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DESIGN/OPERATIONS SESSION

Unique full-scale bollard pull test of large DP vessel newbuilding with six Azipod® CZ thrusters

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Introduction

Six Azipod CZ980 thrusters were selected for an accommodation/work barge. As per Figure 1 below the thrusters were to be installed in a triangle formation with three in the stern (Pods # 1-3) and three in the bow (Pods # 4-6). In the original technical specification the thruster power was 1.8MW and bollard pull requirement was 30 tonnes per thruster. During the project phase ABB conducted Computational Fluid Dynamics (CFD) analysis to verify thruster requirements. The CFD analysis concluded that a thrust deduction of 3-4% could be expected for the side thruster in the stern and the bow.

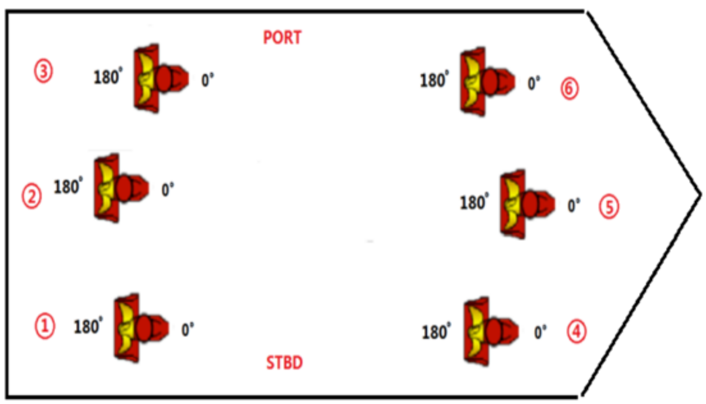

Figure 1 – Thruster Configuration

As a result of these tests and analysis it was decided to increase the thruster power of each Azipod CZ980 unit to 1.9MW. Using reference data from previous open water test with pods of similar power and propeller geometry the expected thrust without any thrust deduction would be 34.5 tonnes. With a 4% thrust deduction the side thrusters should be able to produce 33.4 tonnes of thrust.

This paper will compared the data from the performed bollard pull test with the calculated data from the CFD analysis. The aim is to better understand the impact on delivered thrust based on the specific thruster configuration and test conditions. A better understanding of these factors leading to thrust dedications can be used to further enhance modelling on future projects.

The vessel

The vessel in question is a DP3 ABS classed accommodation/work barge with a capacity for 684 people. She is 115.5m in length with a moulded breadth of 34m and depth of 9.1m. The maximum draft is 6.1m. She was built by COSCO Zhoushan shipyard in China (hull No 636) and will be delivered to the owner during Q3 2017.

ABB's Azipod CZ980 thrusters

Azipod CZ980 unit is a pushing podded thruster with a ducted propeller. The four-bladed propeller has a 2.4m propeller diameter. The nominal RPM is 301 at max power of 1.9MW in bollard condition.

For podded thrusters, the electric motor is mounted directly on the propeller shaft. With gearless drivetrain there are less mechanical losses in the system which improves propulsion efficiency. Podded thrusters also have less critical components including bearings, shafts and seals compared to conventional geared thrusters. As a consequence, the amount of lubrication oil in gearless thruster is less than 100 litres compared to a mechanical thruster typically needing several thousands of litres. The compact design saves space and gives the shipbuilder greater flexibility when designing the vessel.

CFD analysis and cavitation test

The available thrust of the pod has been validated by performing open water test in a towing tank. In addition, ABB has used a cavitation tunnel to test the pod and verify that the propeller and nozzle would be free from thrust breakdown in operating conditions.

Thrust breakdown inception usually occurs when cavitation in the propeller tip region increases to a certain extent, disturbing the pressure distribution around nozzle. The thrust breakdown diagram presents the Propeller thrust and torque coefficient and nozzle thrust coefficient (K_{T_PROP}, $10K_Q$, K_{T_NOZZLE}) ,as function of cavitation number at bollard pull (σ_n)

$$K_T = \frac{T}{\rho * n^2 * D^4}$$

$$K_Q = \frac{Q}{\rho * n^2 * D^5}$$

$$\sigma_n = \frac{P_A + \rho * g * H - P_V}{\frac{1}{2}\rho * (n * D)^2}$$

Rho= water density *n=revolution speed*

D=propeller diameter *PA= Atmospheric pressure*

g=gravity *H=Shaft immersion*

Pv= Vapour pressure

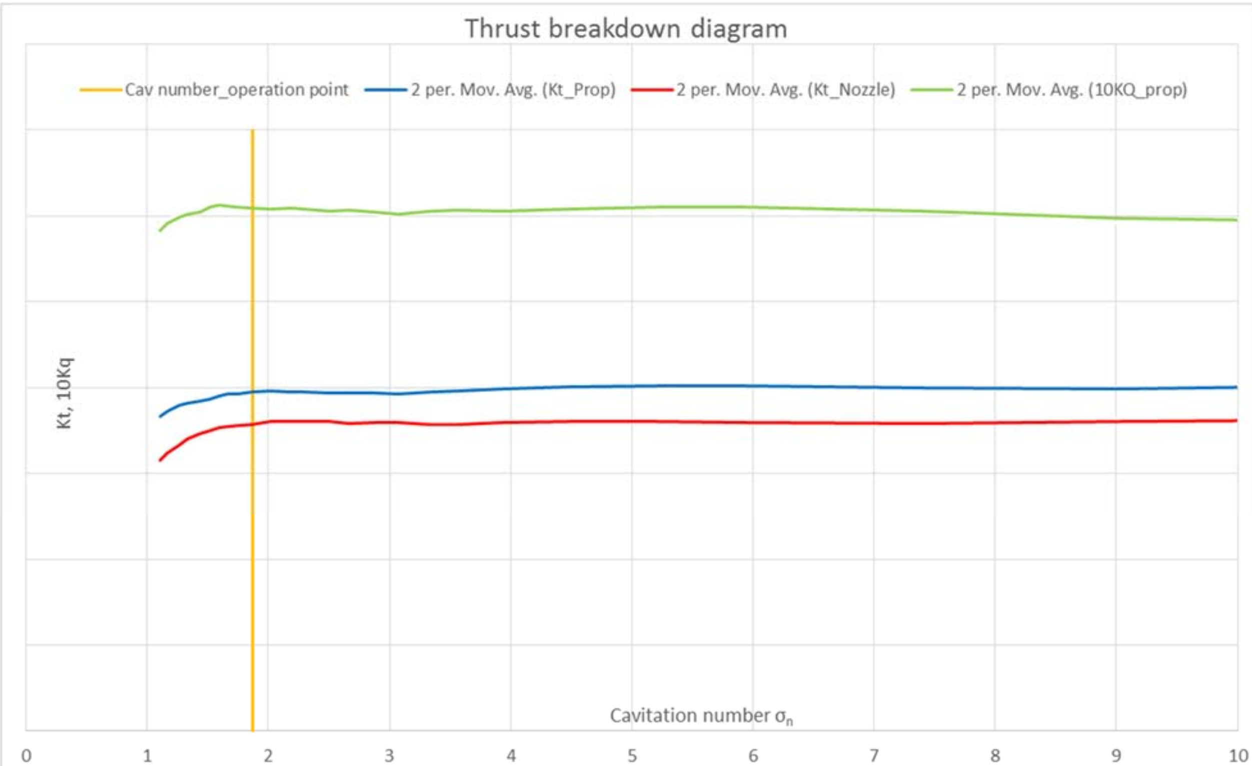

Figure 2. Thrust breakdown diagram for Bollard pull conditions. Yellow line presents the operating point of vessel with 100% Shaft power. The cavitation test was done with 1900kW.

The magnitude of thrust deduction in bollard pull was estimated using CFD calculations. The pod is simulated with and without the vessel by unsteady Reynolds-Averaged Navier Stokes (RANS) approach with SST (Menter) k-ω turbulence model at full scales. Unsteady double-body simulation approach was utilized. The transient sliding mesh approach within commercial CFD code StarCCM+ version 9.06 was used and the total number of cells was 15 million.

All the CFD calculations were done with 1800kW shaft power instead of 1900kW as it was the original input requirement.

Vessel speed was set as close to bollard pull as possible (0.01m/s). The pod thrust was seen as almost identical in open water vs. bollard pull conditions at power identity.

The vessel resistance is very close to zero in the inflow speed in question. Hence the added resistance due to propeller and nozzle induced velocity in bollard pull calculation was seen as the major factor for thrust deduction.

Category	Velocity (m/s)	Thrust or resistance (t)
Pod open water thrust	0.01	33.40
Vessel resistance	0.01	0.01
BP condition pod thrust	0.01	33.44
BP condition vessel resistance	0.01	0.96
Vessel BP including vessel resistance		32.48

Table 1 – Open Water Bollard Pull with 1800kW power

The CFD analysis also looked at the effect of water current in four directions. Most notably the results show that there is about a 3 tonnes deduction/addition per knot if the current is coming from ahead or astern respectively.

Current direction	Current velocity (m/s)	Pod open water trust (t)	Pod shaft power (kW)
From the front	0.1	33.1	1801
	1	30.1	1770
From the rear	0.1	33.9	1811
	1	37.6	1818
Side	0.1	33.2	1790
Opposite side	0.1	33.0	1786

Table 4: Effect of current on Azipod unit thrust based on CFD Calculations.

Recommendations for bollard pull testing

ABB's bollard pull test recommendations for the vessel in question are based on the ITS2002 Bollard pull trial code, bollard pull joint industry project observations and in-house observations. Standard corrections for wind and current does not exist, therefore good weather conditions are very important for a successful test.

The corrections for shallow water and towing line length seems also quite too optimistic according to the ITS2002 Bollard pull trial code and should hence be avoided if possible.

The load cell is to be installed between the strongpoint and towline, either on board or on shore. The load cell should have a digital output and capable to sample with a recommended sampling rate of 0.5 Hz or faster. The reason for the high sampling rate requirement is that the ship together with towing line act as an oscillating mass-spring system. If sampling rate is too low, aliasing may occur.

Towing line length recommendation is 250-300m in order to avoid/delay circulation around vessel. Recommended measurement time of each run is 10 minutes.

In order to avoid shallow water effects, the water depth should be at least 5.5 times the propeller shaft immersion, which means in this case 20m. If actual water depth is below 20m, shallow water corrections should be made according to the existing bollard pull code. However, performing trials in water depth less than 10m is not allowed. Recommended radius around the vessel is 100m.

Current has an adverse effect on the bollard pull, due to the orientation of the vessel and jet direction relative to the current to find an equilibrium between hull forces and propeller thrust. In any way, the current speed is to be less than [0.26 m/s (0.5kn)] from any direction. When the bollard pull trial is performed with side current, the towing vessel is allowed to shift position by letting it move with the current and not to steer against it, while maintaining heading relative to the towline. It is not allowed to fix the position of the towing vessel by cables, other vessels or other means. A current of 1 knot from the bow correspond to a drop in bollard pull of approx. 4 %.

The sea condition at the bollard pull trial site is to be calm, generally without swell or waves. To avoid ship motions affecting the line pull, the maximum wave height recommended is to be lower than 0.5m.

The trials site should be without obstructions (piers, docks, jetties, etc.) close to the towing vessel, which could influence the results. For instance, a legged jetty (no wall) allows the propeller wake to flow through the jetty. For solid piers a 45 degree orientation angle relative to the pier is recommended for maximum dissipation of the propeller wake away from the towing vessel.

Water density affects the developed thrust by the vessel. Water density should be measured directly after the bollard pull on board the vessel, so that the actual water quality (e.g. muddy waters) is measured.

Bollard Pull Test results made at COSCO Zhoushan on July 26th, 2017

Location		Port	Stbd	Mean
Draught (m)	Fwd	5.7	5.5	5.6
	Mid	5.6	5.4	5.5
	Aft	5.6	5.4	5.5
Correction mean draft (m)			5.5m	
Propeller shaft immersion (m)			3.95m	
Load cell type & last calibrated date			HZ-W6-100t. Calibrated 2017-05-16	
Towing line length (m)			~320m	
Water depth during testing (m)			~32m	
Water density & temperature			Density: 1.018 t/m3: 26C	
Air temperature			32C	

Table 2 - Test Conditions

The following Bollard Pull tests were performed:

Test #1 - Azipod #5 center thruster in the bow. Vessel moving stern first with thrusters pushing from the bow.

Test #2 - Azipod #4 and #6 side thrusters in the bow. Vessel moving stern first with thrusters pushing from the bow.

Test #3 - Azipod #2 center thruster in the stern. Vessel moving bow first with thrusters pushing from the stern.

Test #4 - Azipod #1 and #3 side thrusters in the stern. Vessel moving bow first with thrusters pushing from the stern.

Picture showing the bollard pull test position of the vessel.

Each test was performed over a 10 minute period recording a data set point every 30 seconds. In addition to the dynamic load reading the RPM, Power, wind speed/direction, thruster angle and current speed/angle were measured. Based on the sample data the following average bollard pull results were calculated.

Definitions by ITS2002

- Static bollard pull = Mean value of highest 30 seconds values during 10 min test
- Sustained bollard pull values = mean dynamic load value of 10 min measurement

Test #	Pod	Static bollard pull (t)	Sustained bollard pull (t)	Average RPM	Current speed (kn)	Current Direction
1	Pod # 1	34.1	31.7	302	0.9	From stern/port side
3	Pod # 2	37.2	35.9	298	1.1	From stern/port side
1	Pod # 3	34.1	31.7	299	0.9	From stern/port side
4	Pod # 4	33.1	32.4	302	0.3	From ahead/ port side
2	Pod # 5	34.7	31.6	305	0.6	From ahead/ port side
4	Pod # 6	33.1	32.4	307	0.3	From ahead/ port side

Table 3 – Average Values from Test 1-4

Reflections on the test results

Due to the shorter distance to vessel bow and stern, it was expected that Pod#2 and Pod#5 would have the highest bollard pull thrust. The test results supports that prediction as well as the assumptions in regards to the impact from the water current. Pod #2 clearly had the higher bollard pull both looking at static and sustained values of 37.2 and 35.9 tonnes respectively. For Pod#5 sustained bollard pull was only 31.6 tonnes while the static value was 34.7 tonnes. Our engineer observed during the test that the vessel was not always 100% aligned with the towing rope. That could explain the lower numbers during parts of the test which again led to the lower overall sustained bollard pull number for Pod#5.

From the CFD analysis the predicted thrust deduction for the side thrusters was 3-4%. Reviewing the test results the deductions would seem to be higher looking at the static results (5-10%) whereas the sustained bollard pull figures are inconsistent. The latter may again be due to the alignment of the vessel at parts of the test and also varying current during the test.

Pod#5 and Pod#6 produced a higher RPM which would indicate a stronger head current and thereby negative impact on the thrust. Looking at the average current results for the same Pods shows a higher current for Pod#5 compared with Pod#4 but at the same time the current figure for Pod#6 on average is the same as Pod#4 which is more difficult to explain given the difference in RPM values.

Applying the current thrust deduction factors from the CFD analysis we looked at calibrating the results. We used the static bollard pull figures as a basis for the calibration as they seemed to be most consistent. The calibrated bollard pull figures can be seen below in Table 4.

Test #	Pod	Static bollard pull (t)	Average RPM	Current (kn)	Current Direction	Current Effect (t)	Adjusted BP (t)
1	Pod # 1	34.1	302	0.9	From stern/port side	-2-2.5	**32**
4	Pod # 2	37.2	298	1.1	From stern/port side	-2-2.5	**35**
1	Pod # 3	34.1	299	0.9	From stern/port side	-2-2.5	**32**
3	Pod # 4	33.1	302	0.3	From ahead/ port side	+0.1-0.5	**33.3**
2	Pod # 5	34.7	305	0.6	From ahead/ port side	+0.5-1	**35.5**
3	Pod # 6	33.1	307	0.3	From ahead/ port side	+0.1-0.5	**33.3**

Table 4 – Static Bollard Pull figures calibrated with the current thrust deduction

The calibrated static bollard pull results are more consistent when comparing the side thrusters with the center thruster both in the bow and the stern.

Conclusions

The bollard pull test was successful as all six thrusters clearly exceeded the required bollard pull of 30 tonnes.

There was a considerable impact from the water current during all four tests. The direction of the current was changing from 0-100 degrees between each measuring point (every 30 seconds) so the exact thrust vector and calculated thrust deduction was difficult to determine. For the stern thrusters (pods #1-3) the current had a net positive impact with the direction coming from the port stern side. For the bow thrusters (pods #4-6) the current had a net negative impact with the direction coming from port ahead direction. A higher RPM for the bow thrusters was also a verification of the head current.

Looking at the adjusted BP numbers including the current effect we could conclude that the side thrusters produced a thrust that was 5-7% lower than the center thrusters.