AZIPOD PROPELLER BLADE CAVITATION OBSERVATIONS DURING SHIP MANEUVERING

A.V.Pustoshny, S.V.Kaprantsev
Krylov Shipbuilding Research Institute, Russia, St.Petersburg

ABSTRACT
This paper presents results of observations of full-scale propeller blade cavitation patterns carried out on the *Elation* passenger cruiser, the very first ship equipped with AZIPOD electric thrusters. It offers descriptions of test conditions, cavitation photos for a number of maneuvering modes, including acceleration, steering, initial crash stop phase, some comments on cavitation patterns and conclusions about propeller blade cavitation on the pulling option of azimuthal thrusters.

1. INTRODUCTION

Development and practical introduction of electrical AZIPOD-type propulsor units on passenger ships has provoked a noticeable boom in the application of podded propellers for ship propulsion. By now the electric pod power has reached over 20MW instead of just 5~7MW, which used to be the practical limit for Z-drive thrusters. Since the introduction of Finnish AZIPOD propulsors at least three powerful corporations have started to develop their own electrical pods. Even the first implementation of electric pods as main propulsors for the *Elation* cruise liner built by KVAERNER MASA YARDS–Helsinki New Shipyard (see Kurimo, Pustoshny Syrkin, 1997) was quite successful and demonstrated significant advantages of podded propulsors compared to conventional shaft propellers. Among these merits one should particularly mention the following:

- excellent underway maneuverability, including at low speeds, using only the podded propulsors without any rudders;
- powerful and fast crash-stop by reversing the propeller rotation direction, which is typical not only for podded thrusters but generally for electric propulsion systems (for a thruster of about 20MW it takes only about 40s to fully reverse the fixed-pitch propeller and the propeller torque astern can be as high as about 80~85% of the ahead power;
- the podded configuration allows applying pulling propellers, thus providing unprecedented uniformity of ship wake velocities in way of the propeller, and that makes it possible to achieve extremely good cavitation characteristics of propellers and to significantly reduce propeller-induced pressure fluctuations and vibrations.

All these advantages of podded propulsors are associated with their operation modalities that may cause such unique conditions for the propeller like great flow wash angles and fast variations in the propeller load. Therefore, in order to achieve the best possible effect of the podded propulsor option the propeller designers have to tackle certain new challenges. Among these tasks there is the need to study blade cavitation inception and growth under oblique inflow conditions typically associated with different kinds of ship maneuvers with podded propulsors. The issue of cavitation inception and growth when the ship is maneuvering is of course no less important for any conventional “shaft propeller” configuration but, obviously, their inflow angles are always much smaller.

In December 1997 a team of KSRI experts supported and contracted by KVAERNER MASA YARDS-Helsinki New Shipyard carried out cavitation observations during sea trials of the *Elation* – the first passenger cruiser ever built with AZIPODs.

The authors have got permission from KVAERNER MASA YARDS-Helsinki New Shipyard to publish the actual observation results and photos.

2. TEST CONDITIONS AND EQUIPMENT

The observations were carried out with the help of stroboscopic lights brought by the KSRI team. The system included a pulse generator to synchronize the strobes with the AZIPOD propeller speed (one flash per propeller revolution). Initially the flash generator provided flashes of 3~5 Joules as should have been quite sufficient for viewing propellers of any practically possible diameter in clean water. However, the water in the Gulf of Bothnia has turned out to be so muddy that cavitation observations were rather uncertain. Already during the trials the system was modified so that every fourth flash carried 50J of energy. That was enough to record cavitation by a video camera in order to get reliable still views even in turbid waters.

Though the official observation program included only cavitation observations when the ship sailed straight ahead, while the cruiser exercised the trials the team has soon started “free hunting”, i.e. tried to observe different propeller operation modalities without burdening the shipyard with requests to provide any special conditions. That was possible thanks to the fact that all relevant data like propeller revolutions, pod angles, ship speeds, etc. were available in the compartment fitted with observation ports.

Those observations enabled to obtain valuable information on propeller cavitation under different ship operation conditions, including: -

- acceleration;
- crash-stop;
- full-speed maneuvering at both small and big pod angles, i.e. when AZIPOD propellers operated in highly oblique inflow.

Observations of azimuthal thruster propellers during maneuvering involve certain specific features:

(a) Fast variations in propeller loadings, revolutions, and advance ratios at different stages of maneuvers;
(b) Changes in propeller inflow angles due to variations in the ship stern drift angle;
(c) Changes in propeller inflow angles due to the rotation of the thruster pod in the process of steering;
(d) Continuous variations in the thruster position as seen from the observation port, sometimes making the propeller invisible for the observer.

Consideration these features the team had to evolve an observation technique that was somewhat different from the one normally used for conventional propellers. It has soon become obvious that one should consider the effects of maneuvering-related factors upon cavitation patterns as a continuous time series of cavitation pattern variations and make practical conclusions on the basis of such observations. With the propeller so often disappearing form the field of view, the team had to reject the standard photographing procedure since any photos could only show some random positions of the propeller at random instants of pod turning at a particular dynamic condition. The choice was to carry visual observations and video taping. The observers checked the tape quality by a TV monitor installed it the water tank that has been allocated for the observation room and fitted with seven view ports (Fig.1). Subsequently, the videotape was computer-processed to get clear still pictures of individual cavitation patterns associated with maneuvering. Since the propeller was frequently escaping from the camera eye, in order to compile the true cavitation development picture it was necessary to utilize some indirect signs of cavitation on the invisible part of the propeller disk.

Fig. 1

It should be also mentioned that when the ship drifted while turning or reversed to run with her wide stern forward, thick clouds of air bubbles sucked under the hull covered observation ports with a layer of “boiling water”. In spite of all problems the full-scale cavitation observations were carried out successfully and their results may be helpful for practical purposes.

3. ANALYSIS OF OBSERVATIONS MADE DURING SHIP MANEUVERING

A brief analysis of cavitation observations for straight-ahead sailing has been already presented by Kurimo (1998).
AZIPOD propellers have been designed to minimize fluctuating pressures (see Kurimo et al., 1997). This means that the blades have been allowed only limited tip vortex cavitation. According to different sources, particularly including cavitation-tunnel model tests at MARINTEK (Norway), within certain limits this sort of cavitation does not increase the level of fluctuating pressures, which is true at least until the cavitating vortex spreads over a portion of the blade surface as a 3-D vortex attachment or transforms into sheet cavitation along the blade edge. Thus, the propellers were designed with moderately unloaded tips. As reported by Kurimo, under full-scale straight-ahead conditions observations have shown very thin tip vortices appearing at blade angles within -40~-50° to +70~+80° (0° correspond to the 12 o'clock position, 90° means that the blade in near the centerline if the propeller rotation direction is inwards). The full-scale range was found to be about 20° wider both sides than seen during the model tests.
At the same time it appears that even more interesting information may come from observations made while the ship was maneuvering.

Acceleration

Analyzing cavitation phenomena associated with the ship's acceleration from zero speed one can see that the principal and the only kind of cavitation was a very thick suction-side tip vortex. This vortex was significantly thicker than at the full speed of the ship. One could clearly see the "tail" of the vortex trailing from the previous blade. This indicates to a much wider blade angle range occupied by the vortex. The higher became the ship speed, the less was the thickness of the vortex (Fig.2) and eventually it approached the vortex thickness associated with full-speed-ahead conditions.

Crash-stop

For some time in the beginning of the crash-stop maneuver the ship still retains the forward speed, and therefore one can segregate several phases of this maneuver: -

- At the initial phase the ship has a certain forward speed and the propeller revolutions are decreasing. This is accompanied by pressure-side cavitation growing up to a certain moment (Fig.3). Due to the unsteady pattern of the flow in way of the propeller hub, from time to time there appeared a chaotic portion of the vortex stretching along the hub Those pieces of longitudinal vortices were of about the same length as the hub.
- At low ship speeds there were truly fantastic patterns of highly skewed unsteady vortices (Fig.4). It may be assumed that what the observers could see were "fragments" of unsteady vortices generated near the pod due to crash stopping.
- While the ship accelerated astern, there were pronounced pressure-side cavitation vortices stretching along a trajectory going far away from the blade (Fig.5). Chances to observe this cavitation pattern were very limited because of the solid sheet of air bubbles that rapidly covered the windows as soon as the ship moved astern.

When the crash-stop maneuver was made at the full speed, it caused in the observation tank compartment extremely loud acoustic effects resembling an explosion.

Maneuvering by AZIPODs

From the point of view of practical AZIPOD applications the most interesting thing is to observe the maneuvering modes, i.e. when the podded propulsor acts as the sole steering device of the ship.
The performed observations have enabled to identify the following features of the cavitation scenario:

(1) The ship is normally steered by turning the AZIPOD within ±10°. As long as the ship maneuvers within this limits, i.e. keeps a more or less straight course without entering a turning circle, which would mean significant drifting, loosing the speed and increasing the propeller load, the cavitation pattern remains very close to that under straight-ahead sailing conditions (Fig.6). The observers even had an impression that when the AZIPOD took small angles to the centerline the cavitation intensity decreased (the vortices became thinner). That would be only logical considering the inward rotation of the propeller and the additional tangential velocities due to the oblique inflow, which reduce blade top-position loads when the pod turns to the centerline.

(2) When the AZIPOD was kept turned to an angle for a long time, the ship entered a steady turning circle. According to Kurimo (1998) the turning circle diameter for an AZIPOD ship is significantly smaller than for a vessel with conventional propellers, and the involved loss in the speed is much higher. Obviously, under such conditions the propeller load should significantly increase. Accordingly, even at moderate AZIPOD angles

applied at the full ship speed the cavitation phenomena became significantly more intensive: the vortexes grew sizably thicker (Fig.7). When the AZIPOD was turned through more than 15° to either side there was sheet cavitation along the blade edge covering the tip and continuously transforming into the tip vortex. A similar, though more clearly pronounced picture (Fig.8) was observed with the AZIPOD set to 35° for full-speed turning circle. Regretfully, as soon as the pod was ordered “hard over helm”, all view ports were clouded by air bubbles arriving form the involved side of the ship. Due to that it was possible to log the cavitation pattern only when the AZIPOD already started turning back to its position parallel with the centerline.

When the ship circled with the AZIPOD turned to the centerline, the propeller was completely out of sight. Nevertheless, it was possible to get some videos of the cavitation pattern on the turn with the pod at 35° to the centerline. The pictures clearly show 3 “tails” of tip vortexes from starting from different and just entering the camera field of view. This indicates that in the subject case the cavitation region might have been wider than 180° and the blades were cavitating throughout the greater part of their paths (Fig.9). As suggested by English (1998), such a pattern of broken vortices may provoke an increase in high-harmonic pressure pulses.

(3) A fairly consistent picture of the cavitation scenario can be derived from the analysis of transient processes, i.e. those associated with the turns of the pod. When the AZIPOD is turning downwards (from side to centerline), one can clearly see some residues of sheet cavitation that covers the whole upper portion of the blade starting at about 0.9 radius like has been observed on the turning circle.

Cavitation scenarios observed when the pod was turning away from the centerline (Figs.9, 10) tended to be more sophisticated. Obviously, while the AZIPOD was set along the centerline, the dominating role belonged to the suction-side tip vortex. When the pod was turned port or starboard to about 10~40°, the vortex moved from the suction side to the pressure one and then returned to the suction side where it was accompanied by the above-described sheet cavitation. Unfortunately, photographs fail to show the instant the cavitation changed sides but the observers could see the blade tip sticking out of a vortex cloud enveloping it from both sides. Apparently, such rapid changes in the forms of cavitation are associated with the rotation of the pod but to get a better understanding of the process it would be necessary to carefully analyze relations among wake-induced propeller inflow velocities, instantaneous propeller inflow angles considering the drift angle, propeller revolutions, etc.

4. CONCLUSIONS

The obtained results of full-scale AZIPOD propeller cavitation observations under ship maneuvering conditions make it possible to formulate some practical conclusions:

(1) In the view of the present efforts to as much as possible reduce propeller-induced vibrations it can be recommend to maneuver by turning the podded propulsor with pulling propeller for no more than 5~7°, at least at higher ship speeds.

(2) While the ship is accelerating, the dominating form of propeller cavitation for podded propulsors is the tip vortex, and the thickness of the cavitating vortex can significantly increase with the growth of the propeller loading.

(3) Observations, particularly those of more extensive cavitation on steady turns than when course-correcting with the same limited pod angles, indicate that the increase in the loading due to the loss of ship speed appears to be more critical for cavitation inception and growth than moderate (10~15°) inflow angles. Therefore, it could be advisable to apply some rationalistic automatic control for propeller speed on the turn, at least under non-emergency service conditions. This is a new task and it will probably require additional research and engineering efforts but they may result in significantly enhancing comfort conditions on maneuvering ships.

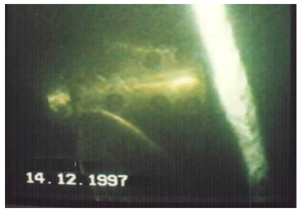
(4) It is necessary to pay attention to the phenomenon of breaking tip vortexes observed when the podded propulsor with pulling propeller operated at larger incidence angles.

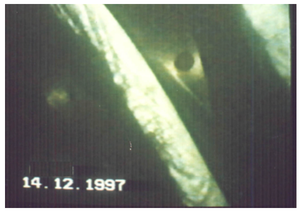
REFERENCES

English J.W. April 1998 Air Injection as a Means of Reducing Propeller Cavitation Induced Ship Vibration. Grenoble, CAV’98 Proceedings, v.1, pp.253-258.

Kurimo R., Pustoshny A., Syrkin E. March 1997 AZIPOD Propulsion for Passenger Cruisers. Sorrento, NAV’97.

Kurimo R. September 1998 Sea Trial Experience of First Passenger Cruiser with Podded Propulsor. The Hague, PRADS’98 Proceedings, pp.743-748.

1


2


3

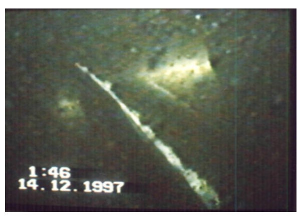

4


5

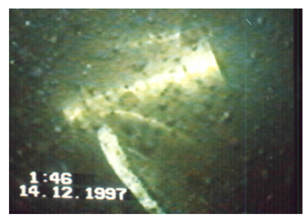

6


Fig.2 Cavitation growth during ship acceleration

One may notice strong cavitation of the tip vortex, which becomes thinner with higher ship speeds

1


2


3


4


Fig.3 Crash-stop. The initial phase

At the initial phase of the stop-crash maneuver one may see a very rapid growth in sheet cavitation along the pressure-side edge of the blade

1

2

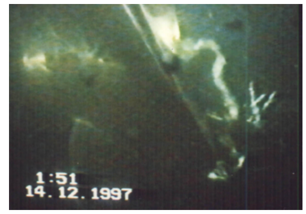


Fig.4 Crash-stop. Changing over to astern sailing

At the instant when the ship starts moving astern the change in the propeller rotation direction is associated with flow separation at the blades

1

2

Fig. 5 Crash-stop (continued)

When the ship starts moving astern (the left photo) one may see cavitation on the trailing edge, which under such conditions actually becomes the leading edge. The right photos demonstrate the separating vortex

1

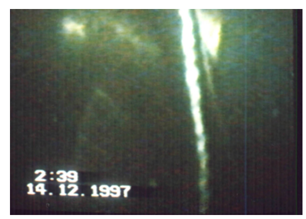
2

3

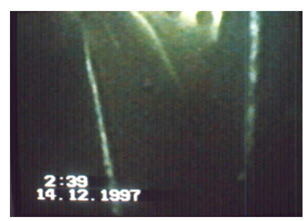
Fig. 6 Cavitation patterns at small AZIPOD angles

Cavitation patterns observed at small angles of the pod are not much different from those when the ship sails straight-ahead at full speed

1



2

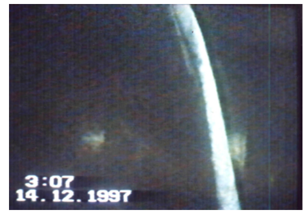


3

Fig.7 Turning circle with the AZIPOD set 15° to the centerline

The thickness of tip vortices is comparable with that at full-speed straight-ahead sailing but the region occupied by the vortices in terms of the blade angels is somewhat wider

1


4


2

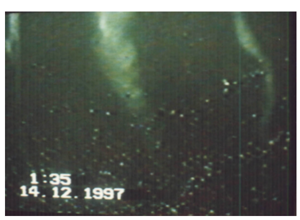

5


3


6


Fig.8 Cavitation scenario observed with the AZIPOD turning towards the centerline from the "hard over helm" position

This series of photographs shows the cavitation scenario observed while the AZIPOD was turning. At greater incidence angles one could see sheet cavitation at blade edges and tip vortices. With the decrease in the pod angle there remains only the tip vortex

1


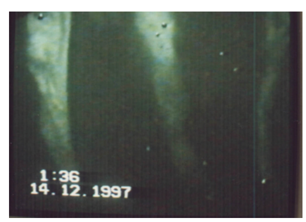
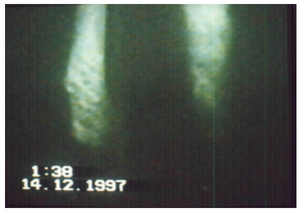
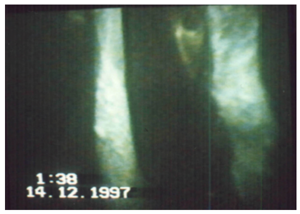
2


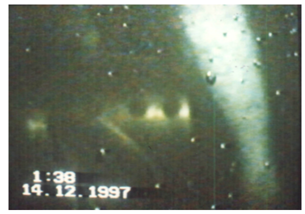
Fig.9 Turning circle with the AZIPOD set 35° to the centerline

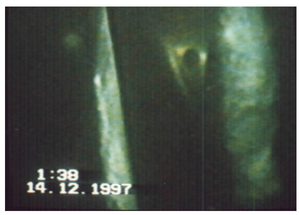
In these photos one may notice tail portions of three breaking vortices trailing from different blades

1


4


2


5


3


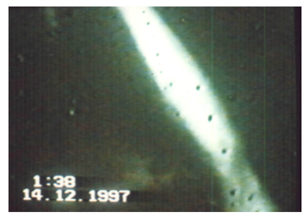
6


Fig.10 AZIPOD turning from the 35° position towards the zero incidence angle

When the blade enters the field of view one can see that its tip portion is enveloped by sheet cavitation transforming into a tip vortex (the lower left photo)