Analysis of DC Motor Performance as Underwater Ship Driver

Sardono Sarwito[1,a,*], Semin[1,b] and Muhammad Badrus Zaman[2,c]

[1]*Doctoral degree, Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*

[2]*Department of Marine Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia*

a. sarsan@its.ac.id, b. semin@its.ac.id, c. druz_zaman @its.ac.id

**corresponding author*

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Abstract: The advantage of dc motors compared to induction motors (AC) is the ease of controlling when operating, although it must ignore the economic problems. For ships that move under water, will have difficulty in the operation of the generator, therefore must be provided a large number of battery accumulator for the operation of equipment on board. This battery is also used to supply electric power to dc motor propulsion drive. This is where the need to learn about the performance of dc motor to support underwater ship operations, need to be studied about the operation of dc motor when the vessel performs maneuvering operations, slow sailing, high speed sailing and other ship operations may be. In the theory of regulating the speed of motor rotation dc there are 3 methods are: first setting magnetic flux, secondly setting the anchor current and thirdly the incoming voltage regulation (terminal voltage). Motor rotation setting through terminal voltage settings is also called Ward Leonard system, this is the smoothest rotation arrangement that has a spin range from zero to motor nominal rotation. From both explanations mentioned above then in this paper will be examined the application of the dc motor as a driver on the ship that moves below the surface of the water, in this study will use ship and motor real data's and in completing it will support by a calculation program. Observation by using software will be focused to get correlation between input voltage, motor rotation and speed of ship and torque. From the results of the assessment will be obtained conclusions about the operational dc motor for maneuvering conditions, slow sailing, fast sailing etc.

1. Introduction

The application of diesel engine as propulsion system have some problems and weaknesses. It is not able to operate when underwater ship is at submerge condition. To overcome those problems, alternative solution of ship propulsion is required. Electric propulsion can be used as this alternative solution. Electric propulsion system is the ship propulsion system using electric motor to replace performance of main engine. In general, special ship use DC motor for propulsion system and commercial ship use AC motor[1].

There are many attractive advantages for using electric propulsion for ships. There is lower propulsion noise and reduced vibration. Efficient performance and high motor torques, as the electrical system can provide maximum torque at low speed.

Underwater ships use DC motor as electric propulsion system because DC motor has advantages of speed control and lower propulsion noise. In the theory of regulating the speed of motor rotation DC there are 3 methods are: first setting magnetic flux, secondly setting the anchor current and thirdly the incoming voltage regulation (terminal voltage). Motor rotation setting through terminal voltage settings is also called Ward Leonard system, this is the most smooth rotation arrangement that has a spin range from zero to motor nominal rotation[1].

The objection of research is to obtain difference characteristics between types of design electric propulsion; required torque and rotation of DC motor, and speed of ship; and application of design electric propulsion for ship operational.

This research has benefits to get characteristic data and performance of electrical propulsion. So that can be used in underwater ship application for further study.

2. Method

This research has several stages to completed as follows.

2.1. Identification and Research Problem

Determination of problem will be discovered and discussed. This research will be discussed about performance of electric propulsion on underwater ship. The method will be used there are simulation using MATLAB Software.

2.2. Determination of Ship Data and Electric Propulsion

Ship data and electric propulsion will be used, there are as follows.

Table 1: Ship data and electric propulsion system

Principal Dimension	
Length	59.7 meters
Inside Diameter	6.2 meters
Height	11.34 meters
Speed max	22 knots
Propeller	
Diameter	3.28 meters
Rotation max	200 rpm
Electric Propulsion	
Battery	480 cells (4 group); 2-3 volt/cell; 10260 AH
DC Motor	Two of DC Motor Shunt; Double Armature; 2x1850 kW; 380 V
DC Generator	480 kW; 1500 rpm; 380 V

2.3. Literature Study

2.3.1. Calculation of Motor Rotation and Torque

n	= (Vt - Ia.Ra) / (C.ϕ)	(rpm)	(1)
Tmotor	= $K \, x \, \phi \, x \, Ia$ (C.ϕ)	(Nm)	(2)

n (rpm) is total rotation that be produced by motor in units of rotation per minute. Vt is terminal voltage. Ia is armature current. C is value of proportional constanta. ϕ is value of magnetic flux. K is value of exponential constanta that show relation between torque and speed.

2.3.2. Calculation of Ship Resistance

RT	= RBH + RAPP	(N)	(3)
RBH	= $\frac{1}{2} \rho \, x \, A \, x \, V^2 x \, C_t$	(N)	(4)
RAPP	= $\frac{1}{2} \rho \, x \, A \, x \, V^2 x \, C_t$	(N)	(5)

RT (Newton) is total resistance of underwater ship. RBH ¬is bare hull resistance and RAPP is appendages resistance such as rudder plan. A (m2) is reference area (wetted area) of underwater ship. V (knot) is speed of underwater ship. CT is non-dimensional drag coefficient. (kg/m3) is density of sea water.

2.3.3. Calculation of Ship Torque

EHP	= RT x V	(kW)	(6)
PHP	= ((1-w)/(1-t)) x EHP	(kW)	(7)
Q	= PHP / 2π x n	(Nm)	(8)

EHP is product of total resistance and the speed expressed in units of horsepower. PHP (Propulsive Horse Power) is power delivered to the propulsor. ((1-w)/(1-t)) is hull efficiency. Q is torque required for underwater ship. n (rps) is rotation of propeller.

2.3.4. Calculation of Brake Horse Power

PHP	= 2π x Q x n	(kW)	(9)
PHP	= ((1-w)/(1-t)) x EHP	(kW)	(10)
Q	= PHP / 2π x n	(Nm)	(11)

Q (Nm) is torque motor. n (rps) is rotation of motor. SHP (Shaft Horse Power) is power delivered by the propulsion device (electric motor). ηm is machinery efficiency. BHP (Brake Horse Power) is brake power will be through to shaft propulsion device and will be operated continuously at ship speed. [6].

2.3.5. Calculation of Ship Speed

Va	= d_{prop} x coef. J x n		(12)
Vs	= Va/(1-w)	(m/s)	(13)
Q	= PHP / 2π x n	(Nm)	(14)

Va is speed of advanced the propeller. Then Vs is ship speed in units of knot.

- Calculating of ship resistance – Calculating ship resistance that will be used to calculate required torque and power of ship
- Calculating of required ship torque – Calculating required ship torque that will be used to simulate on MATLAB software as load of design electric propulsion system
- Creating model of electric propulsion system on MATLAB software – Execution of model electric propulsion on MATLAB software that will be used [7].
- Data analysis – Data from simulation will be processed and calculated; and analysis of torque, rotation and ship speed will be discussed.

3. Result and Discussion

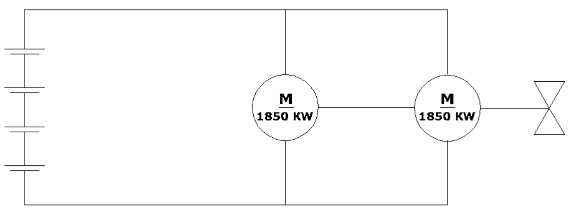
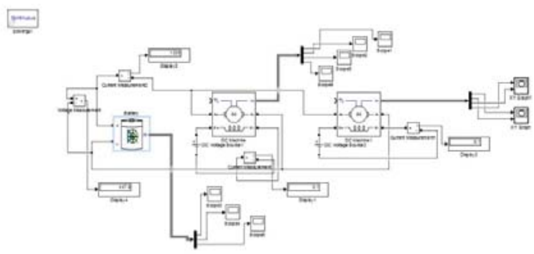
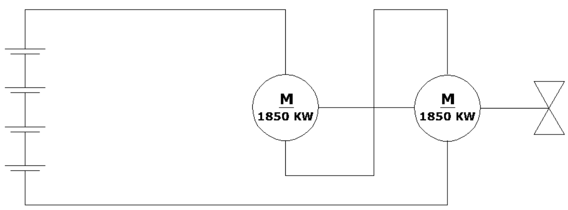
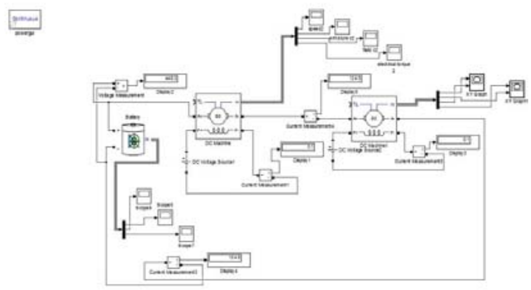
3.1. Data of Electric Propulsion

There are 7 types of electric propulsion design that has been used in this research as model of electric propulsion on MATLAB software. See Table 1.

3.2. Simulation Result

From MATLAB simulation, performance data of electric propulsion model are collected and reviewed. Table 2 shows result of simulation process and calculation.

Table 2: Data of electric propulsion

No	Schematic figure of electric propulsion	Model figure on Simulink MATLAB
1		
2		

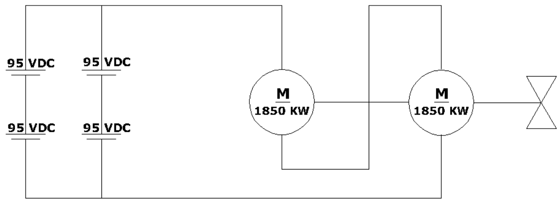
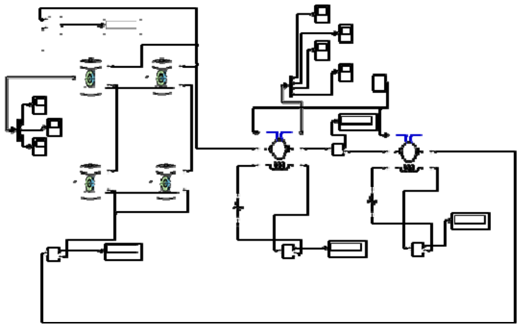
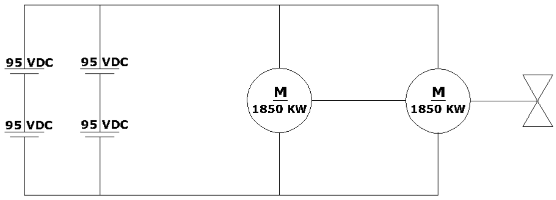
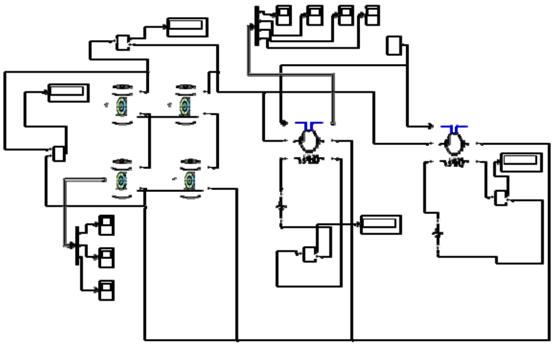
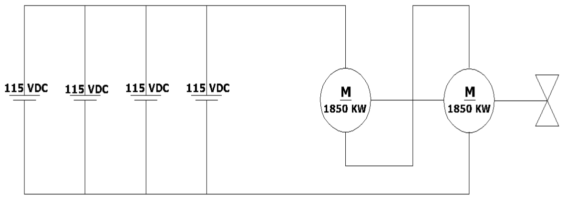
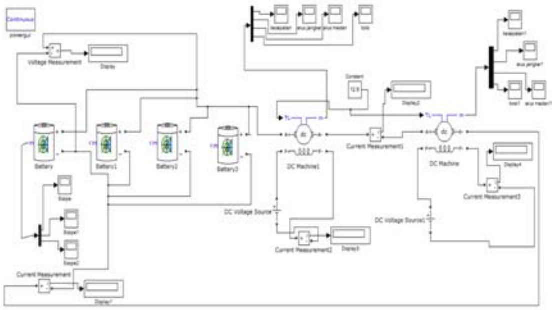
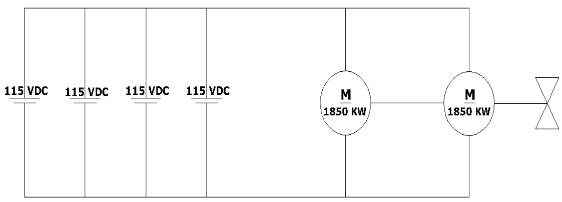
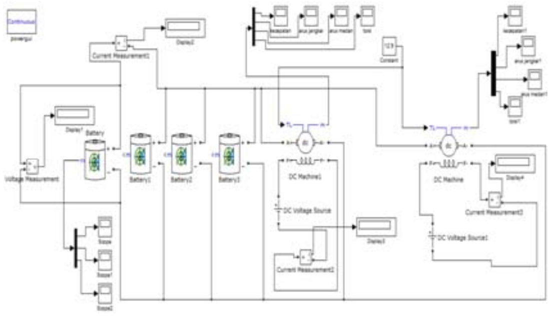
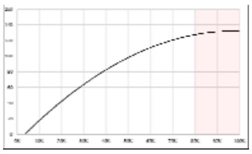
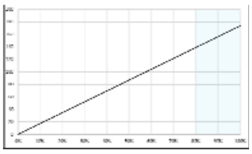
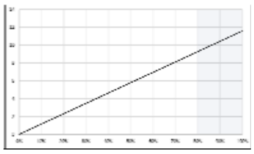
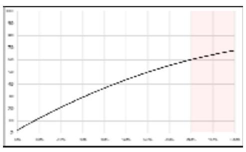
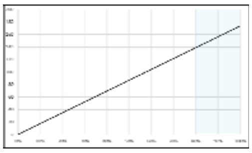
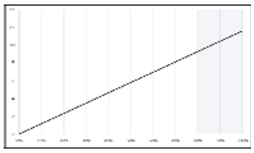
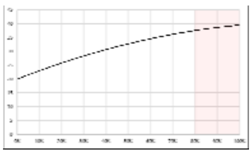
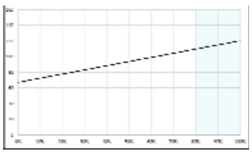
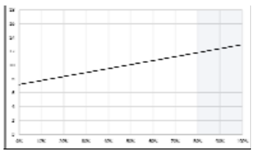
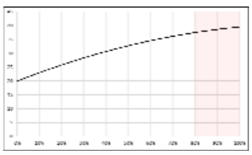
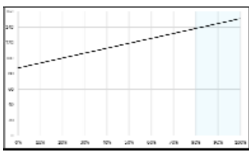
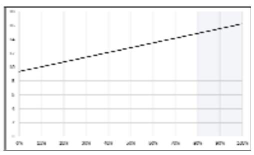
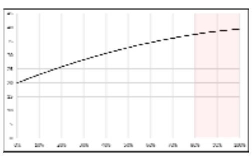
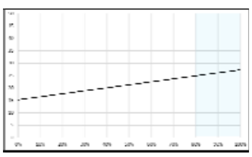
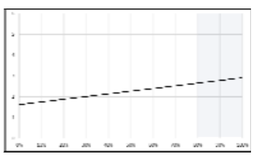
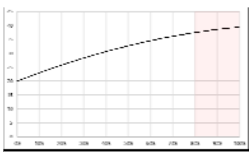
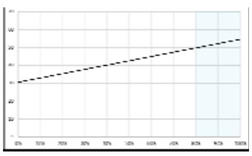
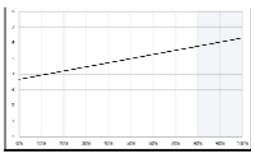
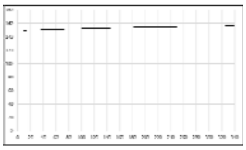
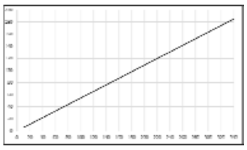
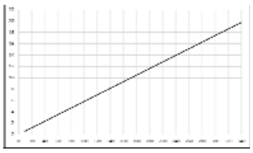
No	Schematic figure of electric propulsion	Model figure on Simulink MATLAB
3		
4		
5		
6		

Table 3: Result of simulation and calculation

<table>
<tr><th>No</th><th colspan="3">Curve</th><th>Condition</th><th>Motor torque (Nm)</th><th>Motor rotation (rpm)</th><th>Ship speed (knot)</th></tr>
<tr><td rowspan="2">1</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>80 %</td><td>117,85</td><td>139</td><td>9,26</td></tr>
<tr><td></td><td></td><td></td><td>100 %</td><td>122,21</td><td>173,73</td><td>11,57</td></tr>
<tr><td rowspan="2">2</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>80 %</td><td>48,01</td><td>139</td><td>9,26</td></tr>
<tr><td></td><td></td><td></td><td>100 %</td><td>62,64</td><td>173,73</td><td>11,57</td></tr>
<tr><td rowspan="2">3</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>80 %</td><td>40,56</td><td>103,3</td><td>11,1</td></tr>
<tr><td></td><td></td><td></td><td>100 %</td><td>40,79</td><td>111,57</td><td>12</td></tr>
<tr><td rowspan="2">4</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>80 %</td><td>40,56</td><td>132, 08</td><td>14,19</td></tr>
<tr><td></td><td></td><td></td><td>100 %</td><td>40,775</td><td>133,5</td><td>14,35</td></tr>
<tr><td rowspan="2">5</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>80 %</td><td>39,6</td><td>23,39</td><td>2,50</td></tr>
<tr><td></td><td></td><td></td><td>100 %</td><td>39,6</td><td>25,26</td><td>2,70</td></tr>
<tr><td rowspan="2">6</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>80 %</td><td>39,3</td><td>46,82</td><td>5,01</td></tr>
<tr><td></td><td></td><td></td><td>100 %</td><td>39,6</td><td>50,56</td><td>5,41</td></tr>
<tr><td>7</td><td>Motor torque</td><td>Motor rotation</td><td>Ship speed</td><td>Controlling</td><td>153,7 -</td><td>5,35 –</td><td>0,57 –</td></tr>
</table>

No	Curve	Condition	Motor torque (Nm)	Motor rotation (rpm)	Ship speed (knot)
	  	terminal voltage 10 – 340 volt	154	184,78	19,79

3.3. Analysis and Discussion

Based on result of simulation and calculation, characteristic of that model, there are as follows:

- Model 1
  DC motor in parallel circuit at full voltage. That will produce motor torque approximately between 117,85-122,21 Nm, motor rotation 139-173,73 rpm and ship speed 9,26-11,57 knot. In that condition, this model will be used for ship operational at slow sailing.

- Model 2
  DC motor in series circuit at full voltage. That will produce motor torque approximately between 48,01 -62,64 Nm, motor rotation 139 - 173,73 rpm and ship speed 9,26 - 11,57 knot. In that condition, this model will be used for ship operational at slow sailing.

- Model 3
  DC motor in series circuit at 95 DC volt. That will produce motor torque approximately between 40,56 - 40,79 Nm, motor rotation 103,3 - 111,57 rpm and ship speed 11,1 - 12 knot. In that condition, this model will be used for ship operational at medium sailing.

- Model 4
  DC motor in parallel circuit at 95 DC volt. That will produce motor torque approximately between 40,56 - 40,775 Nm, motor rotation 132, 08 - 133,5 rpm and ship speed 14,19 - 14,35 knot. In that condition, this model will be used for ship operational at medium sailing.

- Model 5
  DC motor in series circuit at 115 DC volt. That will produce motor torque approximately between 39,6 Nm, motor rotation 23,39 - 25,26 rpm and ship speed 2,50 - 2,70 knot. In that condition, this model will be used for ship operational at maneuvering condition.
- Model 6
  DC motor in parallel circuit at 115 DC vol. That will produce motor torque approximately between 39,3 – 39,4 Nm, motor rotation 46,82 - 50,56 rpm and ship speed 5,01- 5,41 knot. In that condition, this model will be used for ship operational at maneuvering condition

- Model 7
  DC motor in series circuit at 190 DC volt with terminal voltage controlling by using ohmformer. The controlling of terminal voltage between 10 – 340 volt. That will produce motor torque approximately between 153,7 - 154 Nm, motor rotation 5,35 – 184,78 rpm and ship speed 0,57 – 19,79 knot. In that condition, this model will be used for ship operational at maneuvering condition, slow sailing, medium sailing and fast sailing.

4. Conclusions

Conclusion that obtained from research's simulation, calculation and analysis are the design of electric propulsion are suitable for ship operational with several range of speed. For manouvering condition at 2 – 6 knot, circuit model number 5, 6, and 7 are good options; For slow speed at 9 – 12 knot, circuit model number that has better performance are model number 1, 2, 4, and 7; For medium sailing, the model that suitable used are model 3 and 7 with 12 - 14 knot of vessel speed; and for fast sailing at 18 – 20 knot, the best option is only model number 7. Going forward, research needs to be continued with a deeper analysis with performance analysis through advanced simulation and with prototype.

References

[1] Yoshifumi Ajioka and Kiyoshi Ohno, "Electric propulsion systems for ships", Hitachi Review Vol. 62 (2013), No. 3, pp: 231-232

[2] Zuhal. "Dasar Teknik Tenaga Listrik dan Elektronika Daya". Publish: ITB Bandung, 1988.

[3] Implement wound-field or permanent magnet DC machine, (2018).Mathworks.com.http://www.mathworks.com/help/physmod/sps/powersys/ref/dcmachine.html;jsessionid=9b89d0880c24246b9e0a0f76f9d8 [Accessed 4 Feb. 2018].

[4] Eugene Allmendinger, "Submersible vehicle systems design", Publish: The Society of Naval Architects and Marine Engineers, 1990, pp.252-258

[5] Harrington Roy L. "Marine Engineering". Publish: The Society of Naval Architects and Marine Engineers, 1980, pp.334-360.

[6] S.W, Adji."Engine Propeller Matching". Publish: FTK ITS: Surabaya, 2005.

[7] Ni-MH Battery Model, (2018). Mathworks.com. https://www.mathworks.com/help/physmod/sps/examples/ni-mh-battery-model.html [Accessed 4 Feb. 2018].