DESIGN OF POWERPOLE MARINE PROPULSION UNIT

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Abstract

The design gives details on how the materials are selected, the techniques used, production drawing and the components in electric propulsion drive. The principle of operation of electric propulsion was used and how the electric power voltage (220V) current (5.1A) with power factors (cosΦ) 8900.67 was converted to mechanical power output of 0.75KW (1HP) by applying $P = V_1 I_1 \cos\Phi$ where P is the output power to drive the shaft to produce effective power of 0.51KW to propel a vessel. The forces, output powers (P_s, P_D and calculated; P_S is shaft power, P_D is the power delivered and P_E is the Effective power. Calculated by $P_D = P_s \times \eta_S$ where η_S is the efficient of the shaft. $P_E = P_D \times \eta_D$. P_E is the effective power while the η_D is the efficient of the propeller. The speed of electric motor (1HP) n is 310 revolutions per minutes while other speeds at a given delivered power were determined by applying propeller law that says $P_D \propto n^3$.The result shows that the voltage varies from 220 – 240V as shaft power and effective power ranges from 0.75 – 0.82kw and 0.496 – 0.545kw respectively.

Key words: Quasi-propulsion coefficient, Shaft power, Coil pitch, Shaft tolerance, Effective power, Delivered power, Voltage, Current and Power factors.

The marine propulsion system is the heart of ship; its reliability directly determines the safe navigation and operating costs of ship (Yan, 2011). The economy, space requirement, efficiency of propulsion and reliability are the most important parameters to the marine propulsion system (Conglin, 2013). Marine propulsion is a mechanism used to move a ship or boat across water. Most modern ships are propelled by mechanical system consisting of motors or engines which are propelled by turning a propeller (Rourke, 2000). A propeller is a type of a fan that transmits power by converting rotational motion into thrust, pressure difference is produced between the forward and rear surfaces of the airfoil-shaped blade, air or water is accelerated behind the blade. (Shraddha., 2012).

In Electric propulsion system, induction motor is used to drive the marine propeller. The control is affected by ocean surface waves, ocean currents, wind, weather and also ship motion. The speed of induction motor is controlled using flux comparator(Shraddha ,2012).

The use of electric plant has been increasing in recent years, particularly in areas such as deep-water drilling units, shuttle tankers, offshore supply vessels and other ships which require significant power for propulsion service. Today, the energy sector has available mature electric systems which are robust and have high availability (Peter, 2009).

Ships propulsion electrification offers significant anticipated benefits toward ships in terms of reducing ship life cycle cost, increasing ship stealthiness, payload, survivability and power available for non-propulsion-uses, and taking advantage of a strong electrical technological and industrial base. Potential disadvantages include higher near-term costs, increased technical risk, increased system complexity, and less efficiency in full power operations. (Angelos, 2013). A marine propulsion system includes following main parts: main engine, driving device, marine shaft and propeller (Zhou, 2005). The main engine is the impulsion machine engine of the marine propulsion system. The function of the driving device is connecting or parting the energy that the main engine transfers to the marine shaft and the propeller. The marine shaft plays an important role in transferring the energy to the propeller. The propeller promotes the ship to sail. (Conglin, 2013).

Materials and Procedure Used

In order to design a propulsion system, the following procedure should be followed; The input conditions: power input, voltage and current. The output conditions are: losses, efficiencies, shaft power, delivered power, effective power and propeller speed.

Material Selection

The material for propeller - (Aluminium Alloy): Its design compressive stress & bending stresses are [σc = 25000 kgf/cm 2], [σb = 3500kgf/cm 2]. Shaft should be nickel and chrome addition to mild steel. The motor was manufactured from industry based on the recommended specification.

Dimension of the propulsion

I. Electric motor drive dimension

The main dimension of the motor design is presented in Table I below

Table 1: Motor drive dimension

Items	Numbers and weights
Weight stator iron (kg)	10.1
Weight magnet (kg)	11
Outer rotor diameter (mm)	50
Coil pitch	4
Stator diameter	20
No of stator phase	3
Slots/pole and phase	4

(Source: industry based on the recommended specification, 2014)

II. Shaft dimension

Diameter = 20.00mm

Length of shaft =800.00mm

Table 2: Shaft tolerance j6

Max	Min
+0.0005	-0.0003

(Source: Charles, 2011)

III. Propeller dimension

Diameter of propeller = 250.00mm

IV. Frame

Length of the frame = 1000.00mm

Breadth of the frame = 400.00mm

Height of the frame = 700.00mm

V. Bearing

Outer diameter of the bearing= 30.00mm

Inner diameter of the bearing = 20.005mm

Relationship between the powers Propulsion coefficients

P_B= brake power of the prime mover

P_S = shaft power at the flange of the motor system input to the shaft line

$P_S = \eta_{motor} \times$ input power of the motor, = η_{motor}= motor efficiency

P_E = effective power, consisting of the total ships resistance RT at a ship´s speed V; also $P_E = P_D \times \eta_D$

DPE = RT × V -(1)

(Angelos, 2013)

P_D = delivered power, to the propeller by the machinery plant

$P_D/P_S = \eta_{shaft}$ = shaft efficiency -(2)

(Angelos, 2013)

η_{shaft} outlines the loss of power in the shaft line bearings and stertube bearing. These losses do not exceed generally 2% for machinery placed and 3% for machinery amid ship, η_{shaft} = 0.97 - 0.98 (Sources: Carlton, 2007)

Quasi-propulsion coefficient

A meaning measure of efficiency of the propulsion system is the ratio of the useful power been given the name "quasi-propulsion coefficient'', and is define as:

$\eta_D = P_E/P_D$

$= P_E/P_D = (RT \times V)/\omega \times MD = (RT \times V) / (2\pi\ MD\ n)$

$= (R \times V)/ (T \times VA) \times (T \times VA) / (Q\ W)$ - - - - - - - -- -- - - - - - -(3)

(Sajad., 2013)

V_A = speed of advance, which is related to ship's. Speed V by the wake fraction w,

$V_A = (1 – w) V$ - (4)

(Sajad ., 2013)

W

= wake fraction

T =

propeller thrust in open water condition, which is related to ship's resistance by the thrust deduction fraction: $R_T = (1 – t) T$ of the propeller shaft.

Therefore, the ratio $T \times V_A / Q\omega = \eta_O$, is the propeller open water efficiency.

$\eta_D = \eta_H \times \eta_O \times \eta_R$- -(5)

(Sources: Carlton, 2007)

Propulsive Coefficient

Quasi propulsive coefficient as P_E/P_D; the prefix; 'quasi' is used because it does not take any account of the mechanical efficiency of the shaft line and the stern tube. The propulsive coefficient, η_P includes the shaft bearing and the stern tube efficiency η_S and is define as:

$\eta_P = P_E / P_S = (P_E / P_D) \times (P_D \times P_S) = \eta_D \times \eta_S = \eta_H \times \eta_O \times \eta_R \times \eta_S$ -- - - - - - - - -(6)

(Sajad, 2013)

Propulsive Devices

To move the ship with a certain speed, it is necessary to apply a force, which will overcome the resisting forces of water and air. This force, opposite and compensative to the resistance R_T is called the thrust. The thrust is supplied by the propulsive devices.

Parameters for the Electric Motor

I Power output = 0.737KW (1HP)
II. The frequency = 50Hz
III. Speed in (r.p.m) = 310 r.p.m
IV. Voltage supplied = 220V
V. Current supplied = 5.1A
VI. Power factor (cosΦ) = 0.67

(Source: Industry- based on the recommended specification, 2014)

The electric motor conversion to mechanical power is apply by $P_{out} = P_1V_1\cos\Phi$. The power output of the electric motor is the shaft power of the propeller ($P_{out} = P_S$)

$P = V_1 I_1\cos\Phi$ -(7)

(Source: Okoro ., 2010)

The efficient of the shaft is 0.98for the machinery aft and 0.97 for the machinery amid ship. The loss of power in the shaft line bearing and sterntube bearing, these losses do not exceed generally 2% for machinery place aft and 3% for machinery amid ship. (Sources: Shraddha, 2012)

P_S = output power of the motor = shaft power

$P_D = P_S \times \eta_S$ - (8)

(Sources: Shraddha, 2012)

Efficiencies

I. Hull efficiency; $\eta_H = (1\text{-}t)/(1\text{-}w)$
II. Relative rotative efficiency; η_R
III. Propeller efficiency – open water; η_O
IV. Propeller efficiency – behind hull; $\eta_B = \eta_O \times \eta_R$
V. Propulsive efficiency; $\eta_D = \eta_H \times \eta_R$

Total efficiency;

$\eta_T = (P_E/P_B) = (P_E/P_T) \times (P_D/P_B)$

$\eta_T = \eta_H \times \eta_B \times \eta_S = \eta_H \times \eta_O \times \eta_R \times \eta_S$ - -- -(9)

(Gadoue, 2009).

According to propeller law which state that $P_D \propto n^3$

$P_D = Kn^3$

Where k is constant

P_D = propeller power delivered

n = speed of propeller

$P_D \propto n^3$

$P_D = kn^3$ -- - - - - - - - (10)

(Source: Shraddha, 2012

Assembly of Components on the Frame

The components to be assembled to the frame are electric motor drive, propeller shaft, propeller, nuts, bearings and flanges. The electric motor with 1HP is mounted on the end right side of the frame. The propeller shaft is connected to the motor with the help of flange. Bearings used for the tail shaft or propeller shaft are not stern tube bearing in this project because the assembly is not coupled to a vessel. The bearing used is similar to bearing used in pumps. The coupling arrangement can either have a flange forged integrated with the shaft of loosed, depending on requirements, flange that are forged integrated with the shaft have their thickness, determined by classification society rules, at the coupling face. By using this rule, the possibility of using tapered or stepped can be accommodated. The flange thickness should not be less than 0.2 times the diameter of the shaft. The foregoing of the flange with the shaft must be provided with a radius which is machined in and must not be less than 0.8 times the diameter of the shaft. These fitted must have a smooth finish.

Principle of operation of electric propulsion system

The electric motor drives the propeller shaft at a constant speed. This electric motor in turn supplies electricity to electric propulsion shaft which drives the propeller blade. The general opinion for this type of engine is that the electrical motor driving the propeller shaft turns on in one direction with the advent of electric propulsion into the system. The model works as a result of electricity supply of 220V to the prime mover which converts electrical power to mechanical power giving a rotatory motion in the motor. The motor is connected to the intermediate and transmitted to the propeller through the shaft as a result, produces loss of different source such as fraction, and inertial weight

Table 3: Power Outputs and Losses

S/N	**SHAFT POWER** $P = V_1 I_1 \cos\Phi$ kw	**DELIVERED POWER** $P_D = P_S \times \eta_S$ Kw	**EFFECTIVE POWER** $P_E = P_D \times \eta_D$ kw	**LOSSES IN SHAFT** $P_D - {}_S$kw	**LOSSES IN PROPELLER** $P_E - P_D$kw	**SPEED IN PROPELLER** $n = \sqrt[3]{(P_D/k)}$ kw
I	0.75	0.729	0.496	0.022	0.233	310.00
II	0.769	0.746	0.508	0.023	0.240	314.40
III	0.786	0.762	0.518	0.024	0.244	316.65
IV	0.803	0.779	0.537	0.024	0.249	318.99

V	0.82	0.795	0.545	0.025	0.254	319.85

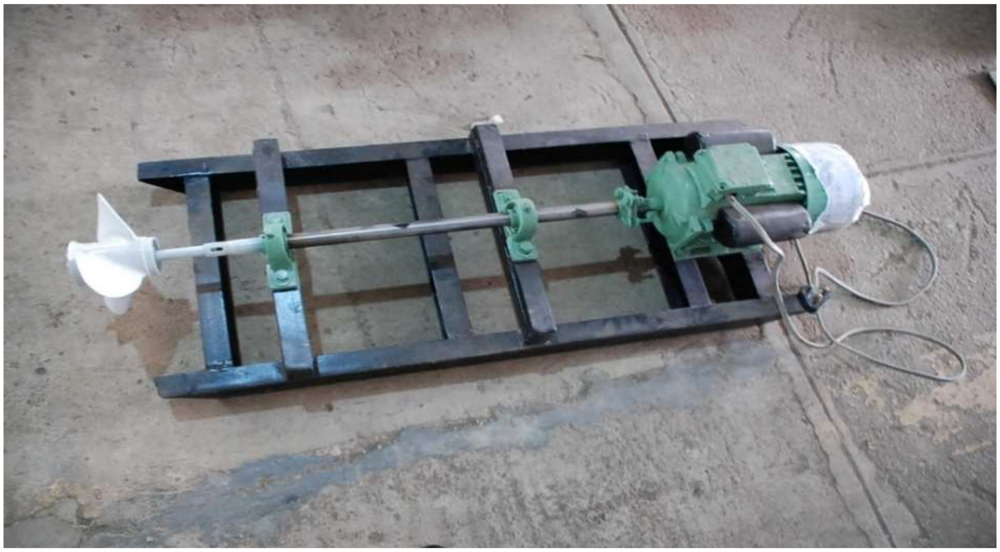


Fig.1 : Full View of The Design

Source: The Authors (2016)

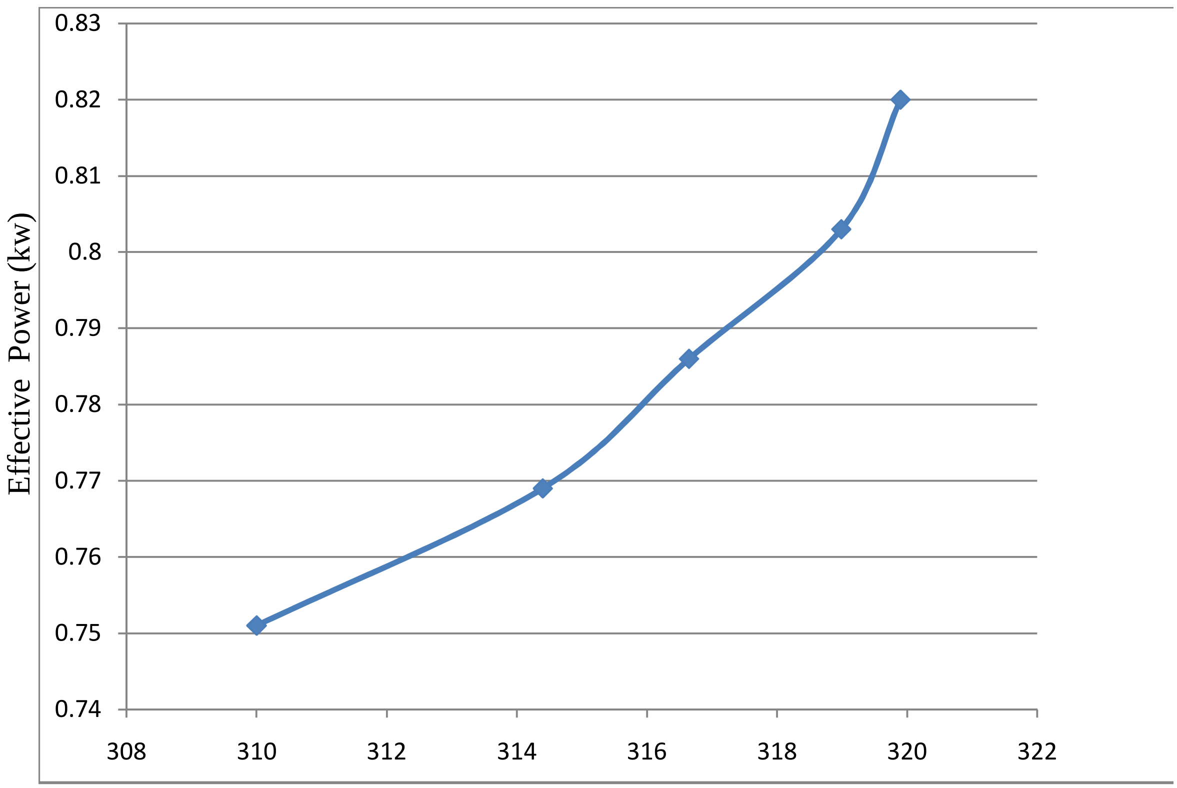
Result

The electric motor used for the project consists of these parameters; 1HP (0.751 KW) output power, input voltages varies from 220V, 225V, 230V 235V and 240V with frequency 50Hz was supplied through current of 5.1A. From the calculation and result obtained, the values for output power, transmission losses, shaft power output (P_S), delivered power (P_D), effective power (P_E), and speed of propeller (n) are obtained. The data will be used to plot graphs of (PE vs. n) and (PS vs. n)

Table 4: Power Outputs and Losses

S/N	Voltages (v)	Shaft power (kw)	Delivered power (kw)	Effective power (kw)	Propeller speed (kw)	Losses in the shaft (kw)	Losses in the propeller (kw)
I	220	0.75	0.729	0.496	310.00	0.022	0.233
Ii	225	0.769	0.746	0.508	314.00	0.023	0.240
Iii	230	0.786	0.762	0.518	316.65	0.024	0.244
Iv	235	0.803	0.789	0.537	318.99	0.024	0.252
V	240	0.82	0.795	0.545	319.85	0.025	0.254

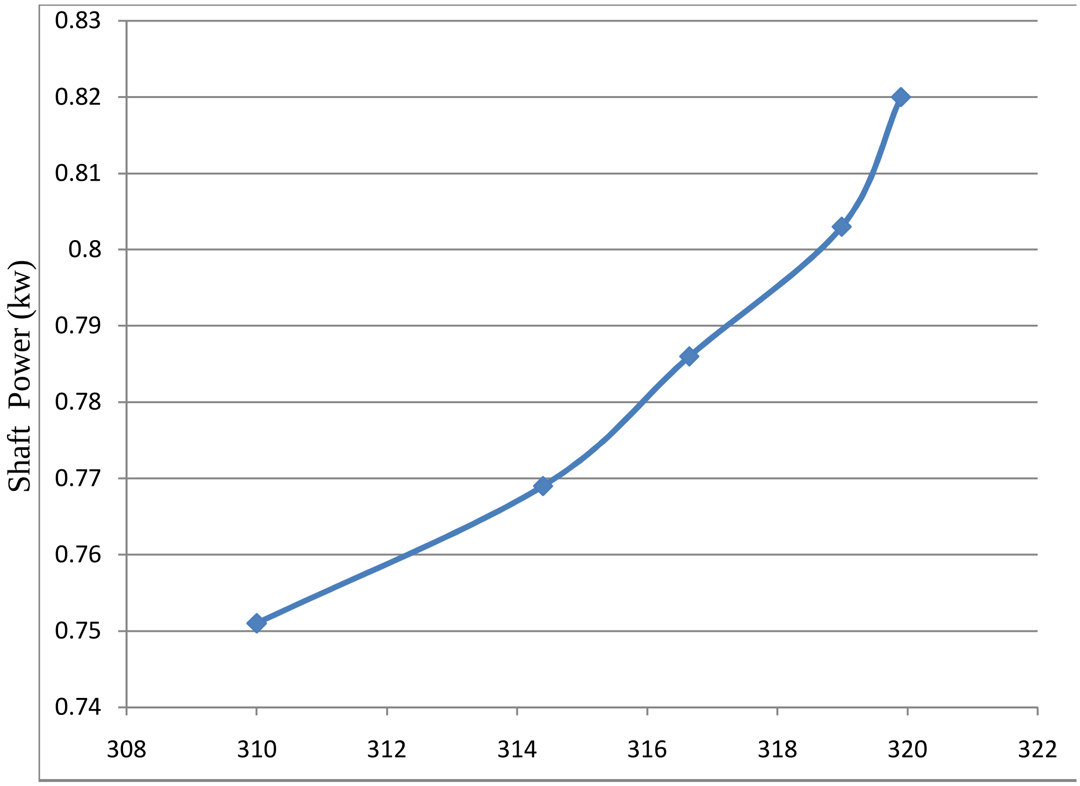
From the table above, it is seen that an increase in voltage lead to increase in the output power of the propulsion system, the transmission losses in the shaft and propeller were also increase with the increment in power outputs. This increased the propeller speed, the transmission losses in the shaft and propeller power. Then the relationship between shaft power and propeller speed shows that an increase in shaft power will lead to increase in propeller speed. This shows that any reduction in shaft power will lead to decrease in propeller speed of the vessel and also it will reduces effective power of the propulsion system.



Propeller Speed (r.p.m.)

Fig.2 Graph of effective power (kW) against propeller speed (r.p.m)

In figure 1, the graph plotted effective power against propeller speed shows that it is positive curve graph. From the graph, it was observed that the increase in effective power tends to an increase propeller speed; any further increase in the power will lead to little increase in propeller speed.



Propeller Speed (r.p.m.)

Fig. 3 : Graph of shaft power (kw) against propeller speed (r.p.m)

In figur3: the relationship between shaft power and propeller speed is that it is also positive curve graph. Increase in shaft power will lead to increase in propeller speed. This shows that the shaft power is directly proportional to the propeller speed, any reduction in shaft power will lead to decrease in propeller speed of the vessel and also, it will reduce effective power of the propulsion.

Conclusions

- An increase in voltage leads to increase in the output powers in the propulsion system. The transmissions losses were increased with increase in power output.
- The graph of effective power against propeller speed shows that, it is positive curve graph. It was observed that an increase in effective power tends to an increase in propeller speed.
- An increase in shaft power will lead to increase in propeller speed. This shows that the shaft power is directly proportional to the propeller speed.

- The relationship between the shaft power and propeller speed shows that an increase in shaft power will lead to increase in propeller sped. This shows that any reduction in shaft power will lead to decrease in propeller speed of the vessel and also will reduce effective power of the propulsion system.

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