Simulating Torque Converter on a 3 GTs Fishing Vessel using Computational Fluid Dynamics

Zulkifly*¹, Baharuddin¹, H Rivai¹, M R Firmansyah² and T M Santoso¹

¹Marine Engineering Department, Engineering Faculty, University of Hasanuddin
²Naval Architecture Department, Engineering Faculty, University of Hasanuddin

*E-mail: navalarchitecture78@gmail.com

Abstract. Torque converter is needed to reduce the difference distance on an engine power curve and propeller operating load curve. Torque converter works by removing and cutting the flow of power from engine to transmission shaft automatically in order to adjust with fluctuative propeller load. Torque converter works on a fluid clutch principal hence it has ability to absorb and reduce excessive torque moments. This research aims to determine the effect of impeller distance against dynamic characteristics of torque converter on a 3 GT fishing vessel. Based on the designed torque converter dimension, a simulation using computational fluid dynamics (CFD) in an ANSYS 16.0 simulation software was conducted. The simulation was done on three distances between impellers i.e. 2.5 mm, 5 mm, and 7.5 mm and on five rotations i.e. 600 rpm, 1000 rpm, 1400 rpm, 1800 rpm, and 2200 rpm. Information obtained from the CFD simulation includes: pressure and shear stress distribution on impeller, flow velocity on the torque converter shell, torque value, as well as maximum transmission power of torque converter. The result shows that the ideal impeller gap for the 3 GTs fishing vessel from the dynamic characteristics parameter of torque converter is 7.5 mm.

1. Introduction

Motorization policy for fishing vessel in South Sulawesi by equipping the vessel with motor and modern technology fishing gear has been applied since the beginning of 1970. The aim of the policy package is to optimize the utilization of sea resources. This policy is in turn reduce significantly the use of sail as the vessel prime mover. Further, the motor in the vessel is supported by single reduction gearbox system. However, the weakness of this system is the existence of differences on the distance in an engine power curve and propeller operating load curve. The latter is constantly fluctuated according to the condition change during ship operation such as change on weather, wave, ship load or change of sea current.

In many cases, there are some damage reports on the shafting system of fishing vessel as the consequences of the condition [1-2]. Among them are misalignment of the engine shaft, drastically damage/worn out on the shaft and its bearing, broken unbalancing propeller as well as early overhaul on the ship main engine. An automatic torque converter for muffling and absorbing the load is needed to minimize the difference on the distance. The load to be reduced in this case is the propeller shaft load which exceed the power availability in the ship engine.

The working procedure for the torque converter (TC) is similar with an automatic transmission system on an automatic motor car. The main difference is on the system and working mechanism and on the working principle of fluid. The advantage of using torque converter on similar system is on its ability to absorb big torque moment. This ability makes it to feasible to be used on a ship to bear power transmission load. On the other side, the maintenance for this system is easy and comparatively...
cheap, the construction of the system is simpler and it has spontaneously output converter to compare with conventional continuously variable transmission (CVT).

2. Transmission System on a Ship
Transmission system on a ship proceeds power from the main engine to propeller. This system moves the ship at the required speed. As can be seen from figure 1, transmission system consists of main engine, fly wheel, thrust block, intermediate shaft, propeller shaft and propeller. Thrust from propeller is used to move the ship through transmission system. Shaft was equipped with thrust block, intermediate bearing and stern tube bearing [3].

![Figure 1. Transmission system on a motorized fishing vessel](image)

Power resulted from a diesel engine is in the form of torsional moment or torsion (T, N.m) and rotation speed (n, r/min) through crank shaft which can be used for many needs such as source of energy for rotating dynamo shaft or can be used for moving both sea and land transportation vehicles. Output power from main engine is resulted from crank shaft as a shaft driver which connected with shaft which is moved by clutch connection.

Clutch is an engine element which connecting and stopping torsion from shaft driver to the driven shaft. On a diesel engine as a ship driver, the shaft rotation speed is bigger to compare with the need of propeller shaft rotation speed (ship propeller). To adapt the differences in speed, gearbox (transmission box) is needed before proceed to the propeller shaft [4]. By adopting an advanced automatic transmission system technology, the same thing can be done on a ship propeller system by using torque converter.

Torque converter is a coupling element which is installed between engine and shaft system. The advantage of the system is coming from power transfer of hydrodynamic principle from engine to transmission system which at the same time works as load diminisher in order to keep other mover component functions as well as to fix economic fuel of the ship fuel (Figure 2).

The development of the concept in the beginning is for hydraulic engines for heavy work (crane and heavy equipment) which have/experience failure because of the damage to the power of transmission gearbox [5].

This research is regarding the effect of the impeller angle speed on the magnitude of centrifugal force on hydraulic liquid of torque converter. The result of the research has provide some recommendation on some optimal angle of the impeller blades including the number of impeller blades. If impeller is rotated by the main engine, the hydraulic fluids inside the impeller shell will be rotate as well and bounce to the torque converter shell wall in the direction of the engine rotation.

The number of area and impeller blades is significantly having effect on torque output, area criteria on torque converter case in the determination of area ratio where the comparison between blade area with the object to be designed [6].
In a modern automatic transmission, lock-up clutch has been implemented in a torque converter to lock engine and shaft transmission in a higher gear ratio. The main advantage of using the lock-up clutch is to increase the torque converter efficiency. The speed ratio and torque ratio without using lock-up clutch will be around 0.9 and 1 respectively. Hence the torque converter efficiency which can be defined as a product from speed and torque ratio can reach 90%. Mechanism in a lock-up clutch increases the efficiency value to be 100% as the rigid connection between pump torque and turbine shaft (Figure 3).

![Figure 2. Torque converter system](image)

In a manual lock-up clutch, there are some unwanted torque values during the using of clutch which affect the driving process. Dynamic torque converter model can be represented by three equations of angle momentum for pump, turbine and stator as well as energy conversion equation. Dynamic model capable to capture transient response of a torque converter during automatic gear shifting as well as transition flow which is caused by engine brake phenomenon. Hence, dynamic torque converter model is being used to evaluate flow characteristic during gear shifting process and engine braking phenomenon. Torque converter model to be proposed is to be integrated with average value engine, transmission and dynamic vehicle longitudinal to evaluate torque converter characteristic in a powertrain model [7]. Based on this model, torque impeller and forces on impeller blades can be identified.

Based on the equation for torque calculation in Guan, Dong and Wu [8], the equation for forces working on torque converter impeller can be seen in the following:

\[ TP = \rho Q \left( \nu u_B^2 - \nu u_B^1 r_B^1 \right) \] (1)
where:
\[ TP = \text{Impeller torque (Nm)} \]
\[ \rho = \text{Fluid density (kg/m}^3\text{)} \]
\[ Q = \text{Flow rate (m}^3\text{/s)} \]
\[ v uB_1 = \text{Inlet tangential velocity (m/s)} \]
\[ v uB_2 = \text{Outlet tangential velocity (m/s)} \]
\[ rB_1 = \text{Inlet blade radius (m)} \]
\[ rB_2 = \text{Outlet blade radius (m)} \]

Impeller rotation will produce kinetic energy on oil fluids which will be received by permanent turbine on output shaft. In this process, turbine blades are received kinetic energy (oil flow) from impeller which then transform it into mechanical energy. Hence, torque output from impeller can be described in the following equation [7]:

\[ T_{\text{out}} (t) = T_{\text{in}} (t) \times GR \times Eff \]  

where:
\[ T_{\text{in}} (t) = \text{Impeller torque (Nm)} \]
\[ GR = \text{Ratio} \]
\[ Eff = \text{Efficiency} \]

From equation (2), output power can be calculated using the following equation:

\[ \text{Power (kW)} = \frac{\text{torque (Nm)} \times 2\pi \times \text{rotation speed (RPM)}}{60000} \]  

3. Research Data
Data of ship to be reference in the torque converter planning is fishing vessel which operated in the area of South Sulawesi is KM Ilda Yanti ship (Figure 4) with ship length is 13 m, breadth 1.5 m dan height 1 m. this ship used main engine with the capacity of 23.1 kW and maximum rotation is 2200 rpm.

Figure 4. 3 GTs Fishing vessel KM Ilda Yanti

The location of the torque converter on the ship in this research is between main engine and the propeller boss with the geometry dimension of the torque converter is following the available room in that place.
4. Torque Converter Geometry Design
The design calculation and impeller area refer to the Zarotti and Nervegna [6] method (Hydraulic torque converter design) where to give comparison on impeller area with case with the value of 0.31. The value with the comparison of impeller area is obtained the impeller radius si 13 cm, the area of impeller blade is 0.01 m² while the area of casing is 0.05 m². Torque converter design is made in 3 difference variations of distances between impeller which are 2.5 mm, 5.00 mm, and 7.5 mm. This distance then will be simulated to analyzed variable which involve with the performance and characteristic of torque converter. Simulation of computational fluids dynamics using software ANSYS 16.0 with the solution fluent and meshing in curvature form with the minimum size is 0.27 mm and maximum size is 10 mm.

5. Simulation Result
The selection of condition as part of the simulation setup by using transient mode and based on the oil fluid density which enter torque converter. Condition variable on running setup is the speed fluid on inlet area of 2 m/s with the steady condition, fluid oil density is 845 kg/m³, and impeller rotation speed with variation 600 rpm, 1000 rpm, 1400 rpm, 1800 rpm, and 2200 rpm. The following arrangement is time step with 0.001 s, the number of each time step is twice and the number of iterations per time step is 20 time of repetition. The variables values for analysis are taken from the post process in simulation step using calculator function. They are consist of pressure value which is taken from the face and back side of the impeller while area value is taken from the face and back area of the impeller.

5.1. Pressure Profile on Impeller Blade and Fluid Flow Speed
The result of simulation with ANSYS on 5 different variation speeds of impeller rotation for pressure and flow speed shows that the impeller average pressure with the average fluid speed on torque converter shell is in line on the rotation up to 1000 rpm and begin to inversely proportional on rotation 1000 rpm until 2200 rpm (Figure 5).

![Figure 5. Illustration on the relationship of pressure with fluid speed on shell](image-url)
The result of the simulation shows that the pressure distribution and the speed of fluid flow are occurring on the same area in impeller surface. On a 7.5 mm impeller gap, the maximum pressure is occurred. Besides, the minimum and maximum flow speed are occurred as well. Based on the visual observation on the impeller gap, the fluids flow turbulence is reduced as the impeller gap becoming wider.

5.2. Shear Stress
Characteristics of average shear stress distribution on impeller surface on rotation speed 1000, 1400, 1800 and 2200 rpm can be obtained from the following illustration in Figure 6.

![Figure 6](image)

**Figure 6.** Shear stress distribution on rotation 1000 rpm (left) and 1400 rpm (right)

![Figure 7](image)

**Figure 7.** Distribution of shear stress on 2200 rpm (left) and 1800 rpm (right)

The result of simulation shows that the contour pattern of maximum shear stress occurred on impeller in 2200 rpm. The ability of impeller to hold drag and strain stresses can be identified from yield stress value. On a 2200 rpm for manganese bronze impeller, the stress value is above the permitted yield and tensile stress value. This is happened possibly because of fatigue on the material. Hence, both side of the impeller blade as well as on bosching part need to be thickened.

5.3. Torque and Transmission Power
The value of torque data is obtained from calculator function on menu result ANSYS and place the centre of torque calculation on impeller output with the assumption that the impeller output which become output torque and output power from torque converter. Hence, maximum power output can be obtained from the Eq. (3).
Correlation on the relationship of rotation on torque and impeller transmission power can be seen in Figure 8:

![Figure 8. Power and torque output of torque converter](image)

Correlation between torque and the power output on some impeller rotations on different impeller distances as shown in Figure 8 are tend to produce the same value on up to 1900 rpm impeller rotation. However, this rotation can be categorized as high for ship primer mover system. Hence, only the stress value in torque converter impeller that need to be considered.

6. Conclusion
The dimension of torque converter for fishing vessel in the area of South Sulawesi is 30 cm in diameter with the geometry area of impeller is 0.0176 m². The length and width of impeller blades is 13.5 cm and 2.5 cm respectively with the number of blades is 16. The impeller distance has effect on the dynamic respond of torque converter including average pressure, shear stress, fluids speed, torque and power which can be transmitted on each distance/gap of impeller.

7. References
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