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On the Passive type Anti-Rolling Tank and its Activation by Air Blower

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Abstract

The systematic results of anti-rolling tanks tests obtained by bench tester and roll test in towing tank have been examined. The effects on the oscillating period of fluid transfer through the duct of U-tube tank due to damper plates and the effects on roll damping moment of the tank due to swash plates are also evaluated from the results. A simple control algorithm for a forced fluid transfer in U-tube tanks is devised to active operation of the tank by air blower. The active performances of the tank are confirmed very effective through the tank tests carried out in the irregular waves.

Keywords: bench tester, damper plates, swash plates, roll damping moment, air-blower

1 Introduction

The U-tube type tanks used for stabilizer of a ship are called passive anti-rolling tank (ART) when the fluid transfer freely in the transverse direction along the wing tanks of both hull side under the tuned frequency in accordance with loading conditions. The tanks are called active ART when the fluid transfers from a wing tank to the opposite tank by the power developed by the automatic control algorithm.

The passive ART has adverse effects when the roll periods of the vessel lie outside of the designed region of the resonant fluid oscillation period in the tank. To broaden the effective frequency region of the tank fluid oscillation produced in the passive ART, damper plates are devised in the lower duct of the ART to adjust the oscillating period of the fluid. The adjustability of the fluid oscillation period and the changes of the stabilizing moments are examined by bench tests under various angles of the damper plates.

The U-tube tank produced the most effective roll damping, when the motion of the vessel was in 90 degree phase difference with that of the water in the tank. The decreasing rate of the roll motions of the vessel are influenced by the magnitude of the damping effects due to the blockage effect of the internal structural members in the passive tanks. Thus the optimum roll damping could be anticipated not only taking into account the resonant region but also the high and low frequency region where the adverse effects occur, if the structural members have been designed carefully. To examine the damping effects on the magnification factors, model tests have been made by installing the transverse swash plates having various effective opening ratio for U-tube tanks.

We developed passive anti-rolling tanks and activated to the active anti-rolling tanks system, which consists of an air blower that transfers the water from one wing tank to the opposite tank, by using an automatic control algorithm. The optimum condition of the passive tank operation could be obtained by allowing the moderate adverse effects and resonant oscillation with the algorithm. The effectiveness of active tank system in the irregular beam and stern quartering waves were confirmed in the towing tank of the Seoul National University.

2 Important parameters of passive anti-rolling tanks

When a passive U-tube tank is designed, the natural frequency of the tank fluid oscillation is generally selected equally to the frequency of roll motion of vessel, firstly. However, the natural frequency of the vessel usually varies with the loading conditions, the oscillating frequency of the tank fluid could be adjusted by varying the cross sectional area of the duct transferring the tank fluid. The period of the ART can be easily computed by characteristics of the ART as shown in Figure 1 obtained by the simple pendulum theory.

$$T = 2\pi\sqrt{\frac{1}{g}(h + \frac{R \cdot A}{a})}$$

where,
h : water depth
A : Breadth of wing tanks
a : Height of ART duct
R : Distance to the wing tanks

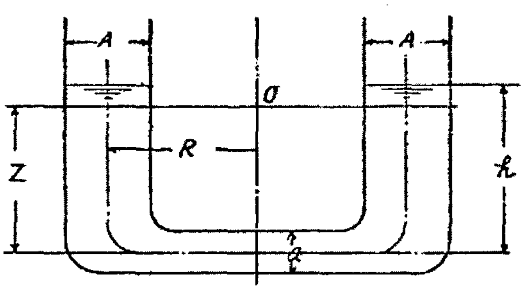

Figure 1: Definition of variables

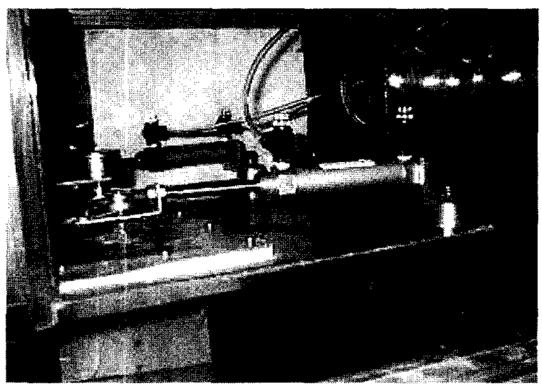

Figure 2: ART model with damper plates on the bench tester

The oscillating period of the water in the ART can be varied by the change of the height of the duct or the breadth of the wing tanks. Two damper plates will be effective in changing the oscillating period of the tank fluid for any particular loading conditions. Secondly, the internal structures including damper plates of the passive tanks should be carefully designed to have the desired tank damping moments. Passive U-tube tanks with optimum damping effects could provide the reasonable stabilization of the vessel in the whole frequency range with allowing the acceptable adverse effect at high and low frequency regions. To examine the damping effects on the magnification factors, we made model tests by using transverse swash plates with various effective opening ratios for U-tube tanks.

Effect of damper plates

The bench tester evaluated the period of the tank fluid oscillation under the various angles of damper plates. Figure 2 shows the installation of two damper plates in the lower duct of the U-tube type ART model. The damper plates are effective in altering the cross sectional area of duct that is most efficient in varying the period of the tank fluid oscillation.

The period of fluid oscillation in the tank could be easily estimated to 1.9 second if the tank fluid is ideal and the damper plates are in a fully-opened position.

The principal particulars of the ART model prepared for bench test are shown in Table 1.

Table 1: Principal particulars of the anti-rolling tank model for bench test

Length	$48cm$
Width	$105cm$
Duct height	$16cm$
Breadth of wing tank	$9cm$
Water level	$16cm$ from tank bottom
Width of damping plate	$12cm$

The bench tests revealed the stabilizing moments and phase angles of the ART model as shown in Figures 3 $\sim$ 8. The test conditions represented by combinations of alphabets and numbers. The alphabets L, M, N represent the roll amplitudes of 9.84°, 6° and 4°, respectively. The following two numbers indicate the angular position of the damper plates. For instance, 0 denotes the damper plate in a fully-opened position, 4 the damper plate rotated to 45°, and 9 the plate in a fully-closed position. Therefore, L49 expresses that the roll amplitude of the ART in the bench test is 9.84° with one damper plate rotated to 45° and the other plate is in a fully-closed position.

When the roll amplitude of the bench tester was adjusted to 9.84°, oscillation test of the tank were carried out for different cross sectional areas of duct which were obtained by combining the rotation angles of the damper plates. The stabilizing moment at various frequencies are shown in Figure 3. The stabilizing moment decreased when the cross sectional area decreased by increasing the rotating angle of the damper plates. The phase angles between roll motion and damping moment at the same condition are shown in Figure 4. The period of fluid oscillation increased as the area decreased by increasing the closing angle of damper plates, as expected. The frequency obtained at 90° phase difference was equivalent to the natural oscillating frequency. For instance, the oscillating period of tank could be estimated to 2.02 s from Figure 4 with fully- open damper plates. The period of fluid oscillation was estimated to be 1.9 s in the design stage, however, the viscous effects induced by the internal members seemed to increase the period.

Similarly the maximum period of the tank could be estimated to 2.25 s with fully- closed plates. Similar test results obtained at 6° and 4° of roll amplitude are expressed in the figures from

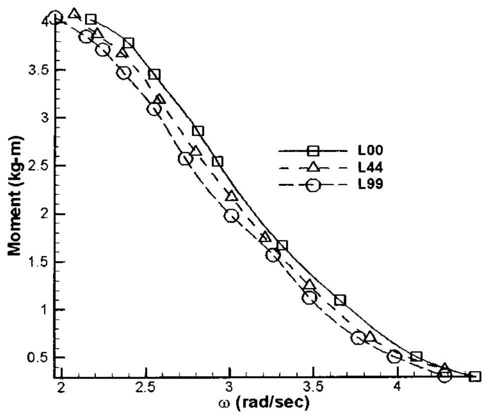

Figure 3: Effect of damper plates on stabilizing moments (9.84 deg.)

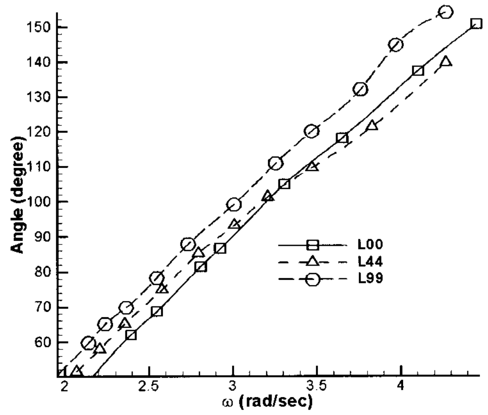

Figure 4: Effect of damper plates on phase angle (9.84 deg.)

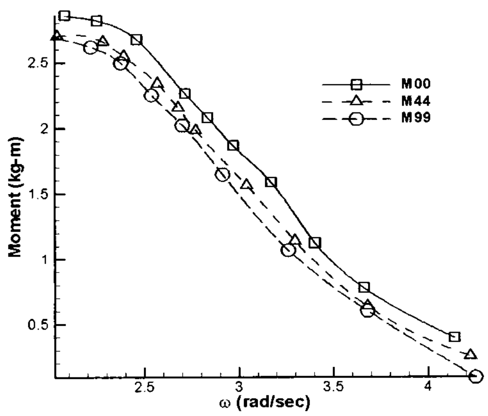

Figure 5: Effect of damper plates on stabilizing moments (6 deg.)

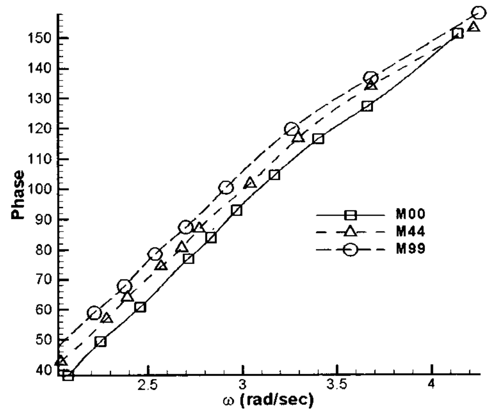

Figure 6: Effect of damper plates on phase angle (6 deg.)

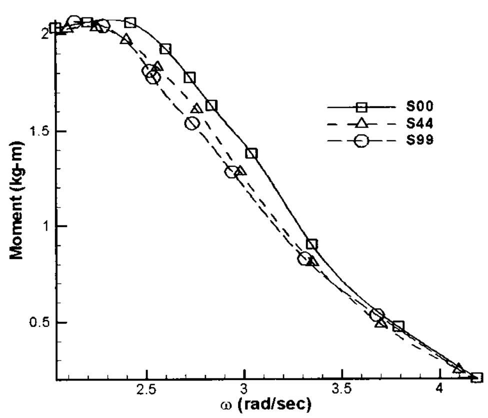

Figure 7: Effect of damper plates on stabilizing moments (4 deg.)

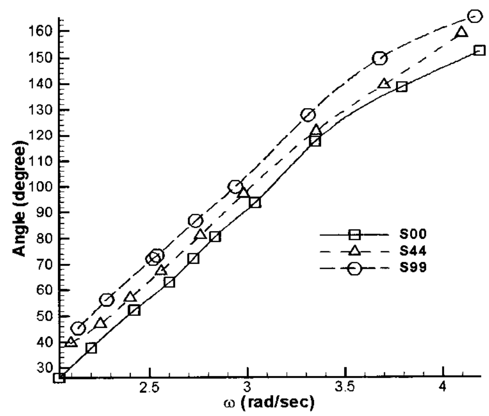

Figure 8: Effect of damper plates on phase angle (4 deg.)

Figure 5 to 8, respectively. The results have similar trends as previous cases. From these results, we concluded that the period of the fluid oscillation could be increased as the stabilizing moment is decreased simultaneously by increasing the closing angle of the damper plates.

Effect of swash plates

Suggested damping effects can be obtained by carefully selecting the internal structure of the U-tube tank in the design stage for practical application. To derive a basic design information in deciding the blockage effects of internal structure, transverse swash plates with different opening ratio were prepared for the tank model and bench tests were carried out in the regular beam waves. Figure 9 shows the body plan of training ship for fishery high school in Wando. The length of ship is approximately 45 m and her principal particulars are shown in Table 2. The punching plates having 46 %, 67 %, and 89 % of opening ratio as shown in Figure 10 have been tested and compared with those of Lee and Vassalos (1996).

Table 2: Principal particulars of fishery-training boat

	Ship	Model
LBP(m)	45	2.4
Bmld(m)	18.4	0.92
Draft(m)	3.3	0.165
$\nabla(m^3)$	913.6	0.1142
Scale Ratio, λ	1	20

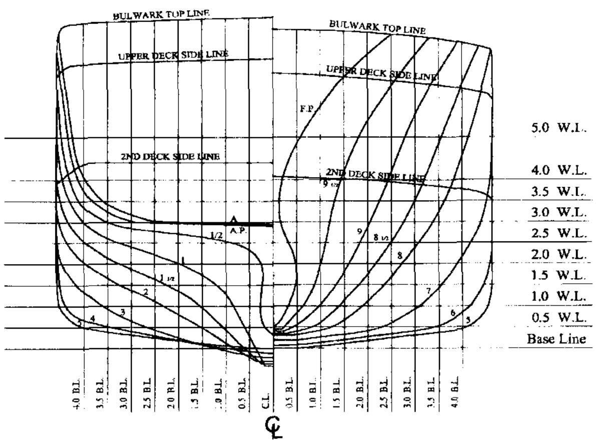

Figure 9: Body plan of Wando fishery high school training ship

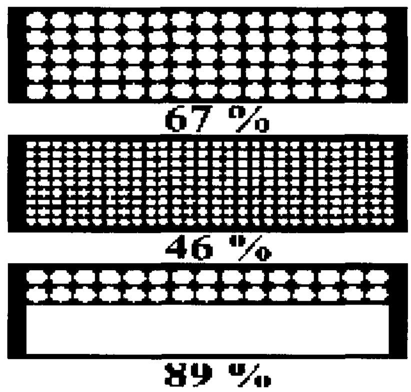

Figure 10: Shapes of punching plates

Figure 11 shows the experimental results.

Due to the swash plates, the roll damping moment in the tanks increased as the opening ratio decreased. When the responses in the resonance range increased slightly, the adverse effect outside of the resonance range decreased considerably.

The swash plates of 46 % opening ratio appeared to produce excessive roll damping moment,

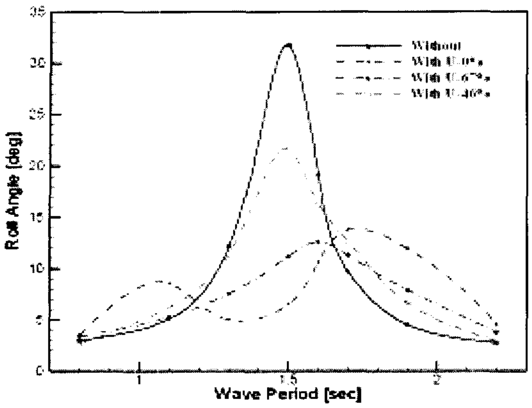

Figure 11: Roll angles of a ship installed U-tube tanks with different swash plates

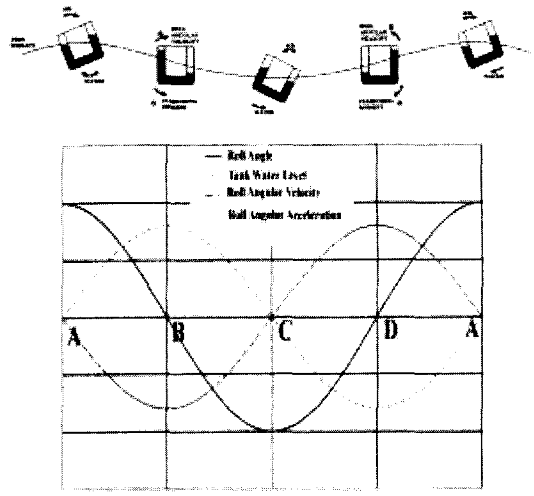

Figure 12: Relation of roll angle velocity and the tank water level

while those of 89 % showed low damping moment. However, the swash plates of 67 % opening ratio showed reasonable performances in the whole frequency ranges In addition, the swash plates were effective in avoiding the tank top hitting of sloshing water in wing tank, and thus, the selection of the opening ratio is important in the design of anti-rolling tanks to operate in the optimum condition.

From the above results, we believe that the swash plate could be applied effectively to ensure the optimum damping moments in the passive tanks if the opening ratio is carefully selected.

Development of the active tanks

When the roll periods of the vessel are laid outside the designed resonant region of the fluid oscillation, the system has adverse effect which could make the passive ART useless. The adverse effect could be prevented by transferring the water from the one wing tank to the opposite other tank to have a proper phase difference and period. Automatically controlled air blower system have been devised for the activation of the passive anti-rolling tank by the algorithm to make the period of fluid transfer coincide with the roll period of the vessel.

The dimensions of the U-tube tanks are selected such that the natural period of the tank fluid oscillation equals the shortest roll period anticipated in service condition of the vessel. Once the dimensions of the tank has been selected, the automatic control algorithm have the function to block the movement of water cyclically to provide athwart effect in tune with the motion of ship to reduce the roll. Control parameters used in the algorithm are roll angle, angular velocity and water level measured by the wave height meter in pair of wing tanks. Roll angles are measured in a close-loop mode by the force-balance tilt sensors named Inclinometer. From the time history of measured roll angle, the angular velocities and accelerations are derived numerically after filtering the noise using the Kalman filter.

When the ship has inclined to maximum roll angle toward the port side, the tank water should flow toward the port side wing tank with maximum velocity from the starboard side tank.

In constructing the control algorithm for active ART tank, the above condition could be considered as the initial condition and denoted as phase position A. At this initial position, the angular velocity of the restoring motion to the upright position begin to appear. At this moment, the free surface of coupled wing tanks has stayed at the same height from base line of the vessel. When the ship is reached to upright position, denoted as phase position B as shown in Figure 12, the angular velocity of list motion to starboard direction became maximum and the water height from baseline in the coupled wing tanks showed maximum height difference, as shown in the diagram. The weight difference caused by location of free surface in the coupled wing tanks produced a stabilizing moment against the roll motion generated by the wave exciting moment.

From the phase position B, the angular velocity of list motion to starboard direction began to decrease and disappeared at phase position C with, recording the maximum list angle to starboard side. At the same time, in the phase position B, the water in the portside wing tank began to move to the starboard side wing tank. At phase position C, the flow velocity in transferring to the starboard side wing tank reached to the maximum velocity and at the same time, the starboard side inclination recorded the maximum list angle. From this phase position where the inclination to starboard direction became maximum, the ship began to restore to the upright position as shown in the diagram with a phase position D. At this position, the restoring angular velocity disappeared, and the change in the depth of water in the coupled wing tanks became maximum. This maximum change could be the maximum stabilizing moment against the roll motion.

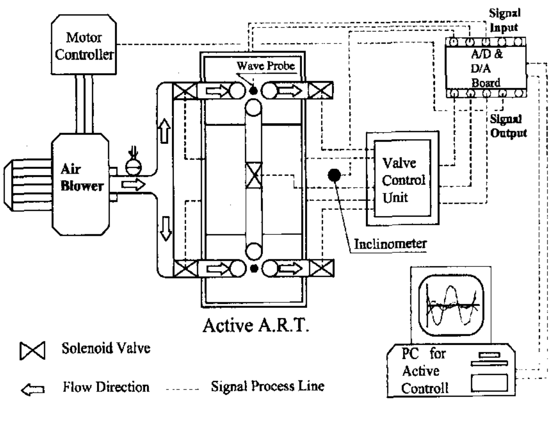

Figure 13: Schematic diagram of active system

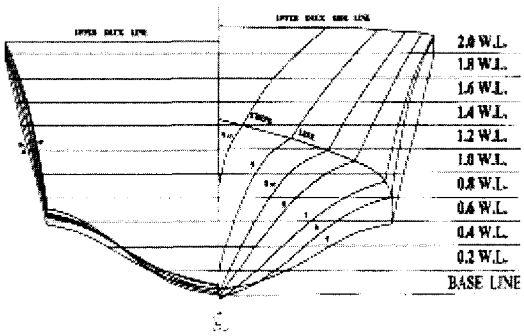

Figure 14: Body plan of 25 ton class patrol ship

In accordance with the above mentioned phase diagram, the active type ART system have been devised as shown in the schematic diagram Figure 13. In addition to the above basic logic derived from phase analysis, the gains in Kalman filter obtained by the model test at the bench tester have been used in developing the automatic control algorithm for the active tanks.

To evaluate the performances of the active tank system, we prepared the model of 25 ton class patrol boat as shown in Figure 14 for the test without advancing speed in irregular beam waves of 1/50 wave steepness. The model that can be described with principal particulars as shown in Table 3 was confirmed to have a natural period of 1.6 s through free roll test, while the natural period of the tank was designed to have a period of 2.0 s for the bench test. Such a large discrepancy of natural period between the tank and model could not improve the performance with simple passive mode operation. However, we can anticipate that the effectiveness of active mode operation by comparing it with the passive mode operation. For this purpose, the test schedule have been prepared intentionally despite the large mismatch of natural period of roll, and tests were carried out under the various loading conditions, which deviate from the design conditions.

Table 3 shows principal dimensions of the model.

Table 3: Principal particulars of ship

Scale	1	1/5
LOA(m)	18.3	3.66
Breadth(m)	4.6	0.92
Displacement Vol.(m^3)	28.67	0.2294
Draft(m)	0.9095	0.1819

From the signal obtained by the inclinometer during the test, in the irregular beam waves without advancing ship speed, have given in Figure 15 to compare the time histories obtained with different test setup. The first time history was obtained by suppressing the movement of fluid transfer by blocking the air valves installed on the connecting conduit between wing tanks to make a condition equivalent to without ART. In the results obtained in this test setup, at the so called "rozen condition", large roll angles exceeding 20° were frequently observed in the time history. The second figure showed the time history obtained in a passive mode operation by opening the air conduits of the ART with the same test setup. Despite the large discrepancy of natural period between the tank and model, the effectiveness of ART is recognized easily in the passive mode operation. The last figure presents the time history obtained from data produced in the active mode operation of ART, which was developed in the present study. The newly devised active type ART driven by air blower with a simple control algorithm, is superior because the roll angles exceeding 10° are hard to find in the time history. Similar test results were also obtained from the irregular stern quartering waves, and these results are shown in Figure 16. The roll damping effect appearing in the record of the time history of motion show the superiority of the newly proposed active ART driven by air blower.

We conclude that the newly devised active type ART driven by air blower is effective in reducing the roll motion in the rough sea, as confirmed by experiments

3 Conclusions

The anti-rolling tank system in passive mode operation was investigated, and such investigations were extended to the system in active mode operation supported by air blower.

The transverse swash plates installed in the passage of the U-tube tank were effective in improving roll outside of the resonant region where the adverse effect appears significantly and in preventing the tank top hitting by sloshing when the opening ratios had been carefully selected to have optimum performance over all frequency ranges.

In the design of the passive type anti-rolling tank, damper plates installed in the passage of U-tube tank could be used to adjust the period of fluid oscillation. The plates can vary the cross sectional area of the duct by selecting the opening angle of the damper plates.

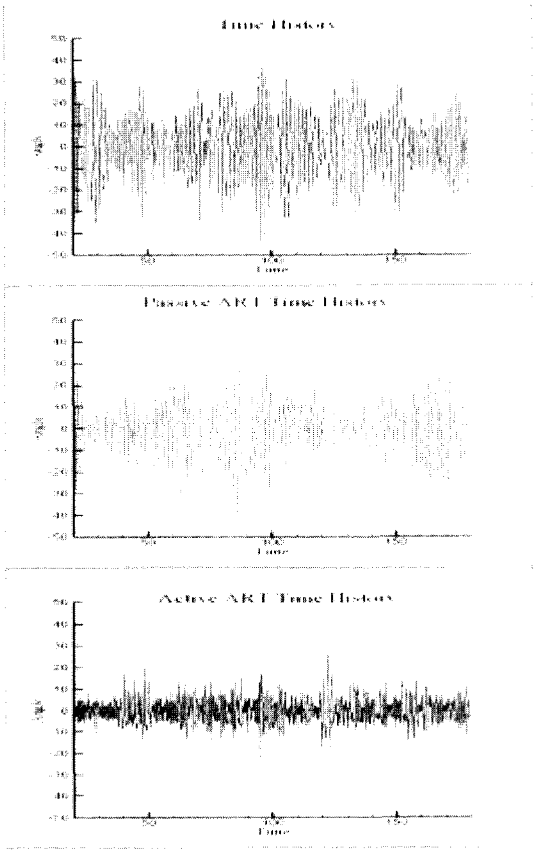

Figure 15: Model test results in irregular beam waves

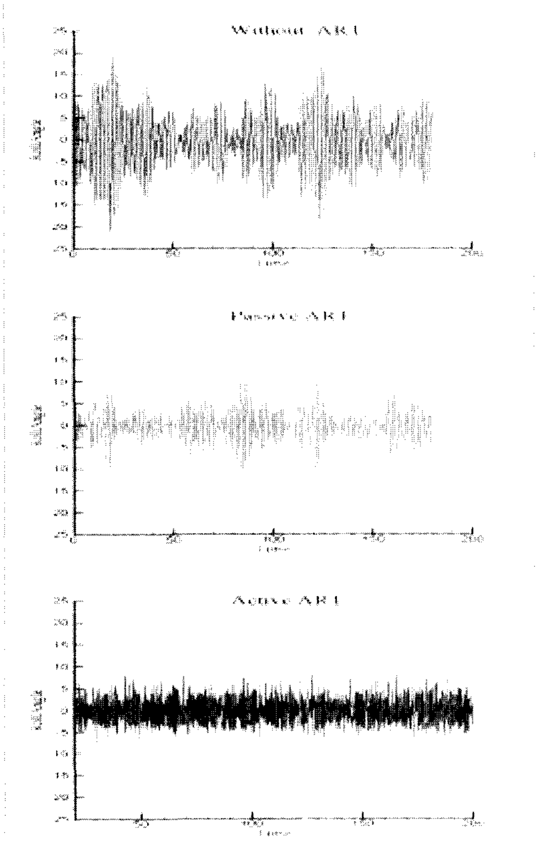

Figure 16: Model test results in irregular stern quartering waves

The anti-rolling tank designed for the passive mode operation could be easily activated with aid of the automatically controlled air blower to improve the stabilizing performance even in the high and low frequency region, where the adverse effects are anticipated.

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