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# Stopping of Ships Equipped with Azipods

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ABSTRACT: The paper contains a description of different possibilities of stopping a large ship equipped with azipods. The model tests were carried out to compare the effectiveness of stopping the ship using the different methods. The ship model used in stopping tests reproduces a large LNG carrier of capacity ~150 000 m$^3$

## 1 INTRODUCTION

Azipods, due to a number of obvious advantages associated with increased propulsion efficiency and better manoeuvrability, are increasingly being used as a propulsion and steering system for many types of modern vessels from passenger ships and ferries starting, by tankers to tugs and small specialist units serving off-shore. The azipod propulsion, consisting of one to three or four propellers which may rotate about a vertical axis and are powered by electrical motor, considerably changed methodology of manoeuvring.

This also applies to the ship stopping manoeuvre. This manoeuvre, due to the possibility of using a number of different ways to do so, and various (often contradictory) opinions about the effectiveness of individual methods, is one of the primary factors influencing the safety of navigation of ships equipped with the azipod propulsion. This follows directly from the analysis of the causes of accidents at sea.

Manoeuvres onboard a ship model equipped with azipods are a big part of practical exercises carried out during different ship handling courses at the Ilawa Ship Handling Research and Training Centre. The Centre has a large manned model representing a large LNG carrier equipped with two pulling azipods. The training model is presented in photo no 1.


Figure 1 The manned model representing a large LNG carrier used for training and research purposes

This model is used more and more often to the training, also the scope of lectures at the request of participants was changed. They request a clear reliable opinion on the effectiveness of existing individual methods of handling ships equipped with azipods. Currently, there is almost total lack of access to results of research and of sea trials. Nevertheless, according to the prevailing opinion of Masters and Pilots, the crash stop distance can be 50% of the same stopping distance of ships equipped with conventional propeller and the crash stop distance depends strongly on its manner of realization.

Therefore, in recent months, to acquire the necessary in training and consulting well-documented knowledge of manoeuvring qualities of such ships, a series of tests using the LNG carrier model were performed at the Ilawa Ship Handling Research and Training Centre. Tests were aimed at stopping manoeuvre using the combination of opportunities provided by the azipod propulsion: changing the direction of rotation of propellers, turning of both azipods around, deflection of azipods at an angle, etc.

## 2 STOPPING MANOEUVRE OF SHIPS EQUIPPED WITH AZIPODS

In addition to the thrust of a propeller or of propellers working astern (case of conventional propulsion), during the stopping manoeuvre the water reaction arising on a azipod housing is used. This housing looks like a rudder but is less efficient due to restrictions concerning its shape. A typical distribution of forces is schematically shown in fig.2. It can be seen that the efficiency of the stopping manoeuvre depends on the optimization of the azipod position and the direction of its thrust.

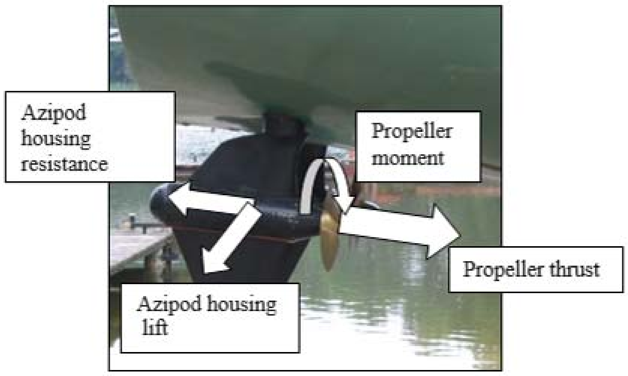


Figure 2. Forces acting on a azipod

The above mentioned forces depend also on interaction effects with other azipods and with the ship hull. Figure 3 shows schematically the interaction causes, so that the optimal choice of azipod angle of deflection and direction of rotation of its propeller is an important factor affecting the efficiency of the stopping manoeuvre.

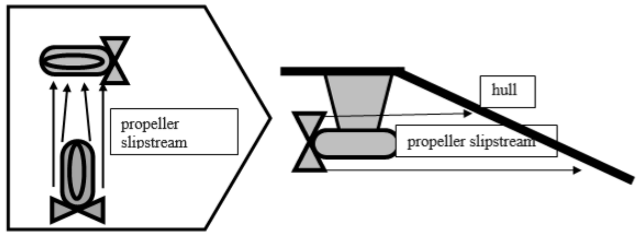


Figure 3. The types of interaction: between azipods and between azipod and the ship hull

Commonly used vessel stopping modes are described below. A ship master or pilot can stop a ship:

- by changing the direction of propeller rotation. Principle is very similar to stopping realized onboard a conventional ship,
- by turning azipods around (180°). Of course this mode is not applicable for ships equipped with a single azipod because of the observed considerable change in the ship's heading. For twin-azipod ships, however, it is quite acceptable and according to many results of tests this mode of stopping is more effective than stopping by changing the direction of propeller rotation.. Undesirable effect of this mode of stopping is the blade loading and associated strengths. According to recent investigations the most dangerous position of azipod is about 60-70° from the ship speed vector. Reducing of the thrust while turning azipods around may diminish the blade loading [2].
- by indirect manoeuvre. As previously, this mode of stopping is not applicable to ships equipped with single azipod. For ships equipped with two azipods, it is possible to turn azipods to opposite helm angles while reversing the thrust. The induced on azipod housings hydrodynamic force (precisely its longitudinal component) can be used as a braking force. Investigations made by Woodward show, that indirect manoeuvre gives the shortest stopping time and distance when comparing with the two previously described modes of stopping. The optimum azipod helm angle was 60° [3]. According to report from sea trials from "Elation" published by Kurimo this mode of stopping allowed to diminish the stopping distance to 2.4 L [3]. Azipod deflection angle applied was 35°.

## 3 THE PROGRAMME OF MODEL TESTS

As already mentioned above, the purpose of the model tests was to obtain data on the effectiveness of different modes of stopping manoeuvre. The tests program has been developed in a manner suitable to demonstrate the potential impact of interaction effect between azipods.

The ship model used for tests has dimensions shown in Table 1 below:

Table 1.

| | | |
|---|---|---|
| Length [m] | 277.5 | 11.56 |
| Breadth [m] | 43.2 | 1.80 |
| Draft [m] | 12.0 | 0.50 |
| Block coefficient $C_B$ [-] | 0.79 | 0.79 |
| Scale | - | 1:24 |
| Number of azipods | 2 | 2 |

The configuration of the stern part of the ship model is presented in figure no 4. You can clearly see the specific shape of the stern of the ship equipped with azipod propulsion improving the propulsion effectiveness and significant skeg area enhancing the course stability.

Figure 4. The LNG carrier model equipped with two pulling azipods used for stopping tests (in this photo the pulling azipods are turned around by 180 degrees)

The model tests were carried out on the lake in deep water. The wind velocity during tests was about 5 knots and less (after conversion to the real ship scale). Current was not observed.

Tests were performed with an initial speed of about 12 knots, that is, for the speed of approx. 65% of the service speed of a typical large LNG carrier. This speed does not coincide with recommendations in standards of manoeuvrability [4], where 90% of the service speed is suggested. Such a choice was dictated however by the demands of the training.

Propeller revolutions working back were the same as in the forward motion. The instantaneous position of azipods and number of revolutions of installed propellers was also measured. The position of azipods and number of their revolutions were changed manually by operators performing experiment.

The model trajectory, heading and speed were measured using precise GPS system operating in RTK mode.

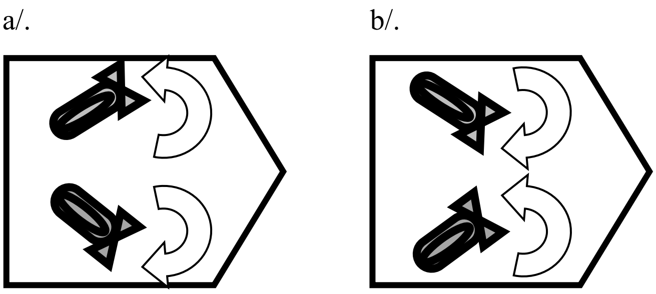


Figure 5 Comparison of outward (a) and inward (b) direction of azipod turning

The azipod slew velocity was 7.5 º/s, time for reversing direction of propeller revolutions was 60 s (both parameters given for the real ship).

The following stopping trials were performed:

1 Inertia stopping (propellers windmilling)with the azipod angle of deflection 90º outwards;
2 Stopping with the azipod angle of deflection 90º outwards. Propellers revolutions not changed.
3 Stopping with the azipod angle of deflection 90º inwards. Propellers revolutions not changed.
4 Stopping by turning azipods around (180°). When turning number of propellers revolutions reduced, afterwards propeller revolutions returned back. .
5 Stopping by changing the propellers direction of revolution. Astern number of propeller revolutions the same as ahead.
6 Stopping by indirect manoeuvre: deflection of azipods 30º outwards, afterwards changing the propellers direction of revolution.

## 4 EXPERIMENTAL DATA

Results of model tests are presented in table 2 below. The stopping distance is given in non-dimensional form as the ratio of track reach to the ship's length $S_d/L$ (track reach is the total distance travelled along the ship's path):

Table 2.

| Case | Description of the stopping procedure | $S_d/L$ |
|---|---|---|
| 1 | Inertia stopping (propellers windmilling) with the azipods angle of deflection 90º outwards | 11.2 |
| 2 | Stopping with the azipods angle of deflection 90º outwards. Propellers revolutions not changed. | 4.0 |
| 3 | Stopping with the azipods angle of deflection 90º inwards. Propellers revolutions not changed. | 3.8 |
| 4 | Stopping by turning azipods around (180°). When turning azipods, number of propellers revolutions reduced, afterwards propeller revolutions returned back. | 2.7 |
| 5 | Stopping by changing the propellers direction of revolution. Astern number of propeller revolutions the same as ahead. | 4.4 |
| 6 | Stopping by indirect manoeuvre: deflection of azipods by 30º outwards, with simultaneous reversing of propellers. Astern number of propellers revolutions the same as ahead | 3.7 |

Some recorded trajectories of the model are also shown. Are presented successively trajectories for the following stopping manoeuvres:

- Inertia stopping (propellers windmilling) with the azipods angle of deflection 90º outwards
- (case described as number 1 in the table no 2, trajectory shown in fig.6a)
- Stopping by changing the propellers direction of revolutions (case described as number 5 in the table no 2, trajectory shown in fig.6b)
- Stopping by turning azipods around (case described as number 4 in the table no 2, trajectory shown in fig.6c)

## 5 CONCLUSION

Experimental data presented in Table 2 show that the azipod propulsion clearly provides a relatively short stopping distance, regardless of the mode of carrying out the manoeuvre. An average value of stopping manoeuvre from initial velocity of 12 knots is about 3.5L.

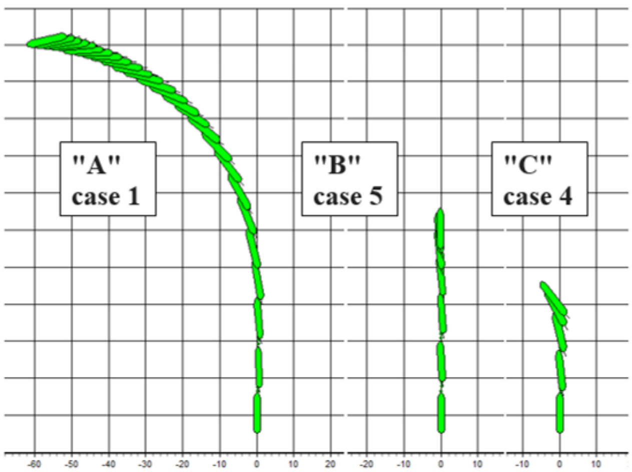


Figure 6 Trajectories of stopping manoeuvre for different modes of its realization

This is because:

- Relatively short reversing time (about 60 s) because of propellers powered by electrical motor compared with the classical Diesel propulsion for which the reversing time is equal from a few to several minutes
- The azipod slew velocity varies in general between 5 and 7.5 °/s, so that the opposite position can be reached after 24-36 seconds.
- The simultaneous use of the hydrodynamic reaction arising on deflected pod housings significantly reduces the stopping distance.
- The so-called indirect manoeuvre not proved to be the best. The non - dimensional track reach was about37% greater than stopping by turning azipods around.
- The effect of interaction between azipods (see results of tests using stopping mode no 2 and 3- inward and outward azipod turning direction) increases slightly track reach during stopping (4L instead of 3.8L)

Analysis of trajectories of the ship model showed a significant effect on the model path shape of the manual method of control of azipod position and propeller number of revolutions. Even small unsymmetrical final position of azipods or small differences during operation of changing their positions give a significant deviation from the expected for twin pod propulsion straight trajectory. That is need for constant control of the direction of motion of the ship, usually having manual control of azipod system of propulsion.

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