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Study of Water Jet Propulsion System Design For Fast Patrol Boat (Fpb-60)

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Abstract: *(FPB-60) is a type of patrol boat built by shipyard in Indonesia to strengthen the needs ofwater territorial.However, the 20 years age caused a decrease in performance of the vessel. The method used was the harvard guldammer method to calculate water jet system parameters at a maximum velocity of 35 knots such as inlet diameter and nossel diameter, pump power, pump type used and other parameters to obtain Overall Propulsive Coefficient at that speed. In the calculation of water jet propulsion system design, the amount of capacity generated water jet pump system obtained was 4.15 m^3 / s with flow velocity on the nozzle/jet of 28.8 m/s. Based on the value of specific swabs of suction (Nss) of 6205.49, the pump for the water jet propulsion system had considered fulfilled the cavitation limit requirement so that it could be used for (FPB-60).*

Keywords: Vessel Resistance, Water Jet, Power, FPB.

1. INTRODUCTION

(FPB-60) is a type of patrol boat built by a shipyard in Indonesia to strengthen the needs of water territorial. However, the 20 years age cause a decrease in performance of the vessel. Based on these demands, it is necessary to have a ship that has good, safe acceleration and maneuverability, and has a low boat loadso that it can be operated in deep or shallow waters (Susanto.et.al. 2017).

With the use of a water jet propulsion system, the vessel can be cultivated to have a smaller load compared to ships that use propellers so that with an increase in thrust generated by the engine it will be able to produce higher vessel speed (Herdzik 2013).

This paper have many supporting its research, for example paper with title An Approximate Method For Calculation of Mean Statistical Value of Ship Service Speed on a Given Shipping Line, Useful in Preliminary Design Stage (Żelazny 2015).Experimental Investigation on Stern-Boat Deployment System and Operability For Korean Coast Guard Ship (Chun.et.al. 2013). Performance of VLCC Ship with Podded Propulsion System and Rudder (Amin 2014). Introduction to Naval Architecture (Tupper 1975). Basic Ship Theory (Tupper 2001). Practical Ship Design (Watson 1998). Ship Resistance and Propulsion : Practical Estimation of Ship Propulsive Power (Anthony F. Molland 2011). Practical Ship Hydrodynamics (Bertram 2000). Effect of Fluid Density on Ship Hull Resistance and Powering (Samson 2015). Ship Design and Contruction (D'arcalengelo 1969). Resistance Propulsion and Steering of Ship (WPA Van Lamerren 1984). Predictive Analysis of Bare-Hull Resistance of a 25,000 Dwt Tanker Vessel (Adumene 2015). Resistance and Propulsion of Ships (Harvald 1992). Hydrodynamic of Ship Propellers (Andersen 1994). Ship Design for Efficiency and Economy (Bertram 1998). Design of Propulsion Systems for High-Speed Craft (Bartee 1975). Amethod of Calculation of Ship Resistance on Calm Water Useful at Preliminary Stages of Ship Design (Zelazny 2014). Increase of Ship Fuel Consumption Due to the Added Resistance in Waves (Degiuli.et.al. 2017). An Inventigation Into The Resistance Components of Converting a Traditional Monohull Fishing Vessel Into Catamaran Form (Samuel 2015). Simulation of a Free Surface Flow over a Container Vessel Using CFD (Atreyapurapu.et.al 2014). Empirical Prediction of Resistance of Fishing Vessels (Kleppesto 2015). Designing Constraints in Evaluation of Ship Propulsion Power (Charchalis 2013). Coefficients of Propeller-hull Interaction in Propulsion System of Inland Waterway Vessels with Stern Tunnels (Tabaczek 2014). Cost optimization of marine fuels consumption as important factor of control ship's sulfur and nitrogen oxides emissions (Kowalski 2013). Numerical Investigation of the Influence of Water Depth on Ship Resistance (Premchand 2015). The Wageningen Propeller Series (Kuiper 1992). Principles of Naval Architecture Second Revision (Lewis 1988). Marine Propulsion (Sladky 1976).

In this paper, we used harvard guldammer method to calculate water jet system parameters at maximum velocity of 35 knots such as inlet diameter and nossel diameter, pump power, pump type used and other parameters to obtain the Overall Propulsive Coefficient at that speed (Kim 1966). With this paper, it was expected that the water jet propulsion system could be used as an alternative for patrol boats to be built and operated in accordance with their duties.

This Paper is organized as follows. Section 2 is the review about basic ship theory. Section 3 were description of result and research discussion. Finally, the conclusion of this paper is presented in section 4.

2. RESEARCH METHODOLOGY

2.1. Propulsion System of The Ship

The ship propulsion system, which is the exact matching between prime mover (diesel engine, gas turbine, steam turbine) and propeller from ship. Matching completion is not only seen from the engine or propeller point of view, but both are an integrated problem (Etter 1975).

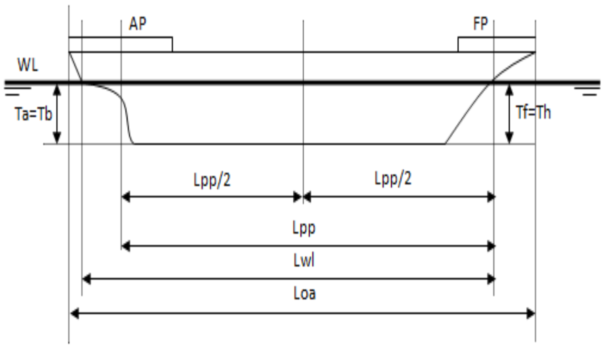

Fig. 1 Longitudinal Shape of The Vessel

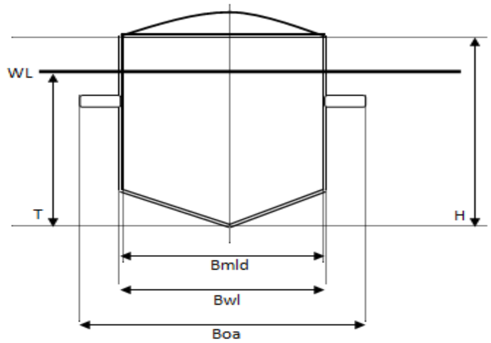

Fig. 2 Cross-sectional Shape of The Vessel

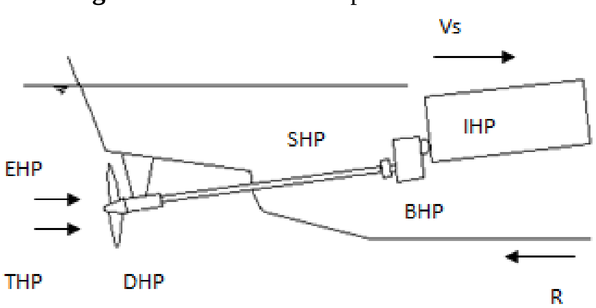

Fig. 3 Propulsion System of The Vessel

Nomenclature

After Perpendicular (AP)
Fore Perpendicular (FP)
Length between perpendicular (Lpp)
Length on the water line (Lwl)
Length Overall (Loa)
Breadth moulded (B/Bmld)
Draft/draught (T)
Dept (H)
Freeboard (F)
Centre line (CL)
Speed of The Ship (Vs)
Ship Resistance (R)
Effective Horse Power (EHP)
Thrust Horse Power (THP)
Delivery Horse Power (DHP)
Shaft Horse Power (SHP)
Brake Horse Power (BHP)

2.2. Water Jet Propulsion on Fast Patrol Boat

The water jet propulsion system has been used as a booster for fast boats over three hundred years ago, but its use is widely knocked on its low propulsive efficiency when compared to ship propulsion systems that use conventional propellers.

The ship with water jet propulsion is a ship which used water jet system as the propellerin its operation in the water media so that the ship can move in accordance with the speed of the desired ship. Ships that use water jet propulsion system is a system consisting of bare hull system and water jet system (Etter 1975).

Bare hull system is a shipbuilding body with no water jet installed. However, in the calculation of weight and the position of center of gravity should be the weight of the ship in a state of operation at sea, so it must be included along with the weight of water entering through the water jet system (entrained water).

The water jet propulsion system generally consists of a pump and a ducting systemsystem. The pump system serves to convert mechanical power into hydraulic power. While the channel system serves to direct the flow rate from the environment to the pump and from the pump to return to the environment.

The water jet propulsion system is widely used primarily for high-speed vessels, because based on studies that have been conducted, it wasshowed that the water jet propulsion system has a feature that has nothing to do with its propulsive efficiency. Some of the features that the water jet propulsion system possesses are described bellow:

1. The absence of propellers and steering outside the vessel is very advantageous because it reduces the total resistance occurring on the vessel and allows the operation of vessels for shallow waters.
2. Have good acceleration ability.
3. Have good shipmotion when the vessel speed is relatively low.
4. Have the advantage when the movement of the ship at a relatively high speed ship.
5. Placement of impeller inside ship body will be able to reduce vibration and noise level on ship.
6. At a relatively high velocity of the vessel, propulsive efficiency can be maintained high enough to be comparable to the propeller propulsion system.

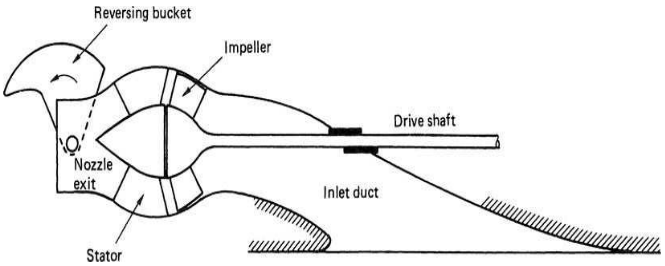

Fig. 4 Water jet System Configuration

2.3. Cavitation Requirements

Cavitation is a symptom of fluid evaporation that is flowing because the pressure is reduced to below the saturation pressure so that the steam bubble would be form and interfere with the work of the pump.

The evaporation of these liquids can occur inside the pump or channel due to high flow velocity (turbulent flow) which can cause the pumped fluid temperature to be higher. At the pump, the cavitation problem often occurs on the suction side when the pump suction pressure is too low or under it saturation pressure (Barrass 2004).

If the pump is cavitated, it will create noise and vibration that will eventually lead to a decrease in performance of the pump. In order for the pump to be safe against cavitation problems, the pump must have a specific suction rotation price which is below the cavitation limit of the pump. The specific rotation price of the suction will be greatly influenced by the magnitude of the Net Positive Suction Head (NPSH) of the pump used.

2.4. Method of Research.

The planning of the water jet propulsion system is based on the following matters

a. The ship data used was Fast Patrol Boats (FPB-60) to be built

b. Calculation of required power and total resistance used Harvarld Guldhamer method.

c. The planning of the water jet propulsion system started by taking the Overall Propulsive Coefficient (OPCo) as a first step to calculate the parameters of the water jet propulsion system until the OPC was obtained in accordance with the predefined OPCo. Thereafter, calculations of the cavitation requirements of the channel system and the propulsor pump were used.

3. RESULT AND DISCUSSION.

3.1 Vessel Data

The data from Fast Patrol Boats (FPB-60) to be used as calculations in the planning of water jet propulsion system were as follows:

a.	LOA	:	60 m
b.	LWL	:	55 m
c.	Breadth (B)	:	8,10 m
d.	Draft (T)	:	2,46 m
e.	Height (H_2)	:	4,86 m
f.	Block Coefficient (Cb)	:	0,350
g.	Velocity (Vs)	:	35 knot

3.2. Resistance Calculation

The magnitude of the resistance on the ship at the planned vessel velocity of 35 knots or 17.99m / s was:

a.	Frictional Resistance	:	82, 463 KN
b.	Residual Resistance	:	1,16 KN
c.	Wind Resistance	:	3,686 KN
d.	Additional Resistance	:	12,22 KN

So the total total resistance that occurs on the ship was 99.53 KN.

3.3. EHP, BHP and SHP Calculation

Based on the total resistance, the amount of effective thrust required to be able to move the ship in accordance with the planned speed could be calculated as follows:

$$EHP = RT \times Vs = 99{,}53 \times 17{,}99 = 1790{,}55 \text{ KW}$$

This plan was assumed to be in an ideal state so that the amount of thrust required was equal to the amount of total resistance that occurred. The water jet propulsion system was planned to use two pumps of propulsor so that the amount of thrust per pump was 49,765 KN. By taking the initial OPC price of 0.57, the amount of BHP could be calculated as follows:

$$BHP = \left(\frac{T_h}{z}\right) \times \frac{Vs}{OPC} = 49{,}765 \times \frac{17{,}99}{0{,}57} = 1570{,}65 \text{ KW}$$

In this water jet system,it was planned that the pump impeller would be driven by a motor with direct clutch transmission, with transmission efficiency between 0.96 - 0.99 per pump. In this planning, the value was 0.96 so the amount of SHP could be calculated as follows:

$$SHP = \eta_T \times BHP = 0{,}96 \times 1570{,}65 = 1507{,}82 \text{ KW}$$

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3.4. Discussion

3.4.1. Dimension and Water Jet System Parameter Calculation

As shown in the figure below, based the amount of thrust per SHP in the unit (lbf / HP), the amount of power density (SHP / Di^2) in units (HP / cm^2) could be known.

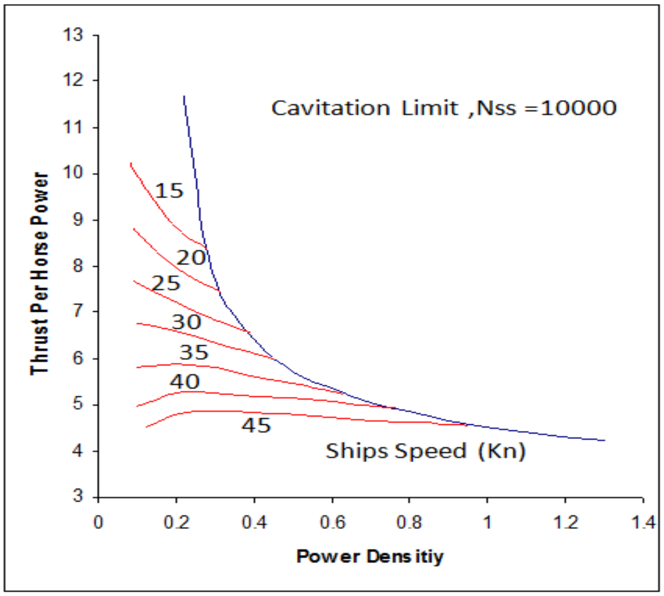

Fig. 5 Chart of Water jet System Inlet Dimension

The amount of thrust per SHP was 5.48 so based on the picture above, the amount of power density at 0.475 was obtained.

From power density, the main dimensions of water jet system could be calculated as follows:

- Inlet Diameter : 0,6682 m
- Inlet Area : 0,350 m2
- Nossel diameter : 0,430 m
- Nossel Area : 0,145 m2

By taking the fraction of the current flow value of 0.05, we could get the inlet speed as follows:
:

$$Vi = (1 - w) \times Vs = (1 - 0{,}05) \times 17{,}99 = 17{,}09 \text{ m/s}$$

So the amount of speed on the outlet or nozzle (Vj) could be obtained by:

$$Vj = 0{,}5 \times \left(Vi + \sqrt{\left(Vi^2 + \frac{4.T}{\rho.An} \right)} \right)$$

$$= 0{,}5 \times \left(17{,}09 + \sqrt{\left(17{,}09^2 + \frac{4 \times 49765}{1024{,}63 \times 0{,}144} \right)} \right)$$

$$= 28.8 \ \frac{m}{s}$$

The amount of flow capacity in the jet / nozzle:

$$Q_J = Vj \times An = 28{,}8 \times 0{,}145 = 4{,}15 \text{ m}^3/\text{s}$$

The comparison of ship speed and flow velocity through the jet could be expressed by:

$$\mu = \frac{Vj}{Vs} = \frac{28{,}8}{17{,}99} = 0{,}625$$

The amount of ideal jet efficiency (ηj_{ideal}) :

$$\eta_j = \frac{2.\mu}{1+\mu} = \frac{2 \times 0{,}625}{1 + 0{,}625} = 0{,}769$$

For the planning of the water jet propulsion system, it was recommended that the value of inlet loss coefficient (ψ) was set between 16% - 20%. In this calculation, the value of inlet loss was 18%, because the water jet system used a flush inlet type and the vessel operated in a relatively clean area of water.

Meanwhile, the value of loss coefficient (ζ) was recommended between 1% - 4%. In the calculations for actual jet efficiency, a value of 2% was chosen because the losses on the nozzle were relatively smaller compared to their inlet channels. So, the actual (ηj_{aktual}) jet efficiency cost for the water jet system could be obtained by:

$$\eta j_{aktual} = \frac{1}{1-w} \times \frac{2.\mu.(1-\mu)}{(1+\psi) - (1-\zeta).\mu^2 + \frac{2.g.hj}{Vj^2}}$$

$$= \frac{1}{1-0{,}05} \times \frac{2 \times 0{,}769 \times (1 - 0{,}769)}{(1+0{,}02) - (1-0{,}18) \times 0{,}769^2 + \frac{2 \times 9{,}8 \times 0{,}881}{28{,}8^2}}$$

$$= 0{,}675$$

In the calculation of the overall propulsion efficiency (OPC), it was assumed that the pump efficiency was 0.89 and the relative rotative efficiency was 0.98. So, the overall propulsion efficiency (OPC) could be obtained by:

$$OPC = \eta j_{aktual} \text{ x } \eta_P \text{ x } \eta_r \text{ x } \eta_T$$
$$= 0,675 \text{ x } 0,89 \text{ x } 0,98 \text{ x } 0,96$$
$$= 0,573 \approx 0,57$$

Based the calculation of Overall Propulsive Coefficient (OPC),an equal value to the previous forecast was obtained so that the calculation could be continued.

3.4.2 Calculation of Pump Characteristic:

a. Pump Rotation

$$N = K \text{ x } SHP^{(1/3)}$$
$$= 69 \text{ x } 2020,45^{(1/3)}$$
$$= 873,66 \approx 874 \text{ Rpm}$$

b. Specific Rotation

The flow capacity (Qj) obtained from the previous calculation was 4.15 (m3 / s) = 146.44 (ft3 / s) converted into gallon units per minute (GPM) to be obtained at 65731.06 GPM. The amount of price for pump Head could be calculated as follows:

$$H = \frac{V_j^2}{2g} - \frac{V_i^2}{2g} + h_{LT}$$

$$= \frac{28,8^2}{(2 \times 9,8)} - \frac{17,09^2}{(2 \times 9,8)} + 5,828$$

$$= 33,25 \text{ m} = 109,06 \text{ ft}$$

So the value of pump specific rotation could be calculated as follows:

$$Ns = N \times \frac{\sqrt{Q_j}}{H^{0,75}}$$

$$= \frac{874 \times \sqrt{65731,06}}{109,06^{0,75}}$$

$$= 6639,69$$

Based on the specific rotation value of the pumps obtained above, the type of pump to be used that corresponds to the specific value of the round was the type of mixed flow pump with a specific rotation between 4000 <Ns <10000

c. Suction Specific Rotation

The value of NPSH could be calculated as follows:

$$NPSH = \frac{\eta_{j.ideal} \times Vj^2}{2g} - hj$$

$$= \frac{0,769 \times 28,8^2}{2 \times 9,8} - 0,881$$

$$= 31,66 \text{ m} = 103,84 \text{ ft}$$

Specific rotation value of suction could be calculated as follows:

$$Nss = \frac{N\sqrt{Q_j}}{NPSH^{0,75}}$$

$$= \frac{874 \times \sqrt{65731,06}}{103,84^{0,75}}$$

$$= 6888,48$$

Based on the image of the Operation Zone of the Mixed Flow Pump below, the planned operating zone of the water jet pump system was located in zone I or continuous operation zone, which was separated by zone II by Nss = 12000 line as the cavitation boundary.
This means that the pump for the planned water jet system met the allowable cavitation requirements so it was safe to use continuously.

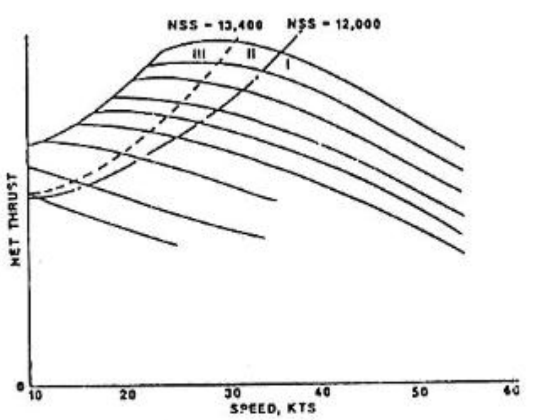

Fig. 6 Mix Flowed Pump Operation Zone

4. CONCLUSION

Based on the calculations,it required propulsor pump drive with power of 1571 KW and round 874 RPM per pump to obtain the maximum planned speed. Based on the result of specific rotation of 6639,69 then the type of pump used in accordance with the specific rotation size is Mixed Flow Pump (4000 <Ns <10000). The thrust force generated by the water jet propulsion system was highly dependent on the amount of flow capacity generated by the pump used. The larger the capacity produced by the pump with a constant nozzle diameter, the nozzle flow rate will also be greater so that the resulting thrust would also be greater. In the planning of water jet propulsion system is obtained the amount of capacity generated water jet pump system is 4.15 m3 / s with flow velocity on the nozzle / jet of 28.8 m / s. From the value of specific swabs of suction (Nss) obtained that is equal to 6205.49 then the pump for the water jet propulsion system has fulfilled the cavitation limit requirements so that it can be used continuously (continuous).

In this water jet propulsion system plan, the amount of capacity generated by water jet pump system was obtainedat 4.15 m^3/s with flow velocity on the nozzle / jet of 28.8 m/s. Based on the value of specific rotation of suction (Nss) obtained at 6205.49,it could be concluded that the pump for the water jet propulsion system had fulfilled the cavitation limit requirements so that it could be used continuously.

5. ACKNOWLEDGEMENT

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