ON AN OCEANGOING FAST SWATH SHIP
WITHOUT PITCHING RESONANCE

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SUMMARY

Considering an oceangoing large fast ship, the punctuality of time schedule and delicate handling in navigation are required even in the rough sea. Thus the seaworthiness that there are no speed drop and absolutely no slamming gains in importance for the fast ships running in ocean waves. In the present work, a "Resonance-Motion-Free SWATH (RMFS)" ship is proposed as the ship satisfied with such requirements. As a first step of the study, experiments in towing tank and theoretical calculations based on the potential theory are carried out to figure out the performance of the RMFS in waves. Particularly the influence of vertical-plane stability due to small water plane area is examined with a soft-spring system. The results are compared with those of typical mono-hull and trimaran ships. The predominance of the RMFS regarding the seaworthiness is recognized.

1. INTRODUCTION

Recently the fast ships with the various hull forms such as a mono-hull, a catamaran and a trimaran attract lots of attention in the world. Above all, the research and development of the oceangoing large fast ship is an important subject. It is supposed that the accuracy of time schedule and delicate handling in navigation are required for the high-valued cargo for fast ship even in the rough sea. Accordingly, the speed drop and slamming, which are caused by large ship motions, must be suppressed at the lowest possible level. That is, the seaworthiness should be put ahead of the performance of resistance, power and fuel consumption especially for the ships running fast in ocean waves. From such a viewpoint, a SWATH ship is considered as a large fast one for the present study. So far there are a large amount of studies on the SWATH ship, e.g. [1][2][3]. Although some advantages for a SWATH ship are recognized in running in waves, it is well known that the control of vertical motions is important for such a ship because of the property with smaller water plane area than that of a mono-hull ship. Nevertheless, making the water plane area extremely small, we obtain the interesting feature with less restoring moment in pitch motion. This idea is already proposed by one of co-authors [4] and we call such a ship a ‘Resonance-Motion-Free SWATH (RMFS)’ in the present study.

The goal of our project is to establish the basic concept of the RMFS as an oceangoing large fast ship. For that purpose, besides for the hydrodynamic performance, the transport efficiency should be discussed from a viewpoint of the accuracy of time schedule and the transport quality after consideration like the damage of goods due to the slamming. However, as a first step, we examine the sea-keeping performance of the RMFS by means of the experimental and numerical approach. The present study has not got to the level to control the vertical plane stability yet, but the influence of the strut length and restoring moment in pitch motion is especially examined for the proposed RMFS. As a feasibility study, ship motions are compared among a mono-hull model, SWATH models including the RMFS and a trimaran model.
2. DESIGN CONCEPT OF THE SHIP

Our design policy of a oceangoing large fast ship is based on the requirements that the ship has 40 knots speed, and 5,000-10,000 tons payload, especially serve the good sea-keeping quality with no speed drop, absolutely no slamming in the waves of sea state 7 (with significant wave height of 6-9 meters) and so on. The outside view of the rough conceptual design [4] of the RMFS is shown in Fig.1. The RMFS has the capability of crossing 4,800 nautical miles of Pacific Ocean in 5 days at a high speed of 40 knots, with total engine power of 352,000 PS, as shown in Table 1. Four pairs of controlling fins are installed near the ends of lower hulls. Each fin should operate at one meter below the wave surface to maintain the stability and superior sea-keeping quality of the RMFS even in the rough sea.

3. MODEL TESTS

3.1 HULL FORMS

Experiments are implemented in two towing tanks. First, experiments of a mono-hull model are carried out at Ocean engineering tank in Kyushu University. The size of the model is 2.5(m) in length, \(L\), 0.192(m) in breadth, \(B\), and with a draft, \(d\), of 0.064(m). The displacement of the model is equal to 14.71(kg).

Secondly, experiments of RMFS models are carried out at Ocean engineering basin in the University of Tokyo. The RMFS model consists of five parts: twin lower hulls, two struts and one upper deck, as shown in Fig.2 and Fig.3. In addition, four pairs of horizontal controlling fins and two pairs of vertical rudders are installed on the lower hulls. The length, \(L\), of lower hull is 2.0(m) and it has circular cross section with the maximum diameter of 0.077(m). The cross sections of struts are elliptical with a length of 0.783(m) and the maximum breadth of 0.0385(m). The height of struts is approximately 0.215(m). Displacement of the model is 15.49(kg). Eight fins and four rudders are all fixed, whose attack angle for the longitudinal hull axes are set to zero degree.

3.2 EXPERIMENTAL CONDITIONS

Three kinds of tests are carried out using a mono-hull and RMFS models, i.e. forced oscillation tests in still water, restrained tests in waves and free motion tests in waves. Froude number, defined as \(Fn = U / \sqrt{gL}\) with towing speed, \(U\), and gravity acceleration, \(g\), is 0.50 for mono-hull model and 0.433 for RMFS model. The adopted Froude number is common in all tests.

For the forced oscillation tests, oscillating frequencies are determined by dispersion relation \(\omega = \sqrt{Kg}\) with the wave number \(K\) varying in a range of \(KL=2.0-40.0\). For the restrained tests in waves to measure the wave exciting forces, regular waves are used as the incident waves and the range of non-dimensional wave length \(\lambda / L\) is 0.4-4.0. All tests are done in head sea condition. For the free motion tests in waves, experimental conditions are the same as those in the measuring wave exciting forces.

3.3 STRUT AND STABILITY

In addition to the experiments of the RMFS models, the ordinary SWATH models, whose strut length is equal to the length of the lower hull, is also tested to examine the influence of the strut length of the SWATH. The differences in both models for motion responses to waves are of interest. In the present study, the model supporting system using four pairs of soft springs is adopted as shown in Fig.2. This is because the restoring moment coefficient of the model has negative value and the model is unstable in measurement of ship motions. Supporting points are located at \(x=0.495(m), y=0.205(m)\) as shown in Fig.3. The springs are settled in a length of 0.100(m) with tensile stress and the model is supported by both upward and downward springs. Thus the free motion tests are carried out by using the models with four kinds of spring constants to examine the influence of the restoring moment in pitch motion. The restoring force and moment...
Fig. 4  Added mass and damping coefficients for heave and pitch

Fig. 5  Coupled added mass and damping coefficients between heave and pitch
of the models with a length of 2(m) are shown in Table 2, where values of the mono-hull and the trimaran are converted to the values of spring strength. Model tests with each spring varied are introduced because the vertical-plane stability cannot be controlled in the present study using fixed fins. For the ordinary SWATH, the free motion tests with the spring support are also performed for comparison although this model has inherent stability.

4. RESULTS

4.1 ADDED MASS AND DAMPING COEFFICIENTS

Hydrodynamic forces and moments, measured in forced oscillation tests by pure heave or pure pitch motion, are shown in Fig.4 and Fig.5. Coefficients \( A_{ij} \) or \( B_{ij} \) denotes added mass and damping coefficient, respectively, in the \( i \)-mode direction induced by the oscillation motion of \( j \)-mode motion. They are normalized by the displacement or the product of displacement and the circular frequency, etc. Fig.4 shows the results in pure heave or pitch motion. On the other hand, Fig.5 shows the results in coupled terms between heave and pitch motion. Experimental results of the mono-hull in Froude number 0.50 and those of the RMFS in Froude number 0.433 with fins and without fins are plotted in the figures. Also calculated results by the new strip method (NSM) for these models are plotted. The viscous effects of lower-hulls and fins and the lift of fins are not considered yet in the calculation for the RMFS.

Experimental results of \( A_{33} \) and \( A_{55} \) shown in Fig.4 are small because the hull form of RMFS is considerably slender compared with that of mono-hull. Calculated results of both models nearly explain the tendency of experimental ones. Likewise, it can be observed from the experimental results of \( B_{33} \) that the order of decreasing magnitude for different hull forms is given as follows: the mono-hull, the RMFS with fins, the ordinary SWATH with fins and the RMFS without fins, while the magnitude of \( B_{55} \) decreases in order of the RMFS with fins, the mono-hull, the ordinary SWATH with fins and the RMFS without fins. For the model with fins, the effects on reducing pitch motion can be expected especially because of the large lever of pitching moment, in spite of the small fin area. In addition, it can be seen that calculated results of the RMFS are much smaller than experimental results. Calculated \( B_{55} \) and \( B_{55} \) are even smaller than experimental results of the RMFS without fins. The difference is due to both contribution of the fin lift and the viscous effect on lower-hulls and fins. In Fig.5, calculated results of both models coincide with experimental results and explain the tendency of those.

4.2 WAVE EXCITING FORCE AND MOMENT

Measured results of wave exciting force and moment acting on the models are presented in Fig.6. In the figures, \( |E_i| / \rho g \zeta_i \) denotes the amplitude of force or moment in \( i \)-mode direction, and \( \zeta_i \) is the incident wave amplitude. It is observed that experimental results of the amplitude of wave exciting force \( |E_3| \) and moment \( |E_5| \) in the case of RMFS are extremely small compared with that of the mono-hull. Consequently, the reason that the SWATH or the RMFS is called “wave excitationless ship” can be well understood. There is little difference in the wave exciting forces \( |E_3| \) and \( |E_5| \) between the models with and without fins, while there is apparent difference in the wave exciting moment \( |E_5| \) between both models with and without fins. The cause is also the effect of fins with the large moment lever. In addition, it can be seen that the RMFS with shorter strut is slightly advantageous in both wave exciting force \( |E_3| \) and moment \( |E_5| \).

4.3 SHIP MOTION

The heave and pitch motion responses of some models are shown in Fig.7 and Fig.8. The RMFS-F is a model with the spring F as shown in Table 2 and it is represented as a model with largest restoring force and moment in the RMFS variants. In the computation of ship motions for the RMFS-F, the ship motions are assumed to be modeled.
with linear differential equations. The measured values of radiation and diffraction forces in the experiments are used in the coefficients of such motion equations. These results are denoted by CAL. in both figures. Accordingly the computed results include the viscous effects and the lift of fins to some levels. Experimental results of the trimaran measured by Saito et al.[5] are also cited. In comparison with the difference among three hull forms, i.e. the mono-hull, the RMFS-F and the trimaran, it is observed that the motion responses of the mono-hull and the trimaran are larger than that of the RMFS-F in both cases of heave and pitch motion. Notably there exist resonant peaks particularly in heave motion. We can recognize that the RMFS model has the great advantage in seaworthiness.

Next we compare two SWATH typed models with different strut length, i.e. the RMFS-F and the ordinary SWATH. These results are shown in Fig.9 and Fig.10. In this comparison, the ordinary SWATH-F with the spring system is also examined besides the ordinary SWATH without the spring system. It is observed that the motion responses of the RMFS-F are small both in heave and pitch motion in comparison with the ordinary SWATH which has about the same restoring force and moment as the RMFS-F. The resonant point in the pitch motion for the ordinary SWATH is near 2.3 in wave length ratio. This causes the increments from the responses for the RMFS-F, but it is not so large compare with that of heave motion. Therefore the influence of strut length on motion responses is more remarkable in heave motion than pitch motion.

Additionally the motion responses for the RMFS-A model are shown in Fig.11 and Fig.12. The computed results of ship motion denoted by CAL. include the viscous effects and the lift of fins, while such effects are not taken into account in the NSM computation. Eigen periods measured in zero speed condition are shown in Table 3. These values indicated in Fig.11 and Fig.12 are well coincident with each resonant point predicted by the

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<tr>
<th>Ship Models</th>
<th>Eigen period $T$ (s)</th>
<th>Corresponding wave length $\lambda / L$</th>
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<tbody>
<tr>
<td>RMFS-A</td>
<td>2.07</td>
<td>3.35</td>
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<tr>
<td>Ord. SWATH</td>
<td>1.63</td>
<td>2.08</td>
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<tr>
<td>Ord. SWATH-A</td>
<td>1.38</td>
<td>1.49</td>
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<tr>
<th>Ship Models</th>
<th>Eigen period $T$ (s)</th>
<th>Corresponding wave length $\lambda / L$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMFS-A</td>
<td>2.96</td>
<td>6.85</td>
</tr>
<tr>
<td>Ord. SWATH</td>
<td>1.72</td>
<td>2.30</td>
</tr>
<tr>
<td>Ord. SWATH-A</td>
<td>1.37</td>
<td>1.46</td>
</tr>
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</table>
NSM. In heave motion, effects by the fins make it possible to suppress an increase in motion very much even at the resonance. On the other hand, even in pitch motion, there are possibilities to suppress an increase below a certain level, although the encounter with such long waves rarely happens. However, we cannot discuss any more because we don’t have any data about longer waves due to the limitation of our experimental facility. Finally in Fig.13 and Fig.14 we show the results on the influence of the soft spring system, which is equivalent to the proportional control action using the fin lift. To exert motion reduction in longer waves, a new control system of ship motion, instead of the present system, should be designed to make a good use of with the advantage of negative restoring moment.

5. CONCLUSIONS

The comparison of ship motion responses among three kinds of hull forms, using experimental results and some data cited from references, are discussed. As a result, it becomes clear that the heaving motion of the RMFS is very small in comparison with those of the mono-hull or the trimaran. On the other hand, the pitching motion of the RMFS is considerably small in comparison with the others as expected. On the strut length, its influence appears more remarkably in heave motion than pitch motion. The pitch motion for the RMFS is not as small as expected in comparison with that of the ordinary SWATH. These reasons are that the soft spring system used in experiments cannot take advantage of the characteristic of the RMFS model with negative restoring moment. Accordingly, a new control system of ship motion using the lift force by fins should be adopted. Additionally, experimental and simulation method need to be established to realize that control system.

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REFERENCES