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The Analysis of Effectiveness Electric Motor As A Main Propulsion In The Navy Ships

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Abstract – Electric motors as the main booster for ships are widely used in submarines. But now, it was used in the Navy Ships type of Xyz Class. In the world, there are quite a several warships that use electric motors as the main propulsion engines because they have high efficiency, especially in terms of maintenance budget requirements and fuel budgets. On the other side, During the operation at the Navy Ships, several advantages were felt both in terms of operation and maintenance. The electric motor was very useful to be used in Navy Ships type of Xyz because it was very efficient in fuel consumption when it was used as the main engine. Now, the Indonesian Navy has had two Navy Ships type of Xyz. And Indonesian Navy hoped that this kind of engine type can be useful and give more beneficial in the future, especially in helping its jobs.

Keywords – Effectiveness, Electric Motor, Main Engine, Navy Ships.

I. INTRODUCTION

The Republic of Indonesia Navy Ships type Xyz is one of the Navy Ships types of the light frigate that the Indonesian Navy currently has. This Navy Ships was designed by the Dutch Damen Schelde Naval Shipyard (DSNS) in 2012 and was produced jointly by PT. PAL Indonesia and the DSNS shipyard from 2014 to 2017. Navy Ships has a length of 105 meters and a width of 14 meters and is designed to be able to carry out anti-submarine warfare, anti-ship surface, and anti-air attack. In the area of propelling, this ship uses a CODOE (Combine Diesel or Electric Motor) type booster system. The diesel propeller is capable of producing a maximum speed of 28 knots, while the propulsion with the electric motor is capable of producing a maximum speed of 16 knots. So far, electric motors as the main booster for ships are widely used in submarines, namely direct current (DC) electric motors, where the operator uses a lot of batteries that are recharged using diesel generators onboard. For the electric motor used in the Navy Ships, which is a type of alternating current (AC) electric motor so it doesn't need a battery but the required electric current is supplied directly by the Diesel Generator (DG) ship. In the world, there are quite a several warships that use electric motors as the main propulsion engines because they have high efficiency, especially in terms of maintenance budget requirements and fuel budgets.

During the operation at the Navy Ships type Xyz, several advantages were felt both in terms of operation and maintenance. Continuous operation for 5 days with a ship speed of 12 knots was carried out at Navy Ships when the sea crossing from Surabaya base to Hawai in the context of the 2018 RIMPAC training with safe conditions, so that Navy Ships was able to sail to Hawaii without having to refuel. This shows that there is significant fuel savings and will be very profitable for Navy Ships operations if it is faced with the limited ability of the government to provide fuel for the Indonesian Navy every year.

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II. MATERIAL AND METHOD

2.1 General

Navy Ships type Xyz has 2 units of ship propelling system (right and left) type Combine Diesel or Electric Motor (CODOE), where each unit of propelling system consists of:

a. 1 unit of the MAN type 20V 28 / 33D STC diesel engine, 10,000 kW, 1,032 rpm as the Main Propulsion, known as the Propulsion Diesel Engine (PDE).

b. 1 unit of the INDAR brand electric motor type ACP-450-S / 4, 1,325 kW, 2,100 rpm as an Auxiliary Propulsion Machine known as the Propulsion Electric Motor (PEM).

c. 1 unit of gearbox brand RENK type ASL - 100E.

d. 1 CPP unit consists of 2 intermediate shaft units, 1 propeller shaft unit, and 1 set of Roll Royce propeller (5 leaves).

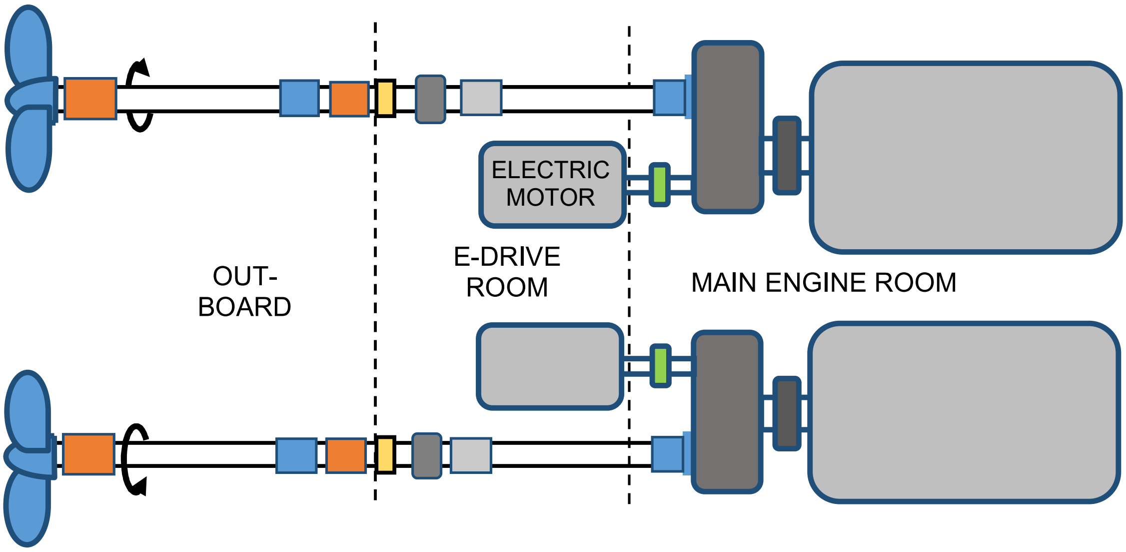

Figure 1. Schematic diagram of Navy Ships Rem-331 pushing system

2.2 Operational Support System

The two booster machines (PDE and PEM) cannot be operated simultaneously but must take turns through the change-over process. Propelling using a diesel engine is capable of producing a maximum forward speed of ± 28 knots at 1,032 rpm engine speed, 218 rpm propeller shaft rotation, and 100% propeller pitch angle. While the maximum speed of the ship is ± 12 knots at 1,000 rpm engine speed, 210 rpm propeller shaft, and 80% propeller pitch angle. While propelling using an electric motor (E-Drive) can produce a maximum ship speed of ± 16 knots at an electric motor rotation of 2,100 rpm, a shaft propeller rotation of 116 rpm, and a pitch angle of 100%.

The use of PDE and PEM as a propulsion machine option is controlled by the IPMS (Integrated Platform Management System) through two Propulsion Control Units (PCU). PCU can control the propulsion system automatically and integrated through the PCU Panel located in the bridge (bridge console) and the Machinery Control Room (MCR) according to the needs (which panel is used as Station in Control / SIC). The transfer of the SIC from the MCR to the Pavilion or vice versa is done by pressing the "Bridge Control" button on the MCR or "MCR Control" on the Pavilion. In addition to operating automatically and integrated through the PCU, in an emergency (PCU failed) this ship propulsion system can also be operated on an emergency basis through the Non Follow Up (NFU) panels at the Pavilion and the MCR.

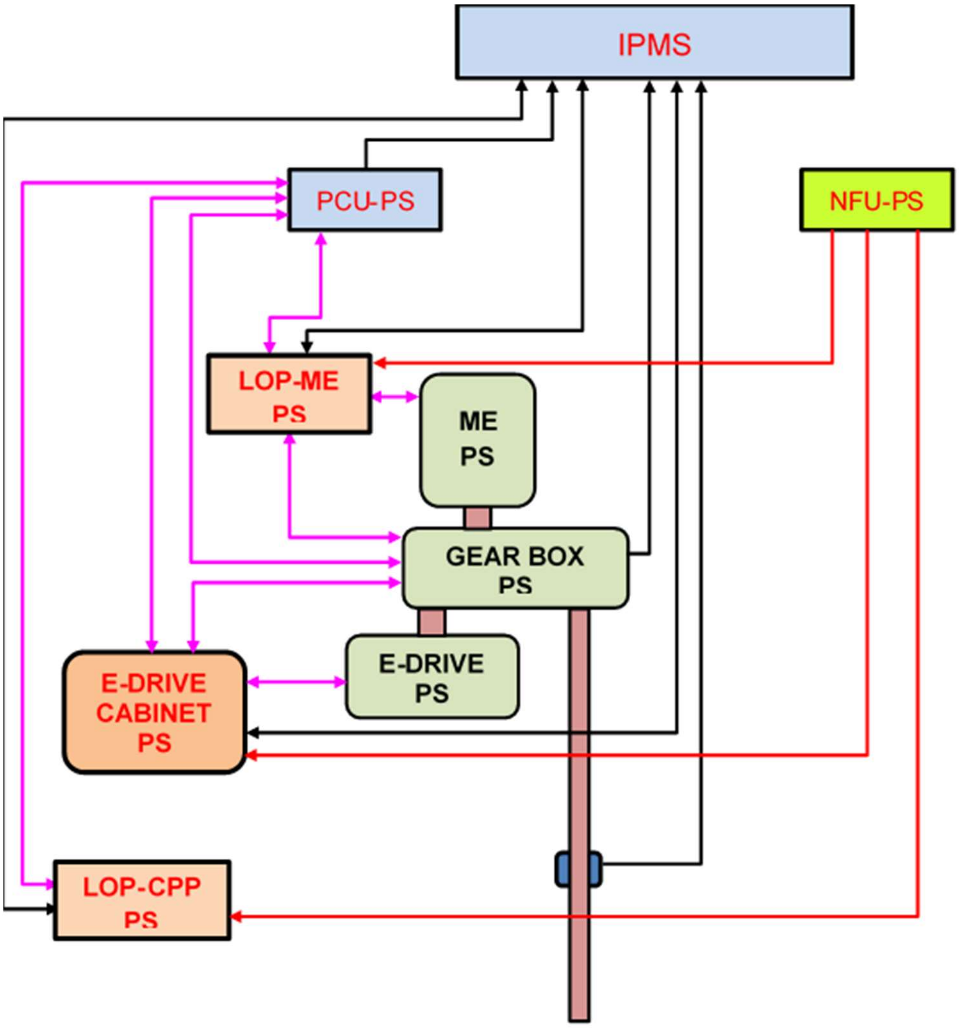

Figure 2. Propulsion Control System (PCS) Block Diagram

2.3 The Needs of Electric Flow

a. Supporting with an electric motor (PEM).

Fulfilling the need for electricity for the operation of the main propulsion electric motor (PEM) and other auxiliary aircraft needs is obtained from 6 units of the Caterpillar C-32 Accert SCAC 440 V, 60 Hz, 740 kW Navy Ships type Xyz class. The operation of the six DG units is controlled by the Automatic Diesel Start and stop (ADS) system, where this system will automatically instruct to start and stop other DGs which are currently in standby depending on the electricity demand, the load received by each DG. as well as the technical conditions of DG which was operational at that time. In other words, If the throttle is increased during operation with PEM and the monitoring system detects the available reserve power (reserve power) on nets less than 200 kW, then in ± 4 seconds the ADS system will automatically start one of the standby DGs at that time. Likewise, on the other hand, if the throttle is lowered and the power reserve available in the nets is> 200 kW, within ± 4 seconds the ADS system will automatically turn off one of the DGs. Besides, the main driving electric motor (PEM) can only start if at least 2 DG is running and it is parallel. Meanwhile, to achieve maximum balancing (2,100 rpm) with a pitch angle of 100%, it takes 4 units of operational DG with an average DG load of 75%. In addition to the ship's main propulsion engine when cruising.

The operational DG needs to support the flow of electricity to the electric motor are as follows:

Table 1. The operational DG needs to support the flow of electricity to the electric motor

No	Electric Motor Rotation Speed	Total Dg Operations	Shaft Prop Round.	Angle Pitch
1	0 - 1,200 rpm	2 units	0 - 66 rpm	0 - 100%
2	1,200 rpm - 1,550 rpm	3 units	66 rpm - 85 rpm	100%
3	1,550 rpm - 1,800 rpm	4 units	85 rpm - 99 rpm	100%
4	1,800 rpm - 2,100 rpm	5 units	99 rpm - 115 rpm	100%

b. Supporting with the main diesel engine (PDE).

On pushing with using 2 units PDE, it takes only 1 unit of operational DG to meet all the needs of electrical equipment with a load of ± 75% (555 kW), except when the ship is carrying out the combat role, 2 units of operational DG are needed in parallel.

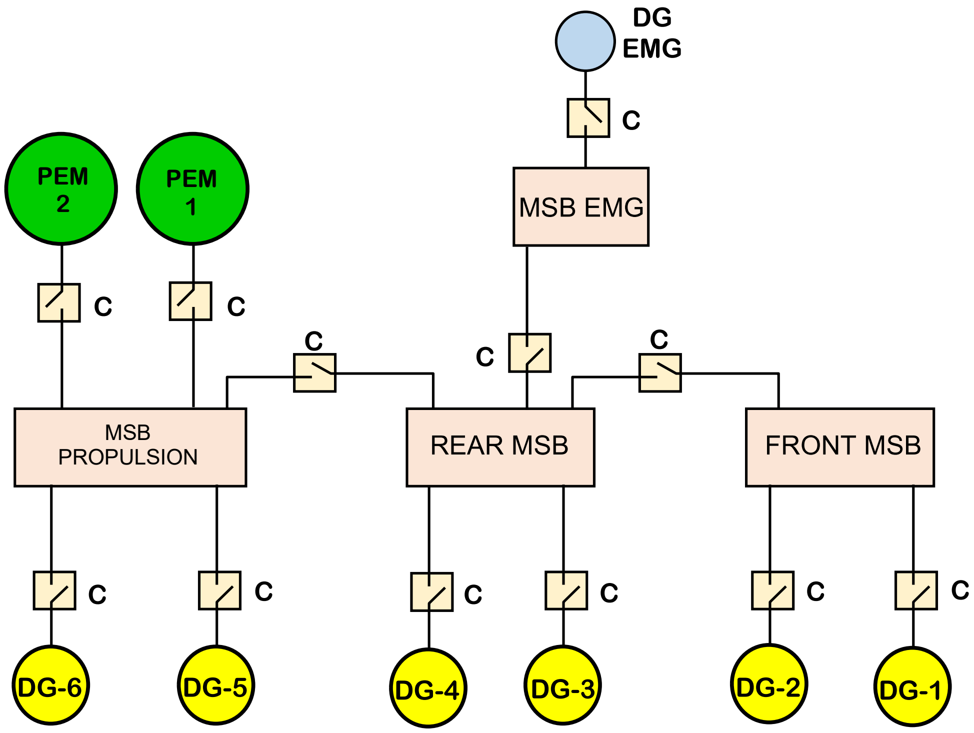

Figure 2. Block diagram of the distribution of NAVY SHIPS electricity type XYZ

2.4 General Technical Data of Navy Ships Xyz

a. Production year : 2013 - 2017.

b. Made in : Vlissingen DSNS Shipyard - Netherlands and PT. PAL Indonesia.

c. Development Activities :

1). First steel cutting : 15 January 2014

2). Keel screen : April 16, 2014

3). Launching : 18 January 2016

4). Enter the ranks of the Indonesian Navy : 27 January 2017

d. Ship Dimensions :

1). Overall Length (L_{OA}) : 105.01 m

2). Water line length (L_{WL}) : 99.07 m

3). Length between perpend. (L_{PP}) : 97.43 m

4). Maximum width (B_{Max}) : 14.02 m.

5). Draft at full load : 5.73 m (including dome)
4.20 m (without dome).

6). Design draft : 4.23 m (including dome).
3.70 m (without dome).

7). Deck Height - 1 : 8.75 m (from keel).

8). Number of Decks : 9 decks.

10). Displ. at full load (Δ_{Max}) : 2,946 tonnes

11). Gross Tonage (GT) : 3,216 tonnes.

e. Operational Capability.

1). Maximum Speed.

a). 2 units of Diesel: 28 knots (Transit Mode).
16 knots (Maneouvering Mode).

b). 2 units of E-Motor : 16 knots (Transit Mode).

2). Cruising Speed : 18 knots (2 units of diesel).

3). Economical speed : 14 knots (2 units of diesel).

4). Endurance : 5,000 Nm (20 days at sea

e. The volume of the Tanks.

Table 2. The volume of the Tanks

No	Type Of Tank	Total	Total Capacity (M^3)
1	FO Storage Tanks	7	330,995
2	FO Service Tank ME PS	1	7,457
3	FO Service Tank ME PS	1	7,457
4	FO Service Tank E-Drive	1	3,859
5	FW. Trim Tanks	2	62,775
6	FW. Dump Tanks	2	62,112
7	FW. Roll Stabilizer Tank	1	145,306
8	Potable Water Tanks	2	107,560
9	Bilge Water Holding Tank	1	4,180
10	Sludge Dirty Oil Tank	1	5,595
11	Aviation Fuel Storage Tank	1	7,968
12	Aviation Fuel Service Tank	1	7,501
13	Lube oil Storage Tank (MAIN ENGINE)	1	7,841
14	Lube oil Storage Tank Gearbox	1	2,315
15	DG Lubeoil storage tank	1	2,058

2.5 Technical data of the Navy Ships Xyz Main Boost System

a. Basic Diesel Engine Technical Data.

1) Brand : MA N

2) Type : 20V 28 / 33D STC

3) Country of manufacture: Germany.

4) Production year : 2014.

5) total : 2 units

6) Round : Idle : 400 rpm.
: Maximum: 1,032 rpm.

7) Maximum power : 10,000 kW.

8) Direction of rotation : Diesel Ka : Counter Clockwise.
: Diesel Ki: Clockwise.

9) Number of cylinders : 20 pieces.

10) Conviguration : "V", 52^0.

11) Cylinder diameter (Bore) : 280 mm.

12) Stride length (Stroke) : 330 mm.

13) Volume per cylinder : 20.3 dm^3.

14) Compression ratio : 14,2

15) The speed of piston is average : 11.4 m / s

16) Crankshaft diameter : 300 mm (at journal).

: 240 mm (at crankpin).

17) Machine dimensions :

a). Max length. : 8,047 mm.

b). Max width. : 2,473 mm.

c). Max height : 3,734 mm.

d). Empty weight : 52.9 tons

18) Lube oil consumptions : 0.48 g / kWh.

19) Type of Oil: Shell Argina T40

20) The total volume of charter oil: 2,440 liters.

b. Technical Data of the Main Drive Electric Motor (PEM).

1). Brand : INDAR.

2). Type : ACP-450-S / 4.

3). total : 2 units.

4). Round : Idle : 840 rpm.

Nominal : 1,800 rpm.

Maximum: 2.100 rpm.

5). Power : 1,325 kW at 1,800 - 2,160 rpm.

6). Voltage : 440V, 3 Phase.

7). Frequency : 60 - 74.2 Hz.

8). Maximum electric current : 1,921 Ampere.

9). Thermal class : Class H

10). Temperature rise : Class B

11). Duty type : S-9

12). Relationship between Circles : Star Relations.

13). Direction of rotation : Motor - 1 : Clockwise.

Motor - 2: Counter Clockwise.

14). Production year : 2014.

15). Motor dimensions :

a). Long : 2,417 mm

b). Wide : 1,709 mm

c). High : 1,915 mm.

c. Gearbox Technical Data.

1) Brand : RENK
2) Type : ASL - 100E
3) Maximum Input Speed : Diesel (n1DE) : 1,032 rpm
: E-Motor (n1PTI) : 2,100 rpm
4) Maximum Output speed : Diesel (n2DE) : 218 rpm
: E-Motor (n2PTI) : 115 rpm.
5) Ratio:
a). DE / Propeller input : 4.73
b). PTI / Propeller input : 18,22
6) Power:
a). Input from DE : 10,000 kW
b). Input from E-Drive : 1,325 kW
7) Empty Weight : 19,800 kg
8) Crankcase Capacity : 1,150 ltr.
9) Production year : 2014.

III. RESULTS AND DISCUSSION

3.1 General

The principal of the main engine system of Navy Ships type of Xyz has 2 types of main propulsion engines, namely a diesel engine and an electric motor. The replacement of the propel mode from diesel (PDE) to the electric motor (PEM) is carried out through the change over the process of the propulsion system. This process can be done at a propeller shaft rotation ≤ 100 rpm (ship speed ± 12 knots) so that without having to go through the process the ship stops (engine stop).

3.2 Fuel Use

The comparison of fuel use between PDE and PEM cannot be based on the resulting propeller axle rotation, because at the same propeller axle rotation between PDE and PEM has a different propeller pitch angle so that the thrust generated by the propeller is different. For the comparison of the effectiveness of pushing using PDE and PEM, the most possible parameter to use is the speed of the ship. In shipping applications, ship speed is greatly influenced by current, wind, and shipbuilding conditions under the waterline at that time. To get a calculation that is close to correct, we use data on the results of shipping in several sea conditions, and the average speed is taken in these conditions.

a. Propagation with Diesel Engine (PDE).

Fuel requirements when using diesel engine propulsion (PDE) cannot be monitored directly through the IPMS monitor or the local PDE panel, so the calculations are carried out in three ways, namely:

1) Calculation theoretically.

The theoretical fuel usage calculation is only based on the fuel demand data provided by the MAN factory following the engine power needed to move the ship at a certain speed and does not take into account current and wind conditions. For example, to reach a ship speed of ± 18 knots at sea stage 1 - 2, a power of 1,955 kW is required per propeller shaft. To produce this power, each MAN 20V 28 / 33D STC engine requires fuel of 220.4 gr / kWh or 509.75 liters/hour, so that 2 MAIN ENGINE units require fuel of 1,068 liters/hour or 25,608 liters/hour. day. Meanwhile, the fuel requirement for 1 unit of operational DG with a load of 473.7 kWh (± 66%) is 231.8 g / kWh or 129.9 liters/hour or 3,117 liters/day. So that the total fuel required to reach ± 18 knots of ship speed is 28,725 liters/day. From the calculation method above, an approximate table of NAVY SHIPS type XYZ 10514 fuel usage is obtained with 2 main diesel engine (PDE) units and 1 operational DG unit as follows:

Table 3. Propagation with Diesel Engine (PDE).

No	Ship Speed (Knot)	The Fuel Needs (Liter / Day)		Total Fuel Requirements (Liters / Day)	
		2 Unit ME	1 Unit DG	Total Bb (Liter / Day)	Value (IDR.)
1	5	6,216	3,117	9,333	110,129,400, -
2	6	6,672	3,117	9,789	115,510,200, -
3	7	7,248	3,117	10,365	122,307,000, -
4	8	7,944	3,117	11,061	130,519,800, -
5	9	8,808	3,117	11,925	140,715,000, -
6	10	9,840	3,117	12,957	152,892,600, -
7	11	11,088	3,117	14,205	167,619,000, -
8	12	12,504	3,117	15,621	184,327,800, -
9	13	14,136	3,117	17,253	203,585,400, -
10	14	15,936	3,117	19,053	224,825,400, -
11	15	17,976	3,117	21,093	248,897,400, -

2) Daily Fuel Volume in Tank.

This method was carried out when Navy Ships Xyz Class conducted a sea trial in the Java sea on September 27, 2016, by a team from the Dutch DSNS, namely by monitoring the reduction in the amount of fuel in the daily right and left MAIN ENGINE tanks and DG daily tanks through monitoring the tank contents on the IPMS panel. Data collection was carried out for 2 hours of sailing with a ship speed of ± 18 knots and estimated fuel leakage due to excess pressure on the injector as much as 25 liters/engine/hour. From the results of pengChecking the daily volume of fuel in the tank, the following data are obtained:

Table 4. Daily Fuel Volume in Tank

No	Hour	PS Service Tank (M3)	SB Service Tank (M3)	DG Service Tank (M3)	Consumption (M3)
1	08.19	5.1	6.0	2.8	
2	08.34	4,9	5.8	2.7	0.5
3	08.49	4,8	5.7	2.7	0.2
4	09.04	4,6	5,4	2.7	0.5
5	09.19	4,3	5,4	2,6	0.4
6	09.34	4,3	5,2	2,6	0.2
7	09.49	4,2	5,2	2,6	0.1
8	10.04	4,1	5.0	2,6	0.3
9	10.19	3,9	5.0	2.5	0.3
TOTAL		**1,2**	**1.0**	**0.3**	**2.5**

From the table above, it is found that the use of fuel for 2 units of Main Engine and 1 unit of DG for 2 hours of shipping at a ship speed of ± 18 knots of 2.5 m3 or 2,500 liters minus the estimated fuel leakage for 2 engines for 2 hours is 100 liters to 2,400 liters. So that the use of fuel for 24 hours (1 day) is 28,800 liters. This result is different from the theoretical calculation of 75 liters (0.3%).

3) Total Fuel Volume in Base Tank.

The calculation of fuel usage can also be done by calculating the reduction in the remaining fuel capacity in the fuel tank with a certain time and a stable ship speed. Calculations in this way have poor accuracy because it depends on the timeliness of the personnel carrying out the recording, the weather (see conditions) at the time of reading the monitor, and the tank sensor calibration. In the shipping journal Navy Ships Xyz Class dated May 31, 2018, to cross the sea from the Surabaya base to Hawaii to participate in the RIMPAC exercise. From this journal, for propelling using a diesel engine (PDE), the following data were obtained:

Table 5. Total Fuel Volume in Base Tank

Date	Time	Ship Speed (Knots)	Machine Speed Rotation (Rpm)		Total Fuel In Tank (Liter)
			Main Engine-1	Main Engine-2	
31-05-2018	12.00	12.8	516	515	299,330
	13.00	12.8	511	512	
	14.00	13.2	515	518	
	15.00	12.7	515	512	
	16.00	12.8	515	512	296,930

From the data from the voyage above, the results show that the use of fuel on the voyage for 4 hours (12.00 - 16.00) using PDE propulsion with ship speeds between 12.7 knots - 13.2 knots as many as 299,330 liters - 296,930 liters

= 2,400 liters, so that fuel usage for primary diesel 1 and 2 for 24 hours to 14,400 liters. While the use of fuel for 1 DG for 24 hours is 3,117 liters, so the total fuel use for PDE boosting with an average ship speed of 13 knots is 17,517 liters. This result is 1.5% (264 liters) greater than the theoretical use of fuel at a ship speed of 13 knots.

From the explanation above, it can be said that the calculation of the use of PDE fuel theoretically obtains almost the same results as the calculation of fuel by reducing the volume of fuel in the daily tank as well as by reducing the total amount of fuel in the main tank, so that the use of material The theoretical calculation of fuel can be used as a reference in determining the use of Navy Ships Xyz Class10514 fuel when using a diesel engine boost (PDE).

b. Supporting with an electric motor (PEM).

Fuel requirements when using electric motor boosters are calculated from the amount of fuel used for each operational DG at that time. The use of fuel (fuel flow rate) can be monitored directly from both the local panel in DG and the IPMS panel in the MCR. Besides, the calculation of fuel use by boosting the electric motor can also be calculated by reducing the total volume of fuel in the main tank.

1) Fuel Usage of Each DG.

The use of fuel for each DG can be monitored from the local DG panel itself or the IPMS panel in the MCR. To compare with the use of fuel using PDE, the reference that can be used as a comparison is the speed of the ship because if you use the axle rotation as a reference, the correct results will not be obtained because at the same propeller rotation between using PDE and PEM has an angle different pitch so that the power (thrust) on the propeller axle is different. The speed of the ship is very much influenced by the current conditions including the direction of currents, winds, sea waves, and the resistance of the hull. To encourage using PEM in different sea conditions, the use of DG (the number of operational DG) can also be different to determine the speed of the ship,

a) The ship speed calculation is taken the average speed. For example, a ship speed of 8 knots is the average speed at the journal between 7.5 knots - 8.5 knots.

b) Total fuel consumption represents average fuel consumption at that speed.

From the shipping journal Navy Ships Xyz Class from June 4, 2018, to August 4, 2018, data on fuel use with PEM boost at several ship speeds were obtained after averaging according to the provisions above, data on fuel use at various ship speeds were obtained as follows:

Table 6. Fuel Usage of Each DG

Ship Speed (Knots)	**Pem Speed (Rpm)**	**Total DG Ops (Unit)**	**Total Fuel Consumption**		
			Ltr / Hour	**Ltr / Day**	**Fuel Cost**
7	1,160	2	266.2	6,389	75,390,200, -
8	1,190 - 1,320	2	314.0	7,536	88,924,800, -
9	1,320	2 - 3	390.3	9,368	110,542,400, -
10	1,530	3	441.6	10,599	125.068.200, -
11	1,400 - 1,800	4	506.5	12,157	143,452,600, -
12	1,550 - 1,800	4 - 5	604.9	14,517	171,300,600, -
13	1,650 - 1,930	4 - 5	696.6	16,719	197,284,200, -
14	1,840 - 1,970	5	790.8	18,978	223,940,400, -

So that if we compare it with the use of fuel using PDE, the differences in budget use are obtained as follows:

Table 7. Use of fuel using PDE

Ship Speed (Knots)	Total Fuel Consumption (Liter / Day)		The Cost Difference In Fuel Per Day
	PDE	PEM	
7	122,307,000, -	75,390,200, -	46,916,800, -
8	130,519,800, -	88,924,800, -	41,595,000, -
9	140,715,000, -	110,542,400, -	30,172,600, -
10	152,892,600, -	125.068.200, -	27,824,400, -
11	167,619,000, -	143,452,600, -	24,166,400, -
12	184,327,800, -	171,300,600, -	13.027.200, -
13	203,585,400, -	197,284,200, -	6,301,200, -
14	224,825,400, -	223,940,400, -	885,000, -

From the table above, it can be explained that the higher the speed of the ship used, the less difference in fuel use between PDE and PEM, even at ± 14 knots ship speed, fuel use with PEM and PDE boost is almost the same.

2) Total Volume of Fuel in Base Tank.

From the shipping journal Navy Ships Xyz dated May 30, 2018, for encouragement using PDE, the following data were obtained:

Table 8. Total Volume of Fuel in Base Tank

Date	Time	Ship Speed (Knots)	Machine Rotation Speed (Rpm)		Total Fuel In Tank (Liter)
			E-Motor 1	E-Motor 2	
30-05-2018	16.00	12.8	1,678	1,678	315,378
	17.00	12.8	1,678	1,678	
	18.00	12.7	1,678	1,678	
	19.00	12.9	1,678	1,678	
	20.00	12.9	1,678	1,678	312,980

From the data from the voyage above, the results show that the use of fuel on a cruise for 4 hours (16.00 - 20.00) using electric motor propulsion (PEM) with an average ship speed of 12 knots of 315,378 liters - 312,980 liters = 2,398 liters / 4 hours, so that the use of fuel for 24 hours of voyage using PEM with the shipping speed according to the above is as much as 14,388 liters. This result is 1,233 liters smaller when compared to the use of fuel with diesel engine propulsion (PDE) at the same ship speed. Calculations in this way have a poor level of accuracy because the time to journal fuel usage is not always the same, for example, 30 minutes before the change of guard. Besides that, the reading of the volume of fuel in a tank is strongly influenced by the condition of the ship at that time (shaking or nodding), so that the determination of fuel use with PEM encouragement is carried out using the monitoring data of fuel used for each DG.

3.3 Maintenance Budget

The maintenance budget requirements for Main Engine, DG, and Electric Motor equipment are divided into 2 parts, namely maintenance at the organic level and maintenance at the intermediate level. Meanwhile, the use of machine rotating hours per year is calculated based on the operating pattern generally carried out in the Indonesian Navy. Following the Navy Ships operating pattern which is used as the basis for making JOP / JOG, in one budget year, Navy Ships carries out operations for 40%, stand-by is based on 30% ready condition and 30% maintenance, so that in one budget year Navy Ships will carry out operational tasks for 146 days or ± 5 months. Following the calculation of the screen allowance (TNL), the NAVY SHIPS that carries out the operation for one month (30 days) is calculated as 20 days at sea and 10 days back, so that within 5 months (150 days) of operation, the Navy Ships will be in the middle of the sea for 100 days and docked in the operating area for 50 days. If the operation of NAVY SHIPS REM-331 is carried out with a pattern of 50% (50 days) screen using PDE and 50% (50 days) screen using PEM, it is possible to obtain additional hours of rotation for Main Engine and Electric Motors each year of 50 days x 24 hours. = 1,200 hours of play. Meanwhile, the addition of DG turning hours when using a PEM booster depends on the speed of the ship being used. Meanwhile, when using PDE support, only 1 unit of operational DG. In the calculations between PDE, DG, and PEM, the analytical approach in calculating maintenance is carried out up to 16,000 Running Hours. From this operating pattern, we get the addition of DG play hours each year as follows:

Table 9. Maintenance Budget

Ship Speed (Knot)	% Ops	DG Ops	Dg Running Hour	Running Hour Addition When Using DG		Total Additional Running Hour /Year	
				PEM	PDE + When Rest (315 Days)	6 DG	1 DG
9	0.05	3	180	4,680	7,560	12,240	2,040
10	0.15	3	540				
11	0.30	4	1,440				
12	0.40	4	1,920				
13	0.10	5	600				

So that for the operation pattern mentioned above, we will get additional rotating hours (Running Hour) of each DG per year of 2,040 hours of play.

Organic level maintenance, namely maintenance carried out by the crew members to maintain the technical condition of the equipment, such as replacing the fuel filter, oil filter, air filter, and DG and Main Engine charter slip oil. As for the electric motor, it does not require a significant budget for maintaining the organic level. The schedule for changing DG filters and engine oil is calculated according to the replacement that is usually carried out at Navy Ships, namely:

1) Oil filter changes every 500 hours of rotation.
2) BB filter replacement every 250 hours of rotation.
3) Air filters change every 2,500 hours of rotation.
4) DG oil change every 500 hours of rotation.

Whereas for the Main Engine Navy Ships Xyz Class the fuel filter (duplex filter) has a very small filter size installed, namely 5 microns:

1) Oil filter changes every 500 hours of rotation.

2) Change of coalescer filter every 1,000 hours of rotation.

3) BB duplex filter replacement every 60 hours of rotation.

4) Air filters change every 1,000 hours of rotation.

5) Change of charter oil every 2,500 hours of rotation.

6) The addition of 200 liters of water coolant every 500 hours of rotation

From the organic maintenance schedule mentioned above, in operations up to 16,000 hours of rotation, the calculation for Main Engine is as follows:

Table 10. The calculation for Main Engine Running Hours

No	Activities	Interval Change (Running Hour)	Total Change	Total Machine (EA)	Total Needs	Unit Price	Total Price
1	Replace the BB Coalescer filter	1,000	16	1	16	37,596,700	601,547,200
2	Change duplex BB filter	60	267	2	534	29,506,700	15,756,577,800
3	Change the oil filter	500	32	2	64	28,542,000	1,826,688,000
4	Oil Change Carter	2,500	7	2,440	17,080	675,000	11,529,000,000
5	Replace air filter	1,000	16	2	32	3,734,600	119,507,200
6	Add water coolant	500	32	200	6400	84,200	538,880,000
	TOTAL COST						**30,372,200,200**

From the calculations in the table above, it is obtained that the budget requirement for MAIN ENGINE organic harvests per hour is Idr. 1,898,263, - / hour. For the maintenance budget for the organic level of each DG up to 16,000 JP as follows:

Table 11. The maintenance budget for the organic level of each DG up to 16,000 Running Hours

No	Activities	Interval Change (Running Hour)	Total Change	Total Machine (EA)	Total Needs	Unit Price	Total Price
1	Replace filter BB separator	250	60	2	120	1,516,870	182,024,400
2	Change duplex BB filter	250	60	2	120	3,187,000	382,440,000
3	Change the oil filter	500	24	4	96	2,325,370	223,235,520

4	Oil Change Carter	500	32	144	4,608	375,000	1,728,000,000
5	Replace air filter	2,500	3	2	6	4,019,500	24,117,000
	TOTAL COST						**2,539,816,920**

From the calculations in the table above, it is obtained the need for the maintenance budget for the organic level for each DG per rotation hour of IDR. 158,739, - / hour.

Meanwhile, electric motors do not require maintenance at the organic level that requires costs, except only for the addition/replacement of lubricant (grease) to bearings, cleaning of heat exchangers, and checking the resistance of motor insulation so that the hourly organic level maintenance budget is included in middle-level maintenance.

a. Middle-level maintenance is maintenance implemented based on rotating hours which aims to maintain the readiness/capability of material-technical conditions and implemented by BMT or shipyard. The calculated use of the budget is an estimate of the number of costs (services and materials) needed to carry out maintenance based on rotating hours according to the schedule set in the manual of the equipment handbook.

1) Main Engine 1 and 2.

The main Engine has a TBO (Time Between Overhaul) for 32,000 hours of play. The amount of maintenance budget required is calculated only up to Middle Overhaul level maintenance (MO) that is, 16,000 hours of play, including maintenance of 8,000 hours of play, 12,000 hours of play, and 16,000 hours of play.

Table 12. Main Engine 1 and 2 Middle-Level Maintenance Cost

No	Activities	Total	Unit	Cost (Per Package)	Cost (Per Hour)
1	Services Har 8,000 JP	1	Package	415,000,000	51,875, -
2	Har 8,000 JP	1	Package	5,657,000,000	707,125, -
3	Services Har 12,000 JP	1	Package	525,000,000	43,750, -
4	Har 12,000 JP	1	Package	9,441,300,000	786,775, -
5	Services Har 16,000 JP	1	Package	650,000,000	40,625, -
6	Har 16,000 JP	1	Package	15,983,000,000	998,938, -
TOTAL				**32,671,300,000**	**2,629,088, -**

From the table, it is obtained that the average level of maintenance costs for each MAIN ENGINE per hour is Idr.2,629,088, -so that if added to the organic level maintenance budget, the required maintenance budget for each Main Engine Navy Ships Xyz Class per rotating hour is Idr. 4,527,350, - / hour.

2) Diesel Generator (DG).

Following the manual hand, book the DG Caterpillar C-32 SCAC Accert has a maintenance time interval of 4,000 turnaround hours which is generally referred to in the Indonesian Navy as Top Overhaul (TO) level maintenance, 8,000 hours of Middle Overhaul (MO) maintenance, and 12,000 turnaround hours of General Overhaul (GO). To have the same value as the Main Engine, which is 16,000 hours of turnaround, the

DG budget requirement after the General Overhaul is still recalculated the need for top overhaul level maintenance budget, so that the total rotating hours are calculated to be 16,000 hours of play.

Table 13. Diesel Generator (DG) Middle-Level Maintenance Cost

No	Activities	Amount	Sat	Cost (Per Package)	Cost (Per Hour)
1	Har TO services	1	Package	228,726,000	57,182, -
2	Har TO	1	Package	827,680,000	206,920, -
3	Har MO services	1	Package	343,090,000	42,886, -
4	Har MO Material	1	Package	1,241,520,000	155,190, -
5	Har GO services	1	Package	571,816,000	47,651, -
6	Har GO material	1	Package	2,069,200,000	172,433, -
7	Har TO services	1	Package	228,726,000	57,181, -
8	Har TO	1	Package	827,680,000	206,920, -
TOTAL				**6,338,438,000**	**946,364, -**

From the table above, it is obtained that the middle level budget requirement for each DG per hour rotates is Idr. **946,364**, - /**Hour**so that if it is added up with the organic level maintenance budget, the total budget needed for the maintenance of each DG per rotation hour is Idr. 1.**107,428, -/Hour**

3) Electric motor.

The maintenance required for an electric motorbike is the maintenance of 5,000 hours of rotation, 10,000 hours of rotation, and 15,000 hours of rotation (overhaul), while other supporting equipment such as Water-Cooling Unit (WCU) and E-Drive Cabinet only require the same service as other electrical systems such as MSB. From the results of calculations according to the maintenance schedule, it is found that the maintenance requirement for the electric motorbike and its supporting equipment for each hour of rotation is Idr. 353,400, -

b. Total Budget Requirement

What is meant by the total budget requirement is the budget requirement for fuel and the budget maintenance for 1 year of operation adjusted to the pattern of TNI AL operations. From the calculation results obtained:

1) Sailing using an electric motor (PEM) for 50 days at sea requires a budget of Idr.9,792,148,193, -

2) A voyage for 50 days at sea using PDE with the same pattern as PEM requires a budget of Idr.19,806,145,600, -

3) The difference in budget use between PDE and PEM for 50 days each sail at sea with the same operating pattern is Idr. 10,013,997,407 or 49.4%.

4) The need for fuel costs and maintenance costs for 1 unit of DG alternately during berthing both at the base and at the operating area for 265 days as much as IDR. 16,790,101,080, -

5) The total budget requirement for Navy Ships Xyz Class (fuel, maintenance costs for the MAIN ENGINE, DG and Electric Motor) for 1 year of operation with a pattern of 50 days of PDE, 50 days of PEM, and 265 days of rest (1 DG) is Idr.46,388,394,873, -.

In several operating patterns (percentages of PDE and PEM usage) the following results were obtained:

Table 14. Total Budget Requirement

Operating Pattern	PDE Fee	PEM Cost	Cost By Standard	Total Cost
100 PDE days, 0 pem days & 265 standard days (1 DG)	39,612,291,200, -	-	16,790,101,080, -	56,402,392,280, -
50 PDE days, 50 pem days & 265 standard days (1 DG)	19,806,145,600, -	9,792,148,193, -	16,790,101,080, -	46,388,394,873, -
40 PDE days, 60 pem days & 265 standard days (1 DG)	15,844,916,480, -	11,750,577,832, -	16,790,101,080, -	44,385,595,392, -
0 PDE days, 100 pem days & 265 standard days (1 DG)	-	19,584,296,387, -	16,790,101,080, -	36,374,397,467, -

3.4 Engine Performance

In the assessment of engine performance (Main Diesel Engine and Electric Motor), it is assessed from several aspects that directly affect the condition of the ship, including:

a. Low vessel body vibration.

An electric motor is a device that can convert electrical energy into mechanical energy, where the electric current coming from the generator has flowed through the stator coil so that a magnetic field induces moving from one pole to another. The movement of the magnetic field causes the rotor shaft which is made of metal to rotate. In the ship propelling system, the rotor shaft is connected to the gearbox which then rotates the propeller shaft. Because the rotation of the rotor shaft is due to the movement of the magnetic field, the vibrations transmitted to the hull are very small.

b. Sound (Noise) Low.

In an electric motor, there is no burning of fuel, which causes an explosion of sound as in a diesel engine the resulting sound (noise) becomes very low.

c. Stable Engine Power.

The output power of a diesel engine is strongly influenced by the quality of the fuel that enters the engine, the perfect fuel intake in the combustion chamber, the tightness of the piston rings so that compression in the combustion chamber is maximized as well as the condition of the suction valve and the pressure valve which impacts the tightness of the valve. This causes the diesel engine power output to tend to decrease along with the addition of rotating hours because there has been a build-up of scale in the suction valve and valve, clogged injectors, reduced piston ring tightness, and so on. This condition is very different from an electric motor, where the output power of the electric motor is only affected by the electric power that enters the motor windings. As long as the incoming power remains the same, the power output (output power) of the electric motor will remain the same,

d. Easy and Cheap Maintenance.

The main parts of an electric motor which only consists of the stator, rotor, and bearing do not require as much complicated maintenance as in a diesel engine, especially the maintenance of the organic level. What is needed is checking the insulation resistance, cleaning the heat exchanger, and adding grease to the bearings to make it easier for crew members to maintain them.

e. PEM motor placement in the engine room.

The small dimensions of the PEM motor, as well as the reduction in supporting aircraft for propulsion, causing the engine room to be even more simple and spacious, besides that the engine room will be kept from cleanliness.

3.5 The weakness of Propulsion Electric Motor (PEM)

Apart from some of the advantages of using PEM compared to PDE, there are several disadvantages of pushing PEM, including:

a. DG control system.

To be able to operate PEM optimally, it takes a DG control system to work properly. If DG control is carried out manually, PEM operation will be more fuel-efficient than PDE because some DG must be on and parallel so that PEM rotation changes can be fulfilled. This is different from the operation of the PDE where the DG operation is not influenced by the needs of the PDE rotation.

b. Requires a larger space with suitable environmental conditions (temperature, humidity, air circulation, etc.) for the placement of a special PEM motor control and control system.

c. Response to Change in Cycle.

The response to changes in axle rotation when using PEM thrust is slower than when using PDE. This is because when the throttle is raised, the propulsion control system will first assess whether there is enough electricity available in the nets of the ship, after sufficient electricity is available, the control system will increase the rotation of the electric motor to increase the rotation of the propeller axle. This process takes ± 4 seconds. Therefore, this propulsion system is not suitable for ships that require fast reactions.

d. Round Change.

The higher the speed of the ship that is needed, the greater the power required by the motor to rotate the propeller shaft, this will cause an increase in fuel demand due to the use of power required by the operating DG, so that at a certain speed it causes the use of PEM thrust to not more efficient than the use of PDE boosters. Vice versa, the smaller the power required; the maximum efficiency value will be obtained.

IV. CONCLUSIONS

Based on the results of the research that has been carried out the author can be given conclusions can be drawn:

a. The operation of propelling ships using an electric motor (PEM) is very effective and efficient for ships that require a constant and low speed, such as transport vessels and auxiliary vessels.

b. At ship speeds between 7 - 14 knots, the use of Navy Ships type of Xyz fuel using PEM propulsion is more economical than using PDE.

c. The lower the speed of the ship used, the more difference in fuel is used for pushing using PEM compared to using PDE.

d. The need for maintenance budget (organic level and intermediate level) for each Main Engine Navy Ships type of Xyz is Idr. 4,527,350, - per hour of rotation, for each electric motor, is Idr. 353,400, -per hour of play and for each DG of IDR. 1,107,428,- per hour played. Meanwhile, the maintenance budget needs and the fuel budget for Navy Ships for 1 year with an operating pattern of 50 days using PDE support, 50 days using PEM support, and 265 days using Idr. 46,388,394,873, -

e. Navy Ships type of Xyz sailing using PEM propulsion for 50 days sailing at sea at a speed of 9-13 knots can save maintenance budget and fuel budget of Idr.10,013,997,407,- (49.4%) when compared with propelling using PDE at the same ship speed and operating pattern.

f. The advantages/advantages of propelling a ship using an electric motor (PEM) when compared to using a diesel engine (PDE) are PEM has very low vibration to the hull, low noise, stable output power (does not decrease with increasing rotating hours) and easy and cheap to maintain.

g. The weakness of propelling ships using an electric motor (PEM) when compared to using a diesel engine (PDE) is that PEM requires the DG automatic control system to function optimally and have a response to slower changes in the axle rotation of the propeller.

V. Future Work

Based on the results of the research that has been carried out the author can be given suggestions for future work as follows:

a. Please carry out a more in-depth study on the use of electric motors as the main driving force for Navy Ships type of Xyz, related to the limited budget for fuel and the Navy Ships type of Xyz maintenance budget.

b. When the auxiliary ships and transports will carry out depot-level maintenance, please conduct a study of the possibility of replacing the main propulsion engine from a diesel engine to an electric motor considering the budget for carrying out maintenance of Main Engine overhaul levels, gearboxes, and other supporting equipment for ships whose depots are quite large, and reduced fuel budget and subsequent maintenance.

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