Lech Kobyliński
Foundation for Safety of Navigation and Environment Protection

PROBLEMS OF HANDLING SHIPS EQUIPPED WITH AZIPOD PROPULSION SYSTEMS

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Abstract: Large ships, mainly large cruise vessels, built during last two decades are quite often equipped with revolutionary propulsion devices known under the name AZIPODs. There are many reasons for choosing AZIPODs as main propulsion units, the main reason being excellent manoeuvring characteristics achieved. However in case of large propulsion units, having power of 15-25 MW, used for propulsion there are also some disadvantages and limitations, the last mainly related to operational factors. Handling of ships equipped with AZIPODS is different from handling conventional ships and in certain manoeuvring situations safety of the ship and of the propulsion units might be endangered. Therefore some limitations imposed on handling procedures are necessary and it is essential that pilots and masters of ships fitted with AZIPODs must be specially trained.

Keywords: ship manoeuvrability, podded propulsion, handling of ships with Azipods

1. INTRODUCTION

During recent times the new type of vessel has been introduced to the world shipping fleet in large numbers. This type is passenger cruise vessel. Statistics of ships in operation and on order reveals that more than 750 ships of different size that could be defined as cruise ships are recently in operation, more than about 50 of them are large ships of more than 250 metres in length and carrying sometimes as much as 6000 passengers.

According to the definition cruise ship is usually a very large passenger ship that makes a roundtrip with several en route stops and takes passengers only at the port where trip begins and ends. This is not very strict definition but it makes clear that the passengers are holidaymakers and the main purpose of the ship is not to make fast trip but rather to assure pleasure spending time visiting several interesting places. This is fast developing business and the number of very large cruise ships in operation since the last decade of the last century is increasing rapidly. This is really type of ship of XXI century. Typical large cruise ship is shown in fig. 1.
It is essential that cruise ships must have excellent manoeuvring characteristics especially at low speed, because they are supposed to call quite often at small ports in remote places where there are no facilities such as deep berthing quays, powerful tugs, etc. Because of that, they are mostly fitted with azimuthing propellers that make possible to manoeuvre the ship effectively in a very confined area.

2. AZIMUTHING PROPELLERS

The idea of azimuthing propulsion units is that they are used at the same time as propulsion devices and as rudders. Azimuthing propulsion devices are known for quite a long time. The most popular azimuthing propulsion device is outboard motor used for many years for driving small boats and yachts. This idea was later followed by installing propulsion motor inside the hull with Z-form transmission where the propeller could be rotated around vertical axis. Later-on this type of propulsion device developed into Schottel propeller allowing to install higher power.

In the early thirties of the last century cycloidal propellers were invented and manufactured, the main representative of which was Voith-Schneider propeller, rotating around vertical axis and with several vertical blades, the angle of attack of which is controlled by special mechanism.

Azimuthing propulsion devices used for propulsion of large cruise ships are at present known under patented name AZIPODs, where the electric propulsion motor is contained in a rotatable housing or nacelle submerged under water. Opposite to the azimuthing propellers mentioned above, that usually were of rather small power not exceeding several hundreds kW, the AZPODs are of rather high power, of the order 14 to 25 MW and
because of that, operation of ships fitted with such high powered propulsion units poses certain problems. The application of this type of propulsion devices is considered here.

AZIPODs are characterized by two main qualities:

- Electric motor is located inside a hydrodynamic optimized submerged housing
- The total unit is rotated with the propeller(s) by 360 degree rotation providing large turning force in any direction without necessity of installation of rudder.

Schematic lay-out of the AZIPOD is shown in fig. 2, whether fig. 3 shows standard installation of twin AZIOPIDs of the power of 17MW each onboard of a large cruise ship.

Fig. 2. Scheme of the AZIPOD unit [7]

Fig. 3. Typical AZIPOD propulsors with pulling propellers [10]
Usually AZIPODs are installed in pairs, because such arrangement is able to provide excellent manoeuvrability at slow speed as well maintains good directional stability. However, there are known many variations of this propulsion systems using AZIPODs where propellers may be pushing or pulling, tandem or contra-rotating. In very large ships sometimes more than two AZIPODs are installed. In special types of ships, such as ships requiring dynamic positioning (off-shore supply ships, anchor handling off-shore ships etc) four or more AZIPODs are sometimes installed, however their power is much smaller than in cruise ships. Some different installations of AZIPODs are shown in figs. 4 and 5.

Main suppliers are Rolls Royce Kamewa/Alstrom, Finland ABB Industry, Siemens-Schottel, and STN Atlas Marine/ John Crane-Lips.

Fig. 4. Installation comprising three AZIPODs, the central one is fixed [10]

Fig. 5. AZIPODs fitted with tandem propellers [10]
3. ADVANTAGES, DISADVANTAGES OF AZIPODS AND DESIGN CONSEQUENCES

The advantages of AZIPOD drives in comparison with traditional diesel propelled vessel with fixed propellers are [9]:
1. Elimination of shaft line, steering gear, rudder and stern thrusters.
2. More cargo space because of possible re-arrangement of machinery space and utilization this space for other purposes.
5. Lower noise level and less vibration.
6. Smaller power required in twin AZIPOD driven ships.

The disadvantages are:
1. Higher capital cost.
2. Generally slightly lower propulsion efficiency and loss of power because of diesel electric propulsion.
3. Stern part of ship must be re-designed in order to accommodate AZIPODs.
4. Limitation of power available for single AZIPOD (up to about 25 MW).

Installation of AZIPODs has important impact on the design features of the ship. In particular as diesel-electric propulsion system is required, internal space of the ship may be arranged differently as in conventional ship, in general more convenient and saving in space. The other consequence is the form of the stern part of the hull that with the AZIPOD propulsion units installed must be flattened (fig.6) in order to accommodate PODs. (see paragraph 3).

![Fig.6](image_url)  
Fig.6. Recommended form of stern part of ships suitable for accommodation of AZIPODs [10]
4. MANOEUVRING CHARACTERISTICS OF AZIPODS EQUIPPED VESSELS

One of the most important advantages of AZIPODs is that manoeuvring characteristics of POD propelled vessels are different, and in general much better than of vessels fitted with conventional propellers. There are three basic manoeuvring characteristics that must be taken into account when designing a ship, namely:

1. Turning ability
2. Course keeping ability or dynamic stability on straight course, and
3. Stopping ability

Turning ability of AZIPODs driven ships is much better than turning ability of conventional ships fitted with conventional rudder. This is obviously the result of high steering forces created by AZIPOD rotated up to 360 deg with the result that the ship may turn even around of its own centre of gravity. Comparison of turning ability characteristics of average conventional and POD propelled vessels is shown in fig.7 [after 9].

The course keeping ability for AZIPOD driven ships is known to be worse than for conventional vessels. The reason of this effect may be attributed to the different form of the stern that is flat in order to accommodate AZIPODs. The course keeping ability is usually assessed by overshoot angles obtained in so called zig-zag test. The same source shows that overshoot angles obtained are in average larger for AZIPOD propulsion than for conventional propulsion, but still seem to satisfy manoeuvring standards adopted by the IMO Resolution [3] (fig.8). With AZIPOD propulsion however, this characteristic depends on the proper installation of fins at the loaf-shaped stern, otherwise course keeping ability would be inadequate.

This was clearly shown during the tests of manoeuvring characteristics performed of AZIPOD propelled vessel in SHRTC Ilawa (Ship Handling Research and Training Centre) in the years 2003-2010. Within the scope of the project large model of gas carrier equipped with one or two AZIPODS was built and tested on the lake [4, 5 and 7].

Fig.7. Comparison of turning characteristics of ships fitted with AZIPODs and conventional propulsion units [after 9]
Subject of special investigation by SHRTC were turning and course-keeping characteristics of POD driven full bodied ships and within the scope of the project several variations of arrangement of skegs and fins at the stern of the model were tested in order to improve inherent poor course-keeping stability and at the same time achieve good turning ability.

As the result of those investigations ultimately the optimum solution was adopted for the model of the above mentioned gas carrier that is now used for training purposes at the Centre. The model tested with fins installed is shown in fig. 9. This optimum solution was achieved after extensive model tests of several variations of arrangement of fins and skegs were tested. Some of these arrangement are shown in fig. 10.

Stopping ability is an important element of manoeuvring characteristics of the ship and stopping distance according to IMO criterion should be not more than 15 ship lengths when crash stop test is performed. With AZIPOD driven ships there are several possible modes of stopping the ship. Main three modes are

1. Conventional crash stop manoeuvre when engines are ordered full astern
2. Stopping (called POD WAY) by turning AZIPODs 180° inwards (or outwards) in opposite directions while maintaining constant shaft torque (see Table 3)
3. Stopping by turning AZIPODs 90° inwards in opposite directions while maintaining constant shaft torque.
On top of these three modes it is possible to stop effectively the POD driven ship by hard turn. However, there are certain limitations in using the above mentioned modes when stopping (see paragraph 5).

5. BASIC CONTROL MODES WITH TWIN AZIPOD CONFIGURATION

The main difference between steering of a ship with conventional propulsion and a ship equipped with AZIPODs, that may be confusing, is that starboard rudder causes the ship turn to starboard whether starboard directed POD causes the ship turn to port (fig.11).

Even the more confusing situation may occur when both PODs (in twin POD propulsion) are used at the same time separately. Without previous training the result of particular setting of PODs may be difficult to predict. Moreover, possibility to rotate PODs by 360° and also the possibility to reverse direction of rotation of propellers causes that many different manoeuvres may be performed other way than with conventional propelled vessels.
In emergency situation in a ship with single screw conventional propulsion bridge personnel have only finite number of options, whether in a ship equipped with AZIPODs the number of options is quite large and the decision which option to use is not clear and is not intuitive.

Three basic control modes for ships fitted with two AZIPODs are as follows [5]:

1. CRUISE MODE, (or open sea mode) where PODs are synchronized. Both PODs deflected to the same angle, in a similar way as it is usually done with two coupled rudders in twin-screw ships fitted with conventional propellers and rudders. Power available is unlimited, but turning angles of PODs are greatly restricted (not more than 35°).

2. MANOEUVRING MODE - SOFT when PODs are not synchronized and operated independently. In this mode often one POD (left or right, depending on the direction of turn) is used to perform maneuvers. Power available is limited to about 50-60% of the total, and the turning angles of PODs are also limited to 35°.

3. MANOEUVRING MODE - STRONG (AZIMAN mode) when PODs are not synchronized and operated independently. In this mode both PODs are used to perform manoeuvres (for example docking operations) and the system will automatically reduce power to about 50-60% (if such control is provided in the ship). Turning by 360° is allowed.
In operation of POD propelled vessel it is very important for bridge team and pilot to be aware at which mode currently ship is operating and what are limitations imposed within this mode. Different manufacturers have different terminology for what is essentially the same mode. This may be confusing. Operators coming onboard various vessels with different terminology need to know what each different term is equivalent to. Therefore the current operating mode should be clearly detected. This is required actually by IMO [2].

6. PROBLEMS WITH THE OPERATION AND OPERATIONAL LIMITATIONS

Azimuthing propellers of the type Voith-Schneider propellers, Schottel propellers or conventional outboard motors having limited power (usually not more than 1MW) are known and operated for many years and their operational limitations are well known. It is different for innovative AZIPOD propulsion units, where electric motor is situated in the underwater housing and the power may be as high as 25MW.

Experience with operation of these high power AZIPOD units, mainly in cruise liners, did reveal some difficulties from the structural point of view, the critical issues being seals and bearings, the result might be leakage, insufficient lubrication etc.

When the AZIPOD unit is turned rapidly to large angle at high speed, very high transverse force would be created that may cause large heel angle of the ship endangering its stability and very high loads on POD construction that may cause serious damage to the POD, its bearings, transmission and shaft. This is prohibited and usually the system will not allow to do so in cruise mode. Table 1 shows recommendations with regard of using three basic modes of operation [8].

<table>
<thead>
<tr>
<th>Mode</th>
<th>Power</th>
<th>Rotation</th>
<th>Synchronized</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open sea cruise mode</td>
<td>Full power (17MW)</td>
<td>&lt; 10°</td>
<td>Pods and rpm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>May be 35°</td>
<td></td>
</tr>
<tr>
<td>Manoeuvring mode</td>
<td>Reduced power (12 MW)</td>
<td>&lt;35°</td>
<td>Pods and rpm</td>
</tr>
<tr>
<td>Fast mode</td>
<td>Reduced power (10MW)</td>
<td>360°</td>
<td>Pods and rpm</td>
</tr>
<tr>
<td>POD WAY mode</td>
<td></td>
<td>independent</td>
<td></td>
</tr>
</tbody>
</table>

AZIPOD construction allows achieving negative thrust in two ways: by reversing propeller revolutions or by rotating the AZIPOD by 180 degrees. However, usage of negative revolutions when manoeuvring is in general not recommended at high speed because of high load on shaft bearings that may be damaged. On top of that with AZIPOD propulsion devices it is possible to accelerate the vessel quickly to any direction and this usually leads to necessary use of high power levels to stop motion. High power at low speed usually leads to harmful heavy vibrations that may reduce life time of mechanical components. Therefore important recommendation and limitation is to operate AZIPODs
as gently as possible and to maintain minimum revolutions as well as, in open sea, to avoid reverse RPM.

The recommendation for use of negative RPM during ship operations are given in the Table 2.

Strong interaction between PODs is expected also in the position when the starboard AZIPOD is turned to 90° whether the port one is at rest (T position). In this position the propeller race of the starboard unit is against the port unit creating the force reducing the starboard thrust and causing severe vibrations. Situations to be avoided according to ABB recommendation are shown in Table 3.

### Table 2

<table>
<thead>
<tr>
<th>Manoeuvring with low speed -2 to 4 knots (docking and undocking)</th>
<th>Position keeping (anchoring, DP)</th>
<th>Channel keeping or approach to pilot station</th>
<th>Normal service speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative RPM allowed</td>
<td>Negative RPM allowed</td>
<td>Negative RPM occasionally allowed</td>
<td>Negative RPM NOT recommended</td>
</tr>
</tbody>
</table>

Bearing in mind the recommendation to avoid all situations where the propeller race of one POD is against the other one, that is shown Table 3, it would be better to perform POD WAY stopping manoeuvre rotating PODs inwards than outwards, although ABB is recommending to perform this manoeuvre as shown in fig. 13. However, as it is seen from the figure, AZIPODs are rotated first by 35° to 45° and then it is recommended to wait until speed drops and then rotate them by 180° [1,8].

When performing stopping manoeuvre some limitations also must be observed.

1. Conventional crash stop, with reverse RPM. This is traditional crash stop manoeuvre. Reversing RPM at high speed is not recommended by the manufactures (compare Table 2). Before RPM are reversed power has to be reduced, or if it is automatically reduced by the system, cruise mode has to be changed to STRONG or AZIMAN mode.

2. Crash stop POD WAY. As AZIPODs could be rotated by 1800°, therefore crash stop could be done POD WAY without reversing propeller rotation. It is recommended that in this manoeuvre AZIPODs are rotated outwards, but rotating them inwards is not prohibited.

The crash stop POD WAY is more lenient on the power plant due to decrease in both fluctuations of the propulsion power and reverse power generated by the propulsion system. Propellers develop more thrust because they rotate ahead direction, the loads on the POD units are reduced and the time and stopping distance is shorter. During crash stop the ship’s course can be controlled (see fig 13).
Table 3

Situations to be avoided according to ABB instruction. (X – mark, to be avoided)

<table>
<thead>
<tr>
<th>Maximum side thrust to port with one AZIPOD</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram of maximum side thrust to port with one AZIPOD" /></td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Maximum side thrust to port with two AZIPODS</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image2" alt="Diagram of maximum side thrust to port with two AZIPODS" /></td>
</tr>
</tbody>
</table>

Cruise mode is changing to strong manoeuvring (AZIMAN) mode. The system will automatically reduce power if there is power limit in this mode. Otherwise RPM must be reduced.

AZIPOD units are turned 35 to 45° outwards. 
Wait until ship speed is about 15 knots (but could be also inwards).

AZIPOD units are turned simultaneously to 180°.

Fig. 13. The procedure of crash stop POD WAY as recommended by ABB [after 8]
3. Turning Stop. Stopping the ship utilizing hull drag and making sharp turn with combination of braking. Speed has to be reduced because otherwise large heel might occur. Turning diameter and advance in this manoeuvre are very small and stopping occurs at a very small distance, however some lateral clearance is required.

4. Crash stop –tranverse arrest procedure. Within this procedure both AZIPODs are turned by 90° to the position opposing each other –to the Tranvers Arrest (TA) position. This gives a very high rate of slow down at higher speeds. As the speed drops down to about 5 knots range, then retardation will be greater by further rotating PODs to create astern thrust. (see fig. 14).

As it is seen from the list, operation of AZIPOD driven ships is not easy and shipmasters and sea pilots taken onboard must be fully aware of all the limitations otherwise they may cause damage to the propulsion units or to the ship itself.

7. SPECIAL TRAINING REQUIREMENTS FOR MASTERS SENIOR OFFICERS AND PILOTS OF AZIPOD PROPELLED SHIPS

Because steering of AZIPOD propelled ship is not intuitive and different from handling of ships with conventional propulsion units, and because there are several limitations and in general AZIPODs must be handling with great care and gently, ship masters and senior officers as well as sea pilots must be specially trained.

With the view of arranging faultless operation and effective training of ship masters and pilots, European consortium was established within Seventh Framework for the realization of the research project under heading: “Intuitive operation and pilot training when using marine azimuthing control devices”, to which SHRTC became the partner. Within the scope of the project all aspects and problems that may arise in operation of AZIPOD propelled vessels were studied and effective programmes of training were proposed and
implemented in the training centres for ship handling using Full Mission Bridge Simulators (FMB) or Manned Models Simulators (MM) [6]. It is recommended that training should be performed on both types of simulators because their purpose is not the same.

Ilawa Ship Handling Research and Training Centre is equipped with MM simulator. There are only four MM simulators currently in the world (France, Great Britain, Australia, and Poland) and Ilawa simulator is the most advanced. The results of the above mentioned project were implemented in SHRTC in a way that one week long specialized training course for ship masters of AZIPOD propelled vessel was arranged and on top of that in all weekly training courses (standard and advanced) for pilots training onboard AZIPOD propelled model are compulsory. This arrangement was supported by majority of pilots who more and more often must assist AZIPODE propelled vessels calling in their ports.

For the purpose of this training mode 11.3 meter long model of the gas carrier equipped with two AZIPODs was constructed (fig. 9) onboard of which manoeuvring exercises were performed according to the standard programme. The detailed description of the lay-out of the training area and programme of exercises is included in [10] and is not repeated here. However in order to give impression of the unusual manoeuvring performance of AZIPOD equipped ships, record of one exercise comprising moving the ship from one berth to the opposite berth in a very confined area is shown in fig.15.

![Fig.15. Harbour manoeuvre of AZIPOD propelled model [10]](image)

**8. CONCLUSIONS**

Novel types of ships, in particular large passenger cruise vessels, are often equipped with azimuthing propulsion devices known under the patented name AZIPODs. AZIPODs are new development where electric motors of the power up to 25 Mw are installed in streamlined housings located below the hull at the ship stern. Although AZIPODs have
many advantages, and ships fitted with AZIPODs have excellent manoeuvring qualities, there are also some difficulties with operation of this type of propulsion devices. Because of that, there is a need to arrange special training for masters and pilots who are intended to operate ships fitted with this kind of propulsion.

REFERENCES

2. IMO Safety of Navigation circular SN.1/Circ.265

PROBLEMY MANEWROWANIA STATKAMI NAPĘDZANYMI PĘDKIKAMI AZYMUTALNYMI -AZIPODAMI

Streszczenie: Duże statki, przede wszystkim wywiercze, budowane w ostatnich dwu dekadach wyposażane są zwykle w nowoczesne pędkiki azymutalne znane pod nazwą komercyjną AZIPODY. AZIPODY są stosowane głównie dlatego, że zapewniają one statkowi doskonałe właściwości manewrowe. AZIPODY jako główne jednostki napędowe wykazują ponadto wiele zalet, jednakże w przypadku stosowania napędów o dużej mocy, rzędu 15-25 MW występują także pewne niekorzystne zjawiska i konieczne jest wprowadzanie pewnych ograniczeń, głównie w odniesieniu do manewrowania nimi. Manewrowanie statkami wyposażonymi w napęd AZIPODAMI różni się od manewrowania statkami konwencjonalnymi i w niektórych sytuacjach manewrowych bezpieczeństwo statku jak i jednostek napędowych może być narażone. W związku z tym wymagane jest zastosowanie specyficznych ograniczających procedur manewrowania i konieczne jest aby zarówno kapitanowie tych statków jak i piloci portowi przechodziли specjalne przeszkolenie.

Słowa kluczowe: manewrowanie statkiem, napęd azymutalny, manewrowanie statkiem wyposażonym w AZIPODY