Experimental Study on Dynamic Positioning Control for a Semi-submersible Lower-hull Type Offshore Platform

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Summary

Dynamic positioning control tests were carried out for a semi-submersible two-lower-hull type platform model in the simulated environment for offshore current, wind and wave in a ship model basin. Prior to the control tests, hydrodynamic characteristics of the platform and the propulsion systems were measured and computer simulations were made to obtain the basis for the design of the dynamic positioning control system. The results of over-all control tests indicate that the dynamic positioning control is duly practicable at the two-lower-hull type semi-submersible platform.

1. Introduction

Offshore platforms, floating or semi-submerged, usually encounter all kinds of drifting forces due to current, wind and wave. To keep the platform stay at desired position and heading, the anchor-chain/wire system has been known as one of the most reliable means at relatively shallow sea area. However, position holding capacity of the anchor-chain/wire system becomes inadequate when the depth of the sea approaches the order of deeper continental shelves. In order to be able to operate the platform in such deep sea area, therefore, position holding device other than the anchor-chain/wire system will be called for. To keep the position against drifting forces by use of the closed-loop control of hydrodynamic propulsion devices ('dynamic positioning system') has been regarded as one of the most effective means to solve the problem.\(^1\),\(^2\) The feasibility of this kind of positioning control has already been verified for drilling ships by use of the systems based on digital or analog computer control methods.\(^2\)

In the present paper, fundamental study is made on the applicability of such system to the positioning of a large-size semi-submersible two-lower-hull type platform.

2. Two-lower-hull type platform and working conditions

In recent years, it is a growing tendency at offshore working platforms to be equipped with self-propulsion devices in order to facilitate means for easy transfer and quick retreat, saving much extra cost for the tow insurance and the tug assistance. Requirement arises, therefore, for minimizing the ahead resistance. As a matter of fact, lower-hull type is best suited for longitudinal propulsion, and many full-scale platform of this type have been designed and built with successful performances.

The present study has been designed, therefore, to make it clear whether the dynamic positioning control can be practicable at this type of platform, where, in contrast to the possibility of minimizing

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the ahead resistance, the lateral resistance is inevitably large. The schematic of a typical form of the
two-lower-hull type platform is shown in Fig. 1. Present study is made for this particular type. As
shown in Fig. 1, it was designed to furnish the platform with two sets of nozzle propeller and four
side thruster units for effective horizontal propulsion in any desired direction. This design of the
propulsion system is based on the considerations of the effectiveness of the horizontal manoeuvres
as well as proven reliability and operational safety. For detailed items of the nozzle propeller and
the side thruster system, much design information is available.1)5)

The working conditions of the platform are assumed as shown in Table 1.

### Table 1 Assumed environmental conditions

<table>
<thead>
<tr>
<th>Environmental conditions</th>
<th>Allowance of position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth of water $H = 300$ m</td>
<td>Horizontal $</td>
</tr>
<tr>
<td>Current speed $U_0 \leq 3$ kn</td>
<td>Heading $</td>
</tr>
<tr>
<td>Wind speed $U_A \leq 20$ m/s</td>
<td>Heave $</td>
</tr>
<tr>
<td>Wave height $h_w \leq 5$ m</td>
<td>Pitch &amp; Roll $</td>
</tr>
</tbody>
</table>

### 3. Measurements of hydrodynamic characteristics

In order to design the dynamic positioning system, it is necessary to know the hydrodynamic
characteristics of the platform and the propulsion systems. Investigations, therefore, were
made for the platform resistance, the nozzle propeller and the side thruster characteristics.
Main particulars of the tested platform model are shown in Table 2.

### Table 2 Main particulars of platform model

<table>
<thead>
<tr>
<th>Items</th>
<th>Model</th>
<th>Full-scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scale $S$</td>
<td>$1/30.0000$</td>
<td>$1$</td>
</tr>
<tr>
<td>Length $L_{oA}$</td>
<td>$3.440$ m</td>
<td>$103.200$ m</td>
</tr>
<tr>
<td>Breadth $B$</td>
<td>$2.570$ m</td>
<td>$77.100$ m</td>
</tr>
<tr>
<td>Draft $\alpha$</td>
<td>$0.600$ m</td>
<td>$18.000$ m</td>
</tr>
<tr>
<td>Displ't $\Delta$</td>
<td>$525.41$ (kg)</td>
<td>$14,541$ (tons)</td>
</tr>
<tr>
<td>Yaw. gyrad.:</td>
<td>$k_{ca}/L_{oA} = 0.30$</td>
<td></td>
</tr>
<tr>
<td>Speed $U$</td>
<td>$0.093924V_e (m/s)$</td>
<td>$V_e$ (knots)</td>
</tr>
</tbody>
</table>

3.1 Effect of current, wind and wave

Effect of current was measured by towing the platform model at various angles of oblique
tow at the speed corresponding to those of the
sea current. The results of measurements are summarized in Fig. 2. Wind resistance was estimated for realistic superstructure configuration. One example of the estimate is shown in Fig. 3. Wave drifting force was measured in regular waves at various angles of wave incidence. Some results are shown, for example, in Fig. 4. From these results, fundamental picture can be obtained of the drifting forces to be overcome by the thrust of the nozzle propellers and the side thrusters.

3.2 Characteristics of nozzle propeller and side thruster

In Fig. 5 and 6, details are shown of the nozzle propeller and the side thruster for the model platform. The main particulars of these propulsion units are shown in Table 3. Fig. 7 shows the results of the ahead and astern self-propulsion tests. One of the test results of the model side thruster unit is shown in Fig. 8. After the measurement of thrust performance of the nozzle propellers and the side thrusters, free-running platform model tests were carried out to obtain the translation and turning characteristics of the platform by proper use of the nozzle propellers and the side thrusters. Some examples of the test results are shown in Fig. 9. From these results, it is possible to make a basic design of the dynamic positioning control system.
4. Design of dynamic positioning control system and computer simulations

In order to investigate the control performance of the nozzle propellers and side thrusters on the basis of the measured characteristics mentioned in the previous section, PID control method was adopted as the basic mean to explore the system
The control algorithms are represented by the following equations:

\[
\begin{align*}
\dot{n}_p &= K_p \left( 1 + \frac{1}{T_{l1}} \left( dt + T_{p1} \frac{d}{dt} \right) dx - K_p \left( 1 + \frac{1}{T_{l2}} \left( dt + T_{p2} \frac{d}{dt} \right) d\phi \right) \\
\dot{n}_y &= K_p \left( 1 + \frac{1}{T_{l3}} \left( dt + T_{p3} \frac{d}{dt} \right) dy + K_p \left( 1 + \frac{1}{T_{l4}} \left( dt + T_{p4} \frac{d}{dt} \right) d\phi \right) \\
\dot{n}_z &= K_p \left( 1 + \frac{1}{T_{l5}} \left( dt + T_{p5} \frac{d}{dt} \right) d\psi + K_p \left( 1 + \frac{1}{T_{l6}} \left( dt + T_{p6} \frac{d}{dt} \right) d\phi \right) \\
\dot{n}_b &= K_p \left( 1 + \frac{1}{T_{l7}} \left( dt + T_{p7} \frac{d}{dt} \right) d\phi - K_p \left( 1 + \frac{1}{T_{l8}} \left( dt + T_{p8} \frac{d}{dt} \right) d\phi \right) \right)
\end{align*}
\]

(1)

where

\[
\begin{align*}
\Delta x &= (x_a - x_0) \cos \phi_0 + (y_a - y_0) \sin \phi_0 \\
\Delta y &= -(x_a - x_0) \sin \phi_0 + (y_a - y_0) \cos \phi_0 \\
\Delta \phi &= \phi_a - \phi_0
\end{align*}
\]

(2)

By use of this control method, it was designed to furnish the system with the ability to perform three different kinds of control modes: automatic translational positioning, automatic keeping of the desired position and manual control.

Computer simulations were made for the over-all closed-loop control, and the parameters for the optimal control were surveyed. Horizontal motions of the platform were represented by the following set of motion equations referring to the coordinate axes fixed to the principal axes of the platform:

\[
\begin{align*}
(m + m_a) \frac{du}{dt} &= -(m + m_b)ur = (P_r' + P_r) - X_0 + X_a + X_w \\
(m + m_a) \frac{dv}{dt} &= (T_{l1} + T_{l2} + T_{l3} + T_{l4}) + Y_0 + Y_a + Y_w \\
(I_{b3} + J_{b2}) \frac{dr}{dt} &= (T_{l1} + T_{l2}) L_2 - (T_{l3} + T_{l4}) L_4 + (P_r' - P_r) b + N_0 + N_a + N_w
\end{align*}
\]

(3)

where \(r = \frac{d\phi}{dt}\). Notations are referred to Fig. 10. The results of the computer simulations were mainly used for the preliminary design of the control, and some of the results are partly shown in Fig. 9 for open-loop control.

On the basis of these results, the computer control hardware system was designed; the brief outline of the system fabricated for the present study is shown in Fig. 11.
5. Control tests in simulated environments

On the basis of the preliminary studies and preparations as described in 3 and 4, over-all closed-loop control tests were carried out at the Seakeeping and Manoeuvring Basin of Nagasaki Technical Institute, M.H.I. Illustrative test arrangement is shown in Fig. 12. The tests were made under diligently simulated conditions of environments, position detection and closed-loop computer control for dynamic positioning. The current effect was simulated by the horizontal translation of the towing carriage relative to the water as described in 3. Wind effect was simulated by the application of the corresponding forces at the estimated application center of the wind resistance by way of the loaded wire-pulley system. Wave was generated by the wave maker. The test program is outlined in Table 4.

![Fig. 12 Over-all DP-control test arrangements](image)

<table>
<thead>
<tr>
<th>Item</th>
<th>Individual</th>
<th>Combined effect</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Magnitude</td>
<td>Direction</td>
</tr>
<tr>
<td>Current</td>
<td>0~2 kn</td>
<td>0~180°</td>
</tr>
<tr>
<td>Wind</td>
<td>0~20 m/s (gust; 30 m/s)</td>
<td>0~180°</td>
</tr>
<tr>
<td>Wave</td>
<td>$\frac{\lambda}{L}=0.4$, $h_w=1.5$, 5.0 m</td>
<td>0~180°</td>
</tr>
</tbody>
</table>

Some examples of the test results are shown in Fig. 13 in the comparisons of the computed and measured quantities. At any case, the response fluctuations of the position and the heading lie well within the limit of the environmental conditions. It is seen that fairly good prediction can be obtained through the computer simulations. The test results indicated that for the present environmental conditions, the dynamic positioning control can be practicable with 55 tons each of the effective thrust at the twin nozzle propellers and 21 tons each of the effective thrust at four side thrusters. The assumptions are that the translational speed is fairly small and the rise of the gusty wind speed lies within the known limit of steepness.
Considerations were made on the full-scale design of the system. In fact, the control system hard-wares have been designed to suit full-scale applications also. And upon the experience of actual performance tests, several items are pointed out and the results are summarized as follows:

1) Sudden rise of drifting forces in the dead calm sea condition more easily invites instability of control than in the case under moderate drifting force conditions. And, therefore, adjustments of control parameters, when necessary, are recommended to be made under dead calm sea conditions.

2) Insertion of the control dead-band invites harmful effect on the stability of control. In considerations of the actual offshore conditions where all kinds of drifting forces are present nearly always, the insertion of the control dead-band can not be a measure to save the control power.

3) It is recommended to eliminate the effect of disturbance due to waves in the channel of the position detection signals by use of the low-pass filters. In this case, however, care should be taken of the choice of the cut-off frequency not to spoil the stability of the control.

4) In adopting so-called feed-forward control, utmost care should be taken in predicting the characteristics of the external drifting forces to come; otherwise stability of the control will be completely spoiled. That is, feed-forward control should be based on as complete descriptions of the external disturbance to come as possible, i.e., in the forms of mathematical or numerical models. In fact,
however, the external disturbance to come contains much unknown in general, and, therefore, it is not always recommendable to adopt the feed-forward control.

5) For possible failures at the control computer, the addition of a manual back-up operation mode will be extremely helpful for full-scale operations at a single computer unit system. From this viewpoint, it is not necessary to install dual computer unit system. In the present study, the auto/manual mode switching was made with balanceless and bumpless signal transfer technique for safety of the above-mentioned back-up operations.

7. Conclusions

For the environmental conditions assumed, the results of the present study can be summarized as follows:

1) The two-lower-hull type semi-submersible platform can be dynamically positioned by PID control algorithms for practicable capacities of the nozzle propellers and the side thrusters.

2) If the active heading operations are allowed, say beyond $\phi \pm 30^\circ$ up to $\pm 90^\circ$, aiming at the heading of least drifting force, the merits of the lower-hull type will be demonstrated quite effectively.

3) For control systems, digital computer method is much more preferable in considerations of its universal functions: of monitoring, filtering, computing, together with the flexibility of the algorithms, data processing and logging, and by far larger capacity of the memory. The system hard-ware fabricated for the present study can be a prototype for full-scale systems.

4) Effectiveness of the computer simulation technique has been verified for the lower-hull type platform equipped with dynamic positioning system. Further study can be made through the computer simulation techniques on the basis of the results of the present study.

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References

2) Overseas survey report on the development of DP-systems; The Japan Machinery Federation (June, 1971).
4) Tank test results on special working platforms for the development of the continental shelves; Report to the Japan Ships Machinery Development Association (March, 1969).