rate is 17%. So, the efficiency of the ship maneuvering became good by using the support system. The number of operation with the support system is less than one without support system. Maximum decreasing rate is 23%. The work-loads of the ship operator is decreased by the support system. The mean side deviation decreased to 58%. The mean course deviation decreased to 54%. The cause can be considered as following. The support system realizes the feedback control to keep course. Therefore, the ship operator can focus on the control of her position.
4. Conclusion

Most of the ship operator's work-load when using tugboats is advanced information processing such as the collection, analysis, decision making and to control tugboats separately. And, if the object movement becomes complicated, those increase indeed. We developed the support system from this viewpoint in this research.

By comparing the result of the ship maneuvering, it is clarified that the object movement becomes more complicated, the difference between the ship maneuvering with and without support system becomes bigger. So, the effect of the support system is big in the condition that the burden of operator is big.

By comparing the evaluation item, it is confirmed that the operation with support system achieves the object movement early with easy command and the accuracy of the ship maneuvering is good. The safety of the ship maneuvering becomes high and the efficiency becomes good and the burden of the ship operator decreases by using the support system.

We understood that the support system realize the effective support for the ship maneuvering using tugboats. It is conceivable that this connects to the improvement of the operation's efficiency and safety in the ship maneuvering using tugboats.