BACHELOR THESIS (ME 141502)

ANALYSIS OF ENGINE PROPELLER MATCHING USING SEPARATELY EXCITED DC MOTOR AS A MAIN PROPULSION BASED ON LABORATORY SCALE

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DOUBLE DEGREE PROGRAM OF
MARINE ENGINEERING DEPARTMENT
Faculty of Marine Technology
InstitutTeknologiSepuluhNopember
Surabaya 2017

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Analisa EPM untuk Sistem Propulsi menggunakan Motor Listrik dengan Tipe Penguatan Terpisah Skala Laboratorium

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APPROVAL FORM

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BACHELOR THESIS

Submitted to Comply One of The Requirements to Obtain a Bachelor Engineering Degree

on

Laboratory of Marine Electrical and Automation System (MEAS)

Bachelor Program Department of Marine Engineering

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Analysis of Engine Propeller Matching Using Separated Excited Dc Motor as a Main Propulsion Based on Laboratory Scale

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ABSTRACT

The development of shipping industry always searches through the most benefits system for reducing costs of propulsion system without create more pollution. Diesel propulsion system or also known as conventional propulsion system is efficient but requires high operating costs and create high level of marine pollution. Electrical propulsion system is using electric motors as the prime mover of the propeller. There are 2 types of electric motors that will be used for research of electric propulsion system, there are; DC motors and three-phase induction motor. As the use of DC motor as a prime mover for this electrical propulsion system, this study determines the characteristic between voltage terminal with torque and also field current with torque. It results that torque produced by the DC motor is in the same magnitude with the speed (RPM). The higher the speed have shaped the value of the torque. The input and terminal voltages adjusts all variables and results. In this study, different field voltage creates different pattern of motor envelope. Its manner to propeller curve occurs total different results. With field voltage of 50 volts, the ranges of motor envelope immoveable in the point of 150% of present speed and 160% power. While field voltage of 60 volts serves larger ranges of motor envelope which possible to reach further than 50 volts curve.

Keywords— ship propulsion system, electric propulsion system, DC motor, torque, rpm, propeller curve, motor envelope

Analisa EPM untuk Sistem Propulsi menggunakan Motor Listrik dengan Tipe Penguatan Terpisah Skala Laboratorium

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ABSTRAK

Perkembangan industri pelayaran selalu mengarah kepada penekanan biaya operasi dengan tidak menambah polusi. Propulsi diesel atau disebut juga propulsi konvensional adalah yang paling efisien sekaligus penyumbang polusi maritime terbesar sampai saat ini. Propulsi elektrik memanfaatkan motor listrik sebagai penggerak utama. Terdapat dua jenis motor listrik yang memungkinkan digunakan dalam sistem propulsi elektrik, yakni; motor DC dan motor induksi tiga fasa. Mengacu pada kemungkinan tersebut, studi ini akan membahas mengenai karakteristik antara voltase terminal dan torsi, juga arus medan dan torsi. Dihasilkan bahwa torsi yang diproduksi oleh motor DC berbanding lurus dengan kecepatan motor (RPM). Peningkatan kecepatan motor akan mempengaruhi besar torsi. Voltase masuk dan terminal sebagai pengatur variabel-variabel hasil dalam pengoperasian motor. Dalam kasus ini, voltase medan yang divariasikan memberikan hasil berupa grafik operasi motor. Dengan voltase medan 50 volts, jangkauan grafik operasi motor maksimum terletak pada 150% kecepatan dan 160% daya. Sementara, dengan voltase medan 60 volts dihasilkan jangkauan grafik operasi yang lebih luas dibandingkan dengan voltase medan 50 volts.

Kata Kunci— sistem propulsi kapal, sistem propulsi elektrik, motor DC, torsi, rpm, kurva propeller, grafik operasi motor

PREFACE

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Finally, I hope this bachelor thesis report can be useful for the readers and for me to finish my bachelor degree. My apologize for all readers if there is any mistake in thesis. In the further I will always improve myself and I hope we all become a person who is always blessed and give many benefits to the others.

Surabaya, July 2016

Ekaprana Danian

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CHAPTER 1
INTRODUCTION

1.1. BACKGROUND

By the definition ship is a vessel larger than a boat for transporting people and goods by sea. For transporting, the ship shall have propulsion system so the ships are able to maneuver in the water. There are several types of propulsion system but nowadays, the most commonly used marine propulsion system converting mechanical energy from thermal forces. Diesel propulsion systems are mainly used in almost all types of vessels.

The development of shipping industry always searches through the most benefits system for reducing costs of propulsion system without create more pollution. Diesel propulsion system or also known as conventional propulsion system is efficient but requires high operating costs and create high level of marine pollution. Compare with all the alternate propulsion system nowadays the best tried out alternative in recent time is electrical propulsion system.

Electrical propulsion system is using electric motors as the prime mover of the propeller. There are 2 types of electric motors that will be used for research of electric propulsion system, there are; DC motors and three-phase induction motor.

In respond to common used electrical propulsion This thesis will discuss about analysis engine and propeller matching for electrical propulsion with DC motor as a prime mover. As the use of DC motor as a prime mover for this electrical propulsion system in this thesis will be discuss about the character relation between voltage terminal with torque and also field current with torque.

As the character, electrical and mechanical of DC motor gained then authors know what is exactly the necessity of DC motor as the prime mover for selecting the engine. To find the proper engine authors can adjust the all variable mentioned before comply the specific of engine based on the variable input of all the parameter before.

For the result authors have to visualize the result of torque by the graphic between power and rpm. The character of the graphic be expected perform by the obtain DC motor suitable as a method of engine propeller matching for electrical propulsion.

1.2. STATEMENT OF THE PROBLEMS

Based on the background that described above, statement of problem from this thesis are;

1. What is the torque characteristic of DC motor?
2. How terminal voltage and field currentaffects to power and speed of DC motor
3. How is the torque graphic characteristic between power and speed of DC Motor?
4. How the Terminal Voltage variable affect the graphic of torque characteristic between power and RPM for Propulsion System?

1.3. RESEARCH LIMITATIONS

The limitations of this thesis are;

1. This study focus on the obtain the character of DC motor on laboratory as a sample for selecting motor.
2. The type of motor DC obtain is Shunt DC motor.
3. Specific propeller and engine not include on this thesis.
4. Cost and economic factor are not included.

1.4. RESEARCH OBJECTIVES

The objectives of this thesis are;

1. Obtain torque characteristic of DC motor shunt.
2. Obtain terminal voltage and field current affect to power and speed of DC motor.
3. Obtain is the torque graphic characteristic between power and rpm
4. Obtain several variable inputs impacts the graphic of torque characteristic between power and RPM

1.5. RESEARCH BENEFITS

The benefits of this thesis are;

1. The data that have been obtained can be used as a reference in developing Engine propeller matching for electrical propulsion.
2. Give a basic guide for selecting DC motor for marine propulsion by knowing the characteristic of the DC motor.

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CHAPTER 2
LITERATURE STUDY

2.1. PRINCIPLE OF DC MOTOR

Refer to Theraja (2005), an electric motor is a machine which converts electric energy into mechanical energy. Its action is based on the principle that when a current-driving conductor is placed in a magnetic field, it experiences a mechanical force whose direction is given by Fleming's Left-hand Rule.

As its construction, there is no basic difference between a DC generator and a DC motor. In fact, the same d.c. machine can be used as mutual as a generator or as a motor. DC motors are also like generators, shunt-wound or series-wound or compound-wound. (Theraja, 2005)

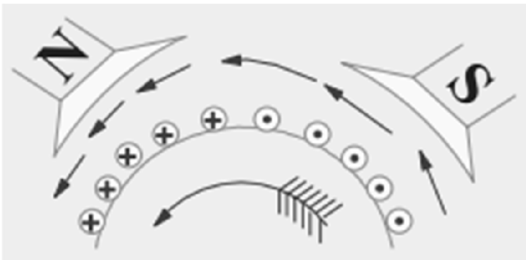


Figure 2.1. DC Multipolar (Thereja, 2005)

In *Figure 2.1 above* a part of multipolar d.c. motor is shown. When its field magnets are excited and its terminal conductors are supplied with current from the supply mains, they conduct a force tending to rotate the terminal. Terminal conductors under N-pole are assumed to carry current downwards (crosses) and those under S-poles, to carry current upwards (dots). (Chapman, 2005)

By applying Fleming's Left-hand Rule, the direction of the force on each conductor can be found. It is shown by small arrows placed above each conductor. It will be seen that each conductor can be found. It will be seen that each conductor experiences a force F which tends to rotate the terminal in anticlockwise direction. These forces collectively produce a driving torque which sets the terminal rotating. (Theraja, 2005)

2.2. DC MACHINES

Chapman (2005) determines DC machines are generators that convert mechanical energy to electric energy and motors that convert DC electric energy to mechanical energy. Most DC machines are like AC machines in that they have AC voltages and currents within them. DC machines have a DC output only because a mechanism exists that converts the internal AC voltages to DC voltages at their terminals. Since this mechanism is called a commutator, DC machinery is also known as commutating machinery.

If the rotor of this machine is rotated, a voltage will be induced in the wire loop. To determine the magnitude and shape of the voltage as shown in *Figure 2.2*. The loop of wire shown is rectangular, with sides ab and cd perpendicular to the plane of the page and with sides be and da paraliel to the plane of the page. The magnetic field is constant and perpendicular to the surface of the rotor everywhere under the pole faces and rapidly falls to zero beyond the edges of the poles (Chapman, 2005)

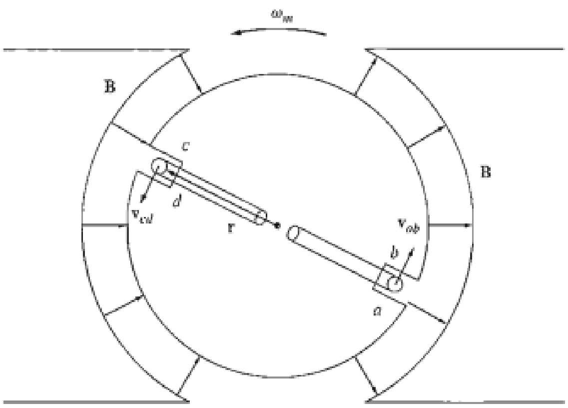


Figure 2.2. Voltages Induced Loop (Chapman, 2005)

When the loop rotates through 180°, segment ab is under the north pole face instead of south pole face. At that time, the direction of the voltage on the segment reverses, but its magnitude remains constant. (Chapman, 2005)

2.3. DC MACHINES CONNECTION

Consider first dc generators. The connection diagram of a separately-excited generator is given in *Figure 2.3*. The required field current is a very small fraction of the rated terminal current; on the order of 1 to 3 percent in the average generator. A small amount of power in the field circuit may control a relatively large amount of power in the terminal circuit; for example, the generator is a power amplifier. Separately- excited generators are often used in feedback control systems when control of the terminal voltage over a wide range is required.

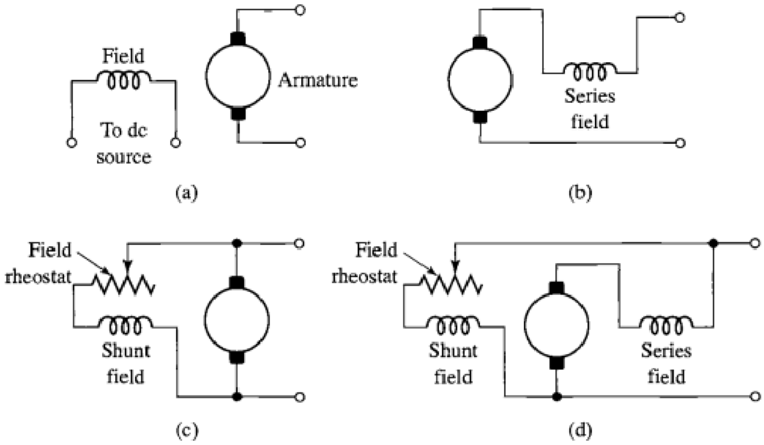


Figure 2.3. DC Machines Circuit Connection (Fitzgerald, 2003)

The field windings of self-excited generators may be supplied in three different ways. The field may be connected in series with the terminal (*Figure 2.3 (b)*), resulting in a series generator. The field may be connected in shunt with the terminal (*Figure 2.3(c)*), resulting in a shunt generator, or the field may be in two sections (*Figure 2.3(d)*), one of which is connected in series and the other in shunt with the terminal, resulting in a compound generator. With self-excited generators, residual magnetism must be present in the machine iron to get the self-excitation process started.

Typical steady-state volt-ampere characteristics of dc generators are shown in *Figure 2.4*, constant-speed operation being assumed. The relation between the steady- state generated emf*Ea* and the terminalterminal voltage *Va* is as shown in *Equation 2.1*.

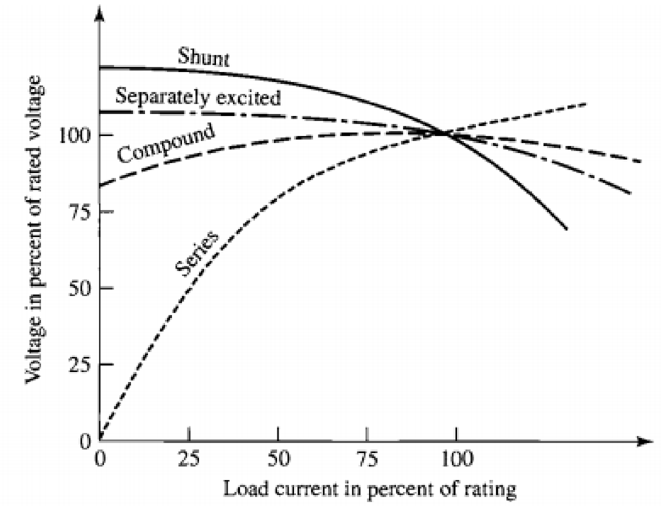


Figure 2.4. DC Generator Typical Volt-Ampere Characteristic (Fitzgerald, 2003)

$$V_a = E_a - I_a R_a \; (watt)$$

Equation 2.1. Steady Ea and Terminal Voltage (Va) Correlation (Fitzgerald, 2003)

where Ia is the terminal current output and Ra is the terminal circuit resistance. In a generator, *Ea*is larger than *Va,* and the electromagnetic torque Tmech is a counter torque opposing rotation.

Any of the methods of excitation used for generators can also be used for motors. Typical steady-state dc-motor speed-torque characteristics are shown in *Figure 2.5*, in which it is assumed that the motor terminals are supplied from a constant-voltage source. In a motor the relation between the emf*Ea* generated in the terminal and the terminalterminal voltage *Va* is as shown in *Equation 2.2*.

In accordance to Fitzgerald (2003), a shunt- and separately-excited motors, the field flux is nearly constant. Consequently, increased torque must be accompanied by a very nearly proportional increase in terminal current and hence by a small decrease in counter emf*Ea* to allow this increased current through the small terminal resistance.

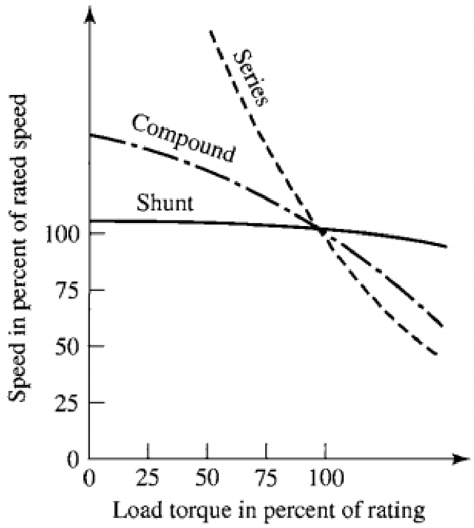


Figure 2.5. DC Motor Speed-Torque Characteristic

$$V_a = E_a + I_a R_a \ (watt)$$

Equation 2.2. DC Motor Ea and Terminal Voltage (Va) Correlation (Fitzgerald, 2003)

where *Ia* is now the terminal-current input to the machine. The generated emf*Ea* is now smaller than the terminal voltage *Va*, the terminal current is in the opposite direction to that in a generator, and the electromagnetic torque is in the direction to sustain rotation of the terminal.

2.4. DC MACHINES LOSSES

Various losses, specified in separately excited DC Machines, can be described as below: (Theraja, 2005)

2.4.1. COPPER LOSSES (TERMINAL)

Losses in Terminal of DC Machines can be expressed in equation below:

$$Armature\ Copper\ Loss = {I_a}^2 R_a \ (watt)$$

Equation 2.3. Terminal Copper Loss (Theraja, 2005)

where *Ra* = resistance of terminal and interpoles and series field winding etc. This loss is about 30 to 40% of full-load losses.

2.4.2. IRON LOSSES (MAGNETIC)

These losses are practically constant for shunt and compound-wound generators, because in their case, field current is approximately constant. These losses total up to about 20 to 30% of F.L. losses

2.4.3. MECHANICAL LOSSES

Friction loss at bearings and commutator, while air-friction or windage loss of rotating terminal. These are about 10 to 20% of F.L. Losses.

2.5. DC MACHINES VOLTAGE EQUATION

The voltage Vapplied across the motor terminal has to; overcome the back emfEb, and supply the terminalohmic drop. The equation as shown below.

$$V_a = E_a + I_a R_a \ (watt)$$

Equation 2.4. DC Machines Voltage (Theraja, 2005)

where *V* = voltage (volt), *Eb* = electrical equivalent to mechanical power (volt), and *IR* = copper loss. The visualization as shown in *Figure 2.6*.

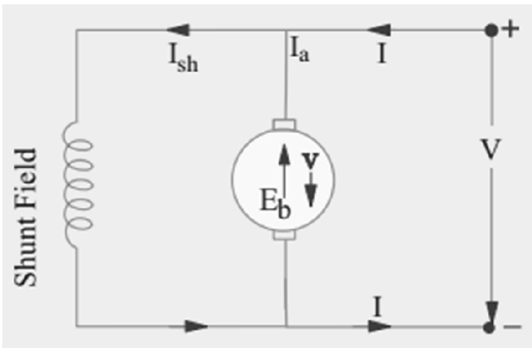


Figure 2.6. Voltage Equation Visualization (Theraja, 2005)

2.6. DC MACHINES TORQUE AND POWER

Consider a pulley of radius r meter acted upon by a circumferential force of F Newton which causes it to rotate at N rpm. Then Torque can be defined by *Equation 2.5*.

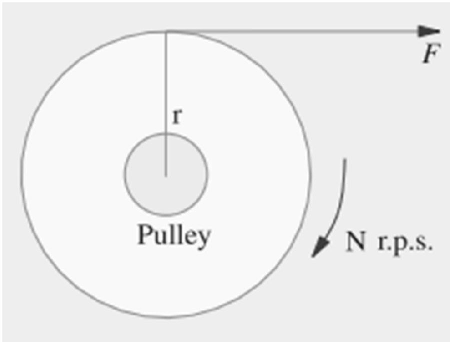


Figure 2.7. Torque Visualization (Theraja, 2005)

$$T = F \cdot R \ (Nm)$$

Equation 2.5. Torque (Theraja, 2005)

where *T* = Torque, *F* = force (N), and *r* = radius (meter). Then the power developed can be expressed by *Equation 2.6*.

$$Power\ Developed = (F \cdot R) \cdot 2\pi N \ (watt)$$
$$P = {}^{2\pi N}/_{60} \cdot T \ (watt)$$

Equation 2.6. Developed Power (Theraja, 2005)

Where 2π N = ω = circular speed (rad/s), *F* = force (N), and *r* = radius (meter).

2.7. DC MACHINES TERMINAL TORQUE

In condition that *Ta* be the torque developed by the terminal of a motor running at N (rpm) If *Ta* is in Nm, then power developed can be figured by the *Equation 2.7*.

$$P = {}^{2\pi N}/_{60} \cdot T \ (watt)$$
$$P_{arm} = E_{arm} I_{arm} \ (watt)$$
$$T_{arm} = \frac{E_{arm} I_{arm}}{{}^{2\pi N}/_{60}} \ (Nm)$$

Equation 2.7. Terminal Torque (Theraja, 2005)

Where P = developed power (watt), Ta = terminal torque (Nm), Ia =terminal current (A), Eb = electrical equivalent to mechanical power (volt).

2.8. DC MACHINES SHAFT TORQUE

The whole of the terminal torque, as calculated above, is not available for doing useful work, because a certain percentage of it is required for supplying iron and friction losses in the motor. The torque which is available for doing useful work is known as shaft torque T_{sh}. It is so called because it is available at the shaft. The motor output is given by *Equation 2.8*.

$$P_{out} = T_{sh} \cdot 2\pi N \; (watt)$$
$$T_{sh} = \frac{P_{out}}{2\pi N/_{60}} \; (Nm)$$

Equation 2.8. Shaft Torque (Theraja, 2005)

Where Pout = output power (watt), and Tsh = shaft torque (Nm).

2.9. DC MACHINES POWER

Gross mechanical power developed by a motor is maximum when back emf. is equal to half the applied voltage. This condition is, however, not realized in practice, because in that case current would be much beyond the normal current of the motor. The gross mechanical power developed by a motor can be expressed by *Equation 2.9*.

$$P_{out} = VI - \; I^2 R \; (watt)$$
$$P_{out} = P_{in} - \; ({I_{arm}}^2 R_{arm} + {I_f}^2 R_f) \; (watt)$$

Equation 2.9. Output Power (Theraja, 2005)

Where V =voltage (volt), Ia = terminal current (A), and R = resistance (ohm).

Moreover, half the input would be wasted in the form of heat and taking other losses (mechanical and magnetic) into consideration, the motor efficiency will be well below 50 percent. Efficiency equation shown in *Equation 2.10*.

$$\eta = {}^{P_{out}}/_{P_{in}} \cdot 100\% \; (\%)$$

Equation 2.10. Power Efficiency (Theraja, 2005)

2.10. DIESEL ELECTRIC PROPULSION

Compared with stationarypower plants, there is one big difference with diesel-electric propulsion systems. With the stationary power plants, it's only the load, due to the varying ship speed, which is changing onboard ships. With diesel-electric propulsion the frequency will also change due to the varying propeller speed.

Throughout the years the onboard power generation has become more efficient. This is because power electronics have made it possible to utilize the power station concept and to install frequency converters.

The first modern passenger and cruise vessel for which the power station concept was utilized was the ''Queen Elizabeth 2''. This cruise vessel had a 95.5 MW propulsion plant consisting of nine MAN B&W 9L 58/64-type medium-speed engines. The ''Queen Elizabeth 2'' also provided another breakthrough. It was the first vessel on which directly resiliently mounted medium-speed engines were used. In this way, the vibration and stringent noise requirements were fulfilled. (Doorduin, 2013)

Figure 2.8. MV. Queen Elizabeth 2 (Doorduin, 2013)

In 1998, the ''Queen Elizabeth 2'' was considered as a trend-setter for modern cruise vessels. This was because of two reasons:

1. The electric power station concept
2. Low noise and vibrations installations onboard

2.11. TYPES OF ELECTRIC MOTOR PROPULSION

Refer to Doorduin (2013), one motor is commonly used for the propulsion of seagoing vessels. This is the synchronous motor. Another commonly used motor is the induction motor. Each of this type of motor has its own disadvantages and advantages which have been found out in our research.

2.11.1. DC MOTOR

In the past DC-motors were used for the propulsion of seagoing vessels, but they are not used anymore. They were used in hydrodynamic survey vessels, because of their main advantage: its smooth running capability. When a ship sails smoother, the measurement of the seabed will be more precise. This is the main reason DC-motors where used in hydrodynamic survey vessels. Another advantage of this motor is that the speed can be controlled relatively easy. Because of the simplicity of the motor a simple power converter can be used. Because of the simplicity of this motor the power is limited to a maximum of around 5 MW. Therefore, the DC-motor isn't used for the propulsion of seagoing vessels. Another dangerous disadvantage of this motor is the maintenance. When maintenance is not carried out correctly, the risk of flashovers in the motor increases. A flashover is strong electrical current between the carbon brushes and the rotor of the motor. A flashover can damage the electrical motor and can even cause a fire. (Wildi, 2006)

2.11.2. SYNCHRONOUS MOTOR

Wildi (2006) determins this motor was commonly used in podded propulsion, because of its great power output. But the induction motor is making a great rise in podded propulsion. The advantage of the synchronous motors is that the power is not limited, motors with an output of 100 MW are possible. But the more power a motor produces, the bigger the motor has to be. Therefore these motors are, in general, heavy and complicated. This is the major disadvantage of the synchronous motor. Another disadvantage of the motor is that it needs a starting application. But this disadvantage can be ''converted'' into an advantage, with the use of frequency converters. With frequency converters the motor can be started, and it's speed can be precisely controlled. This is a great advantage when maneuvering through ports and berthing places.

2.11.3. Induction Motor (Asynchronous motor)

This motor is commonly used on board of ships but not yet for propulsion purposes. However, the induction motor is making a breakthrough in this sector. When used in cooperation with a cyclo-converter, this motor doesn't has any disadvantages. On board the induction motor is commonly used in pumps, fans and other applications. In these applications the motor is commonly started under zero-load or with a star-delta starter. If this star-delta starter or starting under zero-load isn't used the starting current of the motor would be very high. With the immense size of motors we are using for propulsion, the starting current would be so high that there would be no wiring which could resist that kind of currents. Therefore, used cyclo-converter, which eliminates the only disadvantage of the induction motor, the need for a good speed control, and the high starting current. The use of a cyclo-converter also provides better speed controlling abilities. At the moment, the largest podded thruster is using an induction motor which has a power of 20 MW.The induction motor requires a lot less maintenance compared to the DC and Synchronous motor, because it has no carbon brushes. Therefore, the running costs are also lower. Because of all these advantages the induction motor will be the motor for the propulsion of seagoing vessels.(Wildi, 2006)

2.11.4. Permanent magnet motor

Wildi (2006) determines future probability of this motor, it is lighter, smaller and has a higher efficiency compared to the induction and synchronous motors. If the system stays operational there are no problems, but if a problem occurs reparations would be a very difficult operation because of the powerful permanent magnets. Great precaution must be taking when working on this motor. This motor will be discussed in another chapter of the report, where the actual developments of electric motors will be discussed.

2.12. DC Motor Propeller Matching

The condition of certain propeller types has to match to rating engine torque and speed. P1 until P3 is power percentage correlated with N1 to N3, speed of the engine in rpm. It is referred to exact point of pitch matching points.

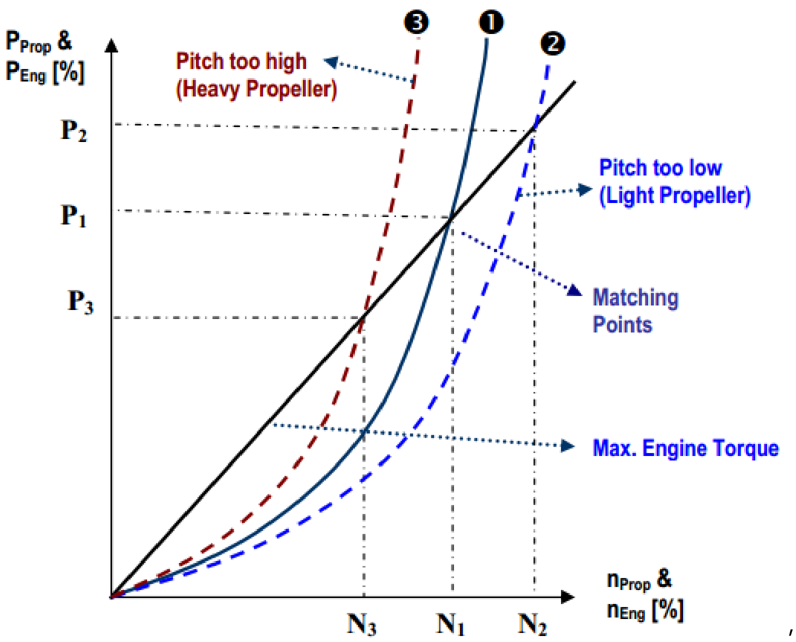


Figure 2.9. Engine Torque and Propeller Curve (Adji, 2008)

2.12.1. SHIP DRIVEN TRAIN

Ship is essentially driven by the forces or thrust of the water. The momentum of the thrust comes from the rotation of the propeller which driven by propulsion system, or in the specific case the power of the propulsion engine. The process for transmitting engine power into the water needs to go through several steps as shown in *Figure 2.10*.

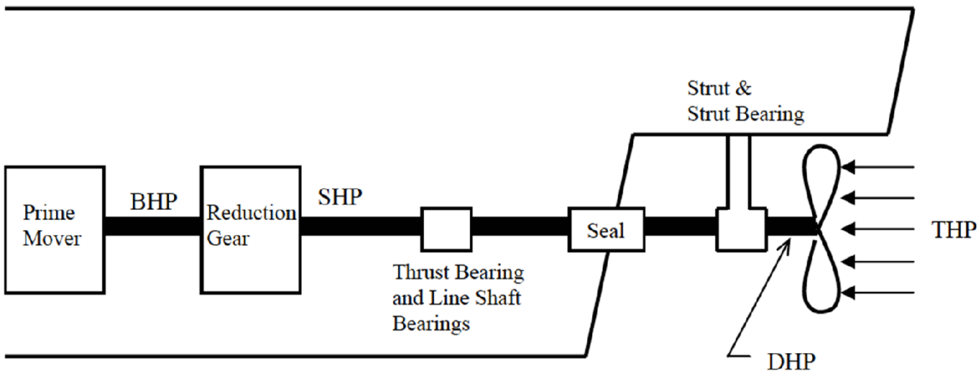


Figure 2.10. Simplified Ship Driven Train

The figure above shown several consistence of variable inside propulsion system, such as listed below.

1. Brake Horse Power (BHP)
   Brake horsepower (BHP) is the power produced by the ship's prime mover. The prime mover is portion of the drive train that converts heat energy into rotational energy. For most ships, the prime mover is a steam turbine, gas turbine, or diesel engine. For some ships, the prime mover can be a large electric motor (electric drive). The output speed of the prime mover is usually quite high (several thousand rpm for a gas turbine at full power) and must be reduced to a usable rotational speed. (Adji, 2008)
2. Shaft Horse Power (SHP)
   Shaft horsepower (SHP) is the power output the reduction gears (if installed). Reduction gears are necessary to reduce the high revolutions per minute (rpm) of the prime mover to a much slower shaft rotation speed required for efficient screw propeller operation. For example, a steam turbine at full power may operate at 5,700 rpm and the reduction gear will reduce that to 258 shaft rpm. In order to accomplish the speed reduction between the prime mover and propeller shaft, and to produce the torque necessary to spin the propeller, a reduction gear is usually quite large and heavy. Reduction gears are very efficient at power transmission, with only a one or two percent loss of power between input (BHP) and output (SHP). The relationship between BHP and SHP is called the gear efficiency (ηgear), and is written as following. (Adji, 2008)

$$\eta_{gear} = {}^{SHP}/_{BHP}$$

Equation 2.11. Gear Efficiency (Adji, 2008)

3. Delivered Horse Power (DHP)
   Delivered Horsepower (DHP) is the power delivered by the shaft to the propeller. The amount of power delivered to the propeller will be less than shaft horsepower because of transmission losses in the shaft. Losses are usually quite small: 2-3%. These losses occur in the bearings, stern tube and its seal, and strut bearings. The thrust bearing takes the axial propeller thrust produced by the rotation of the propeller shaft and transmits the linear force of the thrust to the ship, which in turn produces translational motion of the ship. Line shaft bearings are used to support the weight of the propeller shaft between the reduction gear and stern tube. The stern tube and seal are necessary to keep the ocean out of the ship. (Adji, 2008)

Transmission losses are primarily due to friction and can be felt as heat in the bearings. The difference between delivered horsepower and shaft horsepower is referred to as shaft transmission efficiency (ηshaft), and is defined as following equation.

$$\eta_{shaft} = {}^{DHP}/_{SHP}$$

Equation 2.12. Shaft Efficiency (Adji, 2008)

4. Thrust Horse Power (THP)
   Thrust Horsepower (THP) is the power produced by the propeller's thrust. THP is smaller than DHP due to inefficiencies inherent in converting the rotational motion of the propeller into linear thrust. The propeller is the least efficient component of the ship's drive train. Delivered and thrust horsepower are related through a quantity called the propeller efficiency. Typically, a well-designed propeller will have an efficiency of 70-75% at the ship's design speed. (Adji, 2008)
5. Effective Horse Power (EHP)
   Effective horsepower is determined through model data obtained from towing tank experimentation. In these experiments, a hull model is towed through the water at a given speed while measuring the amount of force resisting the hull movement through the water. Model resistance data can then be scaled up to full-scale ship resistance. Knowing a ship's total hull resistance and its speed through the water, the ship's effective horsepower can be determined using the following figure. The block below shown the resistance or losses causes by propulsion system configuration itself.

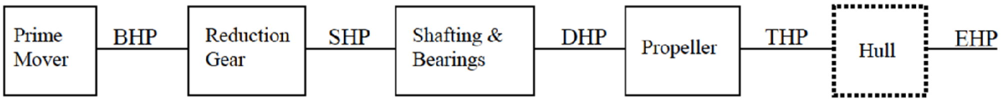


Figure 2.11.Ship Driven Train Block Diagram (Adji, 2008)

6. Hull Efficiency and Hull Resistance
   Once the ship's effective horsepower has been determined, it is now necessary to relate EHP to the power produced by the drive train. This is done by relating the power required to tow the ship through the water (EHP) to the power produced by the propeller (THP). The ratio of effective horsepower to thrust horsepower is called the hull efficiency (ηH), and is defined as following.

$$\eta_{hull} = {}^{EHP}/_{THP}$$

Equation 2.13. Hull Efficiency (Adji, 2008)

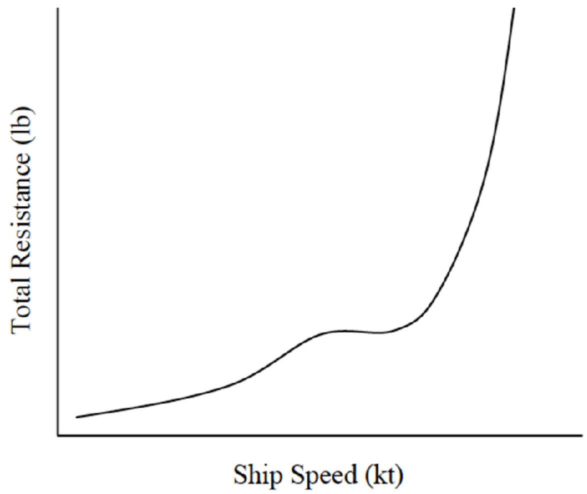


Figure 2.12. Hull Resistance Typical Curve (Adji, 2008)

The principle factors affecting ship resistance are the friction and viscous effects of water acting on the hull, the energy required to create and maintain the ship's characteristic bow and stern waves, and the resistance that air provides to ship motion. In mathematical terms, total resistance can be written as following.

$$R_T = R_F + R_V + R_W + R_{AA}\ (N)$$

Equation 2.14. Hull Efficiency (Adji, 2008)

where; R_T = total hull resistance, R_F = residual resistance, R_V = viscous/friction resistance, R_W = wake resistance, and R_{AA} = additional resistance (wave; wind).

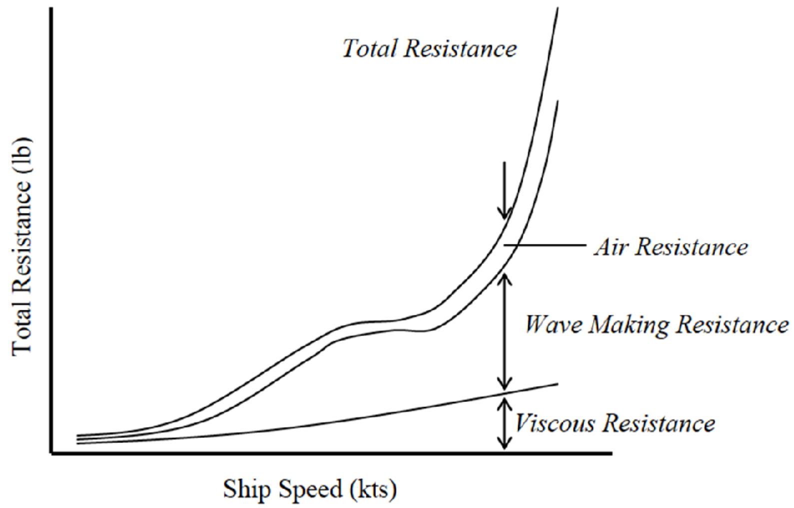


Figure 2.13. Hull Resistance Component Curve (Adji, 2008)

2.12.2. Ship Principal Dimension

In this study, the focus is on the affection of the terminal voltage changing due to the motor powered propulsion system characteristic. Noted that the propeller curve need to be determined based on certain ship principal dimension, or to be specific. Considered an operated exist vessel to be include for the analysis; Bulk Carrier vessel. The detail information of the vessel attached in the *Enclosure E*.

2.12.3. Propeller Curve

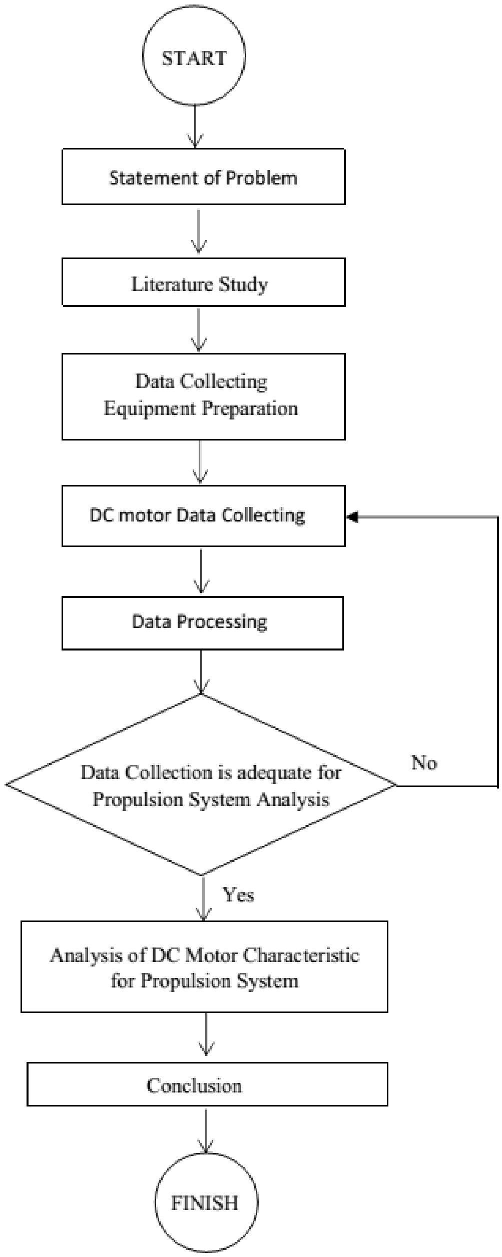
As mentioned in Figure 2.9, propeller curve to be constructed an fitted to the engine/motor envelope. Its curve shaped from BHP (kW) vs. speed (RPM) correlation graph in percentage value. It indicates operating point of the propeller in certain percentage point of the power and the speed.

2.12.4. Motor Envelope

The same way as the propeller curve, engine envelope indicates the operating area of the motor in power and speed boundary. It shaped certain capability area to serve the propeller to do propulsion task. It is possible to conclude that the propeller is working effectively when it crosses the optimum point inside the motor envelope area, for example between 80-100%. (Adji, 2008)

CHAPTER 3
METHODOLOGY

3.1. METHODOLOGY FLOWCHART



3.2. DEFINITION OF METHODOLOGY FLOW CHART

3.2.1. STATEMENT OF PROBLEMS

This stage intended to make describe the outline of this thesis, all supporting items such as problem and question prepared to specify objective of this thesis. All the content and problem of this thesis as already mentioned earlier will comply with many information regarding to the content and the problem.

3.2.2. LITERATURE STUDY

Right after the problems is raised, a literature study is performed. In this stage, literature will be used to connect the problems with existing theories and facts from various sources. The study of literature is done by reading papers, journals, thesis, media and literature books that relates and able to support this thesis.

3.2.3. DATA COLLECTING EQUIPMENT PREPARATION

After literature study which support the thesis has been done, The next stage is prepare all the supporting equipment to which will be use during the experiment such as DC motor shunt, rectifier, Regulator, multimeter, tachometer, Generator, Cable, Ampere meter and other supporting equipment.

3.2.4. DC MOTOR DATA COLLECTING

This stage is about start from making the circuit to connect the power input to DC motor shunt. On this stage will be prepared all the equipment to perform the observation for the next step.

3.2.5. DATA PROCESSING

On this stage, all the result after several data collecting and variable input will be gather and observe is there any mistake or not during the data collecting and also on this stage will be calculated the constant work, power input, power output, and efficiencies. Graphical representative will be performed on this stage to visualize the result. The data from the observation analyzed to verified the character of torque and speed regarding to variation input of voltage to maintain the torque and speed on the different load.

3.2.6. Data Collection is adequate for Propulsion System Analysis

The result from data processing will be determine whether it is capable to be compare to Propulsion System needs or graphic. Thus, will be gather together with Engine Propeller Matching (EPM) characteristic.

3.2.7. Analysis of DC Motor Characteristic for Propulsion System

Correlation of of DC motor characteristic and EPM will be visualize in one conclusion chart. Graphical result will be the output of this stage.

3.2.8. Conclusion

This final stage is intended to resume the result of this thesis. On this stage will be describe and explain the value of data collecting. Also on this stage questions and problems are answered specifically in order to meet the specific objectives of this thesis. The conclusion of the thesis is to fulfill the statement of the problems mentioned earlier

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CHAPTER 4
CALCULATION AND RESULT

4.1. GENERAL

Two separately excited DC motor data collecting deducted in two different state of load, zero load and loaded. Zero load scenarios with initial condition; constant field voltage (V_F), serves the output data of terminal current (I_{Term})and rpm. While loaded scenarios with initial condition; gradual decreased input voltage (V_{in}) from 10 until 30 volt, serves an information the output data of terminal current (I_{Term}), terminal voltage (V_{Term}), output voltage (V_{out}), and rpm.

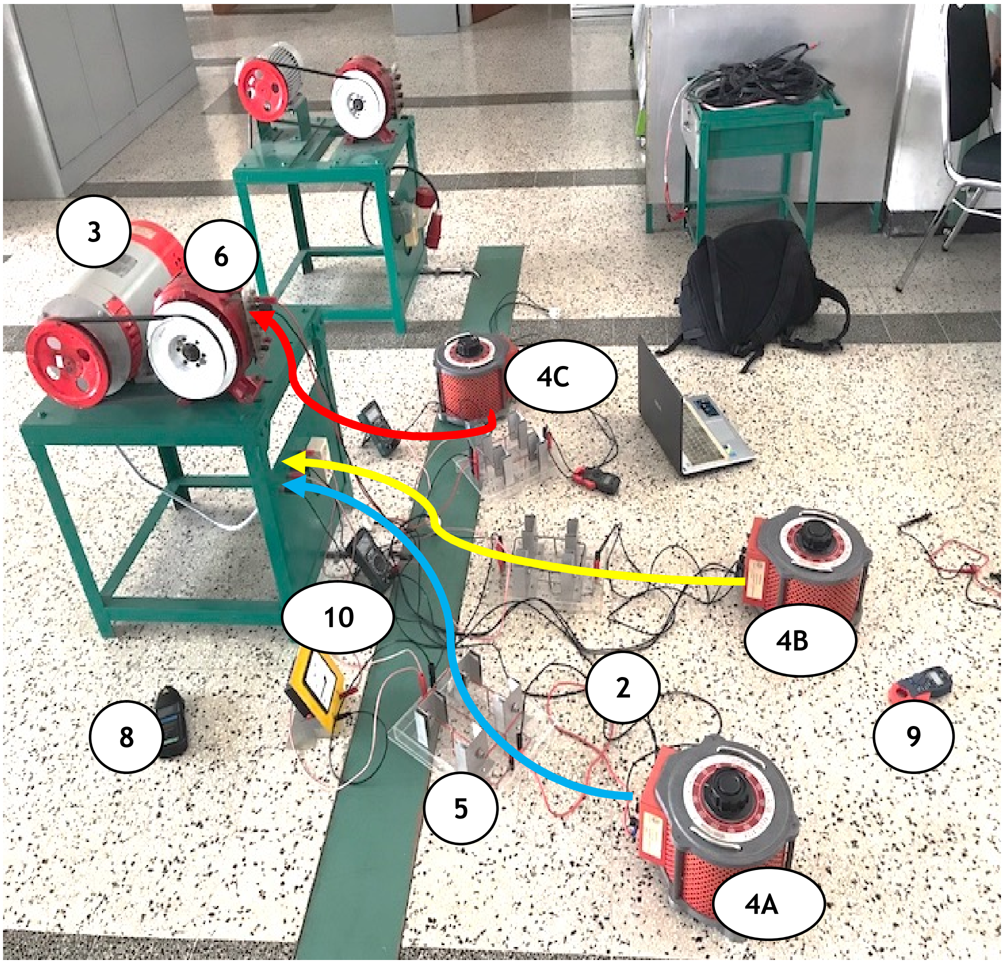


Figure 4.1. Data Collecting Process

Below listed the sequence of data collecting process;

1. Preparing data collection gears; motor, generator, cables, regulators, rectifier, and measurement tools (voltmeter and amperemeter).
2. Constructing electrical circuits with cables for data collecting purpose.
3. Motor as data collection object connected with two circuits; Terminal and Field.
4. Regulator as variation of motor input voltage-regulating device. It placed before the rectifier. Three regulators used in this study. Each placed in the circuit of terminal, field, and generator input. Regulator pointed with 4A used in field circuit as field voltage variation regulator. Named with 4B placed in terminal circuit as terminal voltage variation regulator. Whilst, pointed with 4C is input voltage variation regulator as resistance.
5. Rectifier is converter of AC current to DC current. It placed after the regulator. Two rectifiers used in this study. Each placed in terminal and field circuit.
6. Each circuits connected with generator as resistance.An electric generator is a device that converts mechanical energy obtained from an external source into electrical energy as the output. It placed as resistance inside the operation of the circuits. It uses the mechanical energy supplied to it to force the movement of electric charges present in the wire of its windings through an external electric circuit
7. Measurement tools located within in aim to collect electric voltage and current information. Those consist of tachometer, clampmeter, and multimeter.
8. Tachometer placed to measure speed or RPM of the motor.
9. Clampmeter or amperemeter placed in the cable of the circuit to measure current.
10. Multimeter (gray) and voltmeter (yellow) placed in order to measure voltage of the electric curcuits.
11. Representing collected data and variations as in the *Table 4.2* and *Table 4.3*.

4.2. DC Motor Data Collection

Data collection implemented with separately excited type of DC Motor. The specification of the motor, output power, voltage, and nominal speed, presented in *Table 4.1*.

Table 4.1. DC Motor data Collection

SEPARATELY EXCITED DC MOTOR **FUJI ELECTRIC Type: GGA 8117 A**		
Max. Output Power	8.7	kW
Volt DC	140	Volt
Max Current	33	Ampere
Speed	2500-200	rpm

Sort of data gathered in data collecting serves in two different categories, zero load and loaded. Hereby the sample of zero load condition initial data with initial condition field voltage (V_F) 50volts presented in *Table 4.2*and *Table 4.3*.

Table 4.2. Zero Load Condition Data Collection (V_F = 50 V)

Zero Load Condition						
Con.	V.F (V)	I.Arm (A)	I.F (A)	RPM	Varm (V)	V.in (V)
A	50	2.61	0.32	957	40	10~30
B	50	2.37	0.32	1070	45	10~30
C	50	2.57	0.32	1178	50	10~30
D	50	2.68	0.32	1330	55	10~30

Table 4.3. Loaded Condition Data Collection (V_F = 50 V)

A: Loaded Condition (V.Arm starting 40, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.55	0.32	40	50
A-1	10	0.1	2.8	0.32	41	50
A-2	15	0.1	3.04	0.32	42	50
A-3	20	0.2	3.37	0.32	43	50
A-4	25	0.2	3.61	0.32	44	50
A-5	30	0.2	3.76	0.32	45	50

No.	V.in (V)	RPM
A-0	0	957
A-1	10	994
A-2	15	993
A-3	20	1025
A-4	25	1030
A-5	30	1046

4.3. Input Power (P.in) Calculation

Input Power (P.in) is the developed power in watt units. It consists of multiplication of current in ampere and electrical equivalent to mechanical power in volt. Which in this case consist of sum of two section, terminal and field. Current presented by I.Term for terminal current and I.F for field current. While electrical equivalent value (E) presented in V.Term for terminal voltage and I.F for field voltage.

Referred to *Equation 2.7*, *Table 4.4* shown the example with initial condition field voltage (V_F) 50 volts and sample of loaded condition initial data with terminal voltage (V_{Term}) start on 40 volts.

Table 4.4. Input Power Result

A: Loaded Condition (V.Arm starting 40, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.55	0.32	40	50
A-1	10	0.1	2.8	0.32	41	50
A-2	15	0.1	3.04	0.32	42	50
A-3	20	0.2	3.37	0.32	43	50
A-4	25	0.2	3.61	0.32	44	50
A-5	30	0.2	3.76	0.32	45	50

No.	V.in (V)	RPM	P.in (W)
A-0	0	957	0
A-1	10	994	130.80
A-2	15	993	143.68
A-3	20	1025	160.91
A-4	25	1030	174.84
A-5	30	1046	185.20

4.4. Losses Variable Calculation

Losses including in the calculation is terminal copper loss.It is later correlated with electromotive force (EMF) and the power output of DC motor. The variable consist of current in ampere and resistance in ohm. Which in this case consist of separated of two zone, terminal and field. Current presented by I.a for terminal current and R.a for terminal resistance. While for field current presented by I.f and R.f for terminal resistance. The equation below shown the connection of current and resistance to the EMF.

Calculation refers to *Equation 2.2* and *Equation 2.3*, *Table 4.5* shown the example with initial condition field voltage (V_F) 50 volts and sample of loaded condition initial data with terminal voltage (V_{Term}) start on 40 volts.

Table 4.5. Losses Variable Result

A: Loaded Condition (V.Arm starting 40, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.55	0.32	40	50
A-1	10	0.1	2.8	0.32	41	50
A-2	15	0.1	3.04	0.32	42	50
A-3	20	0.2	3.37	0.32	43	50
A-4	25	0.2	3.61	0.32	44	50
A-5	30	0.2	3.76	0.32	45	50

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	957	0	0	0	0
A-1	10	994	130.80	11.2	31.36	11.26
A-2	15	993	143.68	12.16	36.97	11.26
A-3	20	1025	160.91	13.48	45.43	11.26
A-4	25	1030	174.84	14.44	52.13	11.26
A-5	30	1046	185.20	15.04	56.55	11.26

4.5. Electromotive Force (E) Calculation

Electromotive force (EMF) is electrical equivalent to mechanical power in volt units. In this case, it is necessary to be calculated to acquire terminal electrical equivalent value to its mechanical gain. As shown in Equation IV.2,its stand for terminal voltage minus the terminal loss. It represents by the *Equation 2.4*.

Table 4.6 shown the example with initial condition field voltage (V_F) 50 volts and sample of loaded condition initial data with terminal voltage (V_{Term}) start on 40 volts.

Table 4.6. Terminal Electromotive Force Result

A: Loaded Condition (V.Arm starting 40, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.55	0.32	40	50
A-1	10	0.1	2.8	0.32	41	50
A-2	15	0.1	3.04	0.32	42	50
A-3	20	0.2	3.37	0.32	43	50
A-4	25	0.2	3.61	0.32	44	50
A-5	30	0.2	3.76	0.32	45	50

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	Ia^2.Ra	If^2.Rf
A-0	0	957	0	0	0	0
A-1	10	994	130.80	11.2	31.36	11.26
A-2	15	993	143.68	12.16	36.97	11.26
A-3	20	1025	160.91	13.48	45.43	11.26
A-4	25	1030	174.84	14.44	52.13	11.26
A-5	30	1046	185.20	15.04	56.55	11.26

No.	V.in (V)	Ea (W)
A-0	0	0
A-1	10	29.80
A-2	15	29.84
A-3	20	29.52
A-4	25	29.56
A-5	30	29.96

4.6. TORQUE CALCULATION

In this case of DC motor, terminal torque is to be acquire in order to gain the information of the torque escalation with the speed increase due to the increasing of terminal voltage.Terminal torque consist of multiplication of terminal electromotive force in watt and terminal current in ampere, divided by two times phi speed in rpm and constant of 60. Its equation explained in *Equation 2.7*.

Table 4.7 shown the example with initial condition field voltage (V_F) 50 volts and sample of loaded condition initial data with terminal voltage (V_{Term}) start on 40 volts.

Table 4.7. Terminal Torque Result

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	Ia^2.Ra	If^2.Rf
A-0	0	957	0	0	0	0
A-1	10	994	130.80	11.2	31.36	11.26
A-2	15	993	143.68	12.16	36.97	11.26
A-3	20	1025	160.91	13.48	45.43	11.26
A-4	25	1030	174.84	14.44	52.13	11.26
A-5	30	1046	185.20	15.04	56.55	11.26

No.	V.in (V)	Ea (W)	Torque (Nm)
A-0	0	0	0
A-1	10	29.80	31.66
A-2	15	29.84	34.45
A-3	20	29.52	36.60
A-4	25	29.56	39.07
A-5	30	29.96	40.62

4.7. OUTPUT POWER CALCULATION

Input Power (P.out) is the developed power minus terminal and field losses. It represents the gross mechanical power developed by a motor is maximum after losses being calculated. Its correlation with the developed power and losses shown in *Equation 2.9*.

Table 4.8 shown the example with initial condition field voltage (V_F) 50 volts and sample of loaded condition initial data with terminal voltage (V_{Term}) start on 40 volts.

Table 4.8. Output Power Result

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	Ia^2.Ra	If^2.Rf
A-0	0	957	0	0	0	0
A-1	10	994	130.80	11.2	31.36	11.26
A-2	15	993	143.68	12.16	36.97	11.26
A-3	20	1025	160.91	13.48	45.43	11.26
A-4	25	1030	174.84	14.44	52.13	11.26
A-5	30	1046	185.20	15.04	56.55	11.26

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)
A-0	0	0	0	0	0
A-1	10	29.80	31.66	2.64	88.18
A-2	15	29.84	34.45	2.63	95.45
A-3	20	29.52	36.60	2.72	104.22
A-4	25	29.56	39.07	2.73	111.45
A-5	30	29.96	40.62	2.77	117.39

4.8. Power Efficiency Calculation

Efficiency is comparison between the output power and input power. It represents the effectiveness of the DC motor to deliver the output of the motor through its losses. It consistence shown in the *Equation 2.10*.

Table 4.9 shown the example with initial condition field voltage (V_F) 50 volts and sample of loaded condition initial data with terminal voltage (V_{Term}) start on 40 volts.

Table 4.9. Power Efficiency Result

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	Ia^2.Ra	If^2.Rf
A-0	0	957	0	0	0	0
A-1	10	994	130.80	11.2	31.36	11.26
A-2	15	993	143.68	12.16	36.97	11.26
A-3	20	1025	160.91	13.48	45.43	11.26
A-4	25	1030	174.84	14.44	52.13	11.26
A-5	30	1046	185.20	15.04	56.55	11.26

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	29.80	31.66	2.64	88.18	67.4%
A-2	15	29.84	34.45	2.63	95.45	66.4%
A-3	20	29.52	36.60	2.72	104.22	64.8%
A-4	25	29.56	39.07	2.73	111.45	63.7%
A-5	30	29.96	40.62	2.77	117.39	63.4%

4.9. Loaded Condition Iterm vs. RPM

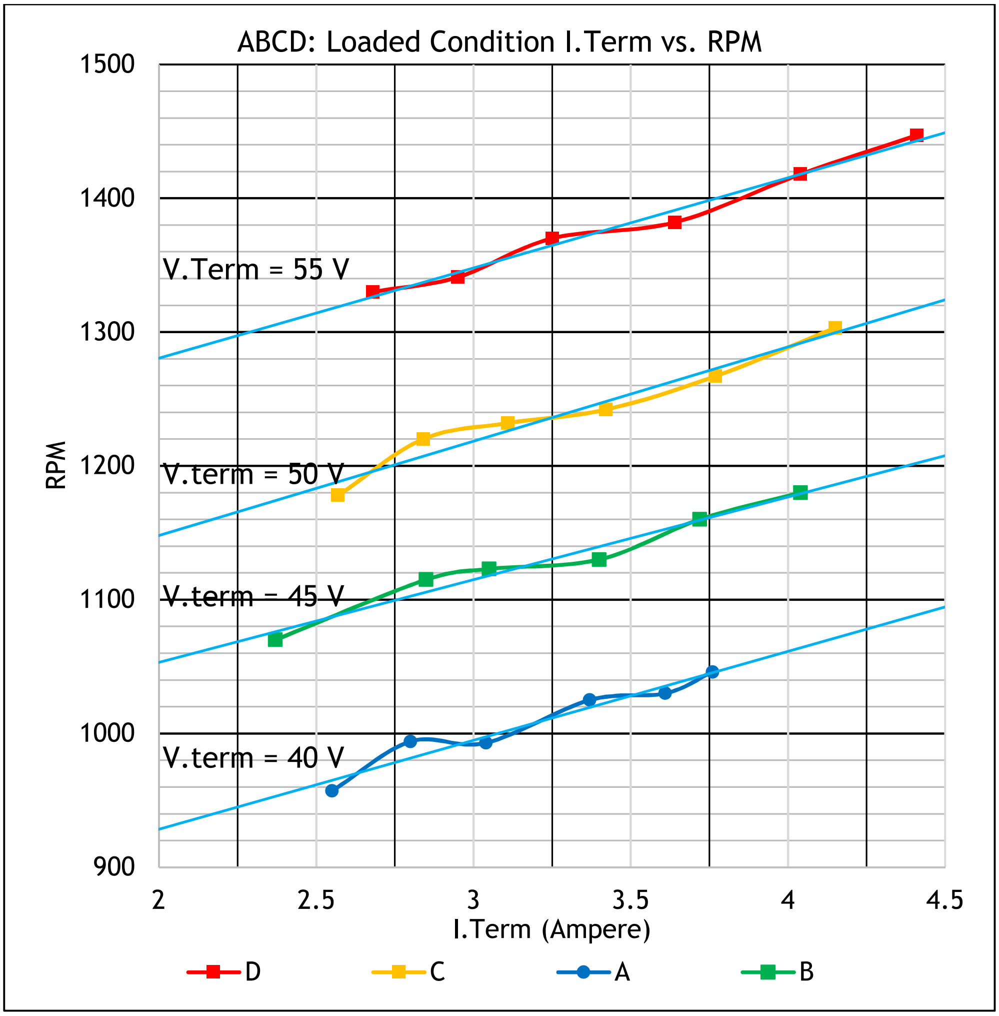


Figure 4.2. Loaded Condition I.term vs. RPM Graph (I.F 0.32 A)

Sequences from A to D, *Figure 4.2*shown different terminal voltage starting point with constant field current of 0.32 ampere. The input voltage increasing from 10 to 30 volt will deliver an increase of terminal voltage as shown in *Table 4.3*. Its condition represents in graph of terminal current (I.term) versus speed (RPM). Shown the I.term and RPM is increasing along with starting voltage condition. The light blue trendlines indicates the maximum error of served data collecting comes in scenario A 2nd point that shown 20 rpm above the trendlinelocated in 980 RPM. It marks 2% of error in scenario A operating condition.

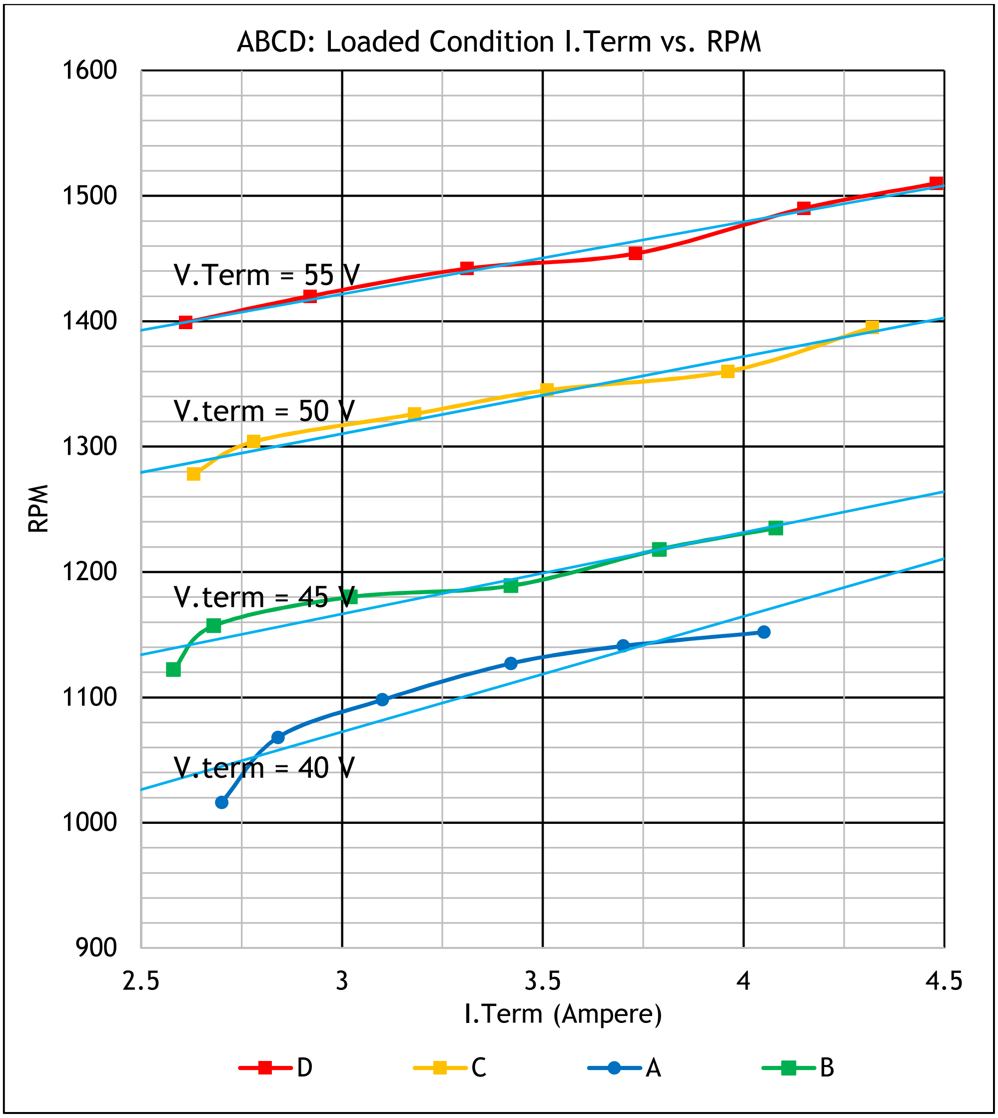


Figure 4.3. Loaded Condition I.term vs. RPM Graph (I.F 0.38 A)

Series from A to D, *Figure 4.3* shown different terminal voltage starting point with constant field voltage of 0.38 ampere. The input voltage increasing from 10 to 30 volt will deliver an increase of terminal voltage as shown in *Table 4.3*. Its condition represents in graph of terminal current (I.term) versus speed (RPM). Shown the I.term and RPM is increasing along with starting voltage condition. The light blue trendlines indicates the maximum error of served data collecting comes in scenario A 3rd point that shown 20 rpm above the trendlinelocated in 1080 RPM. It marks 1.85% of error in scenario A operating condition.

4.10. Loaded Condition Torque vs. RPM

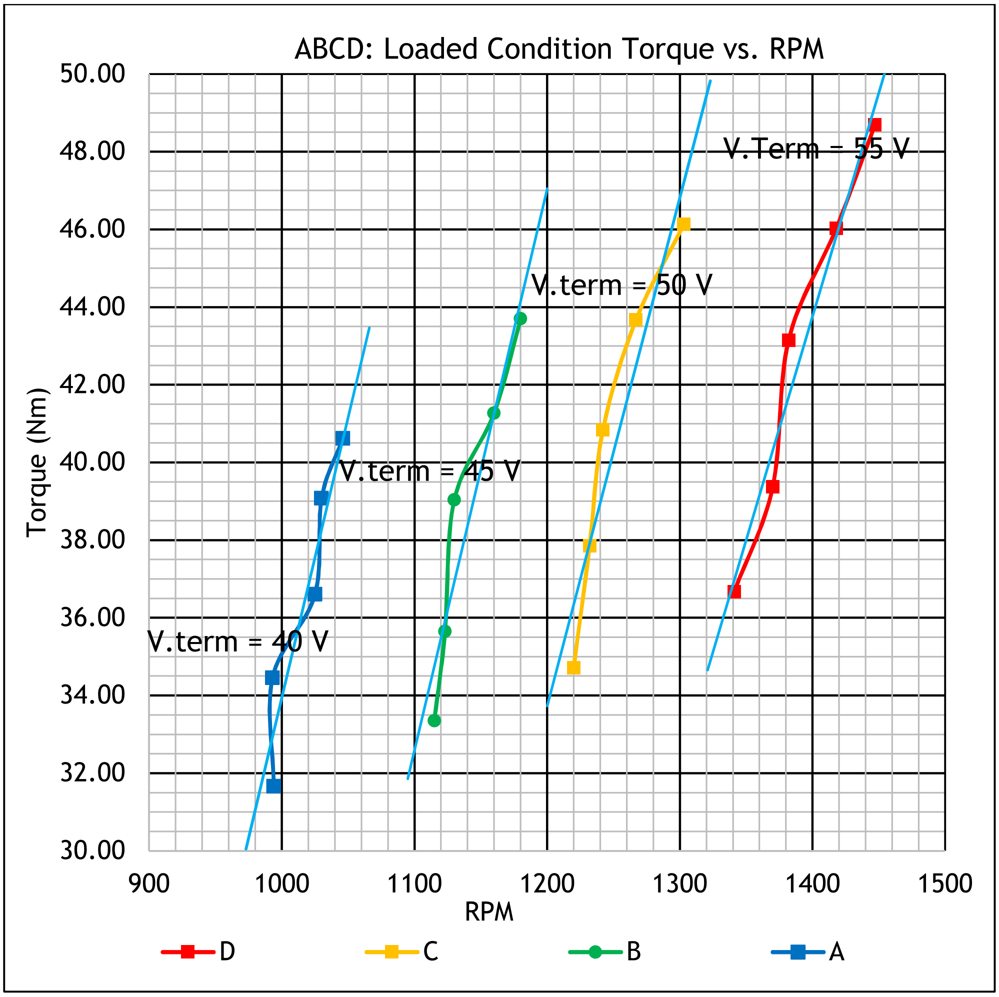


Figure 4.4. Loaded Condition Torque vs. RPM Graph (I.F 0.32 A)

Sequences from A to D, *Figure 4.*4shown different terminal voltage starting point with constant field voltage of 0.32 ampere. The input voltage increasing from 10 to 30 volt will deliver an increase of terminal voltage as shown in *Table 4.3*. Its condition represents in graph of terminal Torque (Nm) versus speed (RPM). Shown the torque and RPM is increasing along with starting voltage condition. The light blue trendlines indicates the maximum error of served data collecting comes in scenario B 3rd point that shown 2Nm above the trendlinelocated in37 Nm. It marks 5.4% of error in scenario B operating condition.

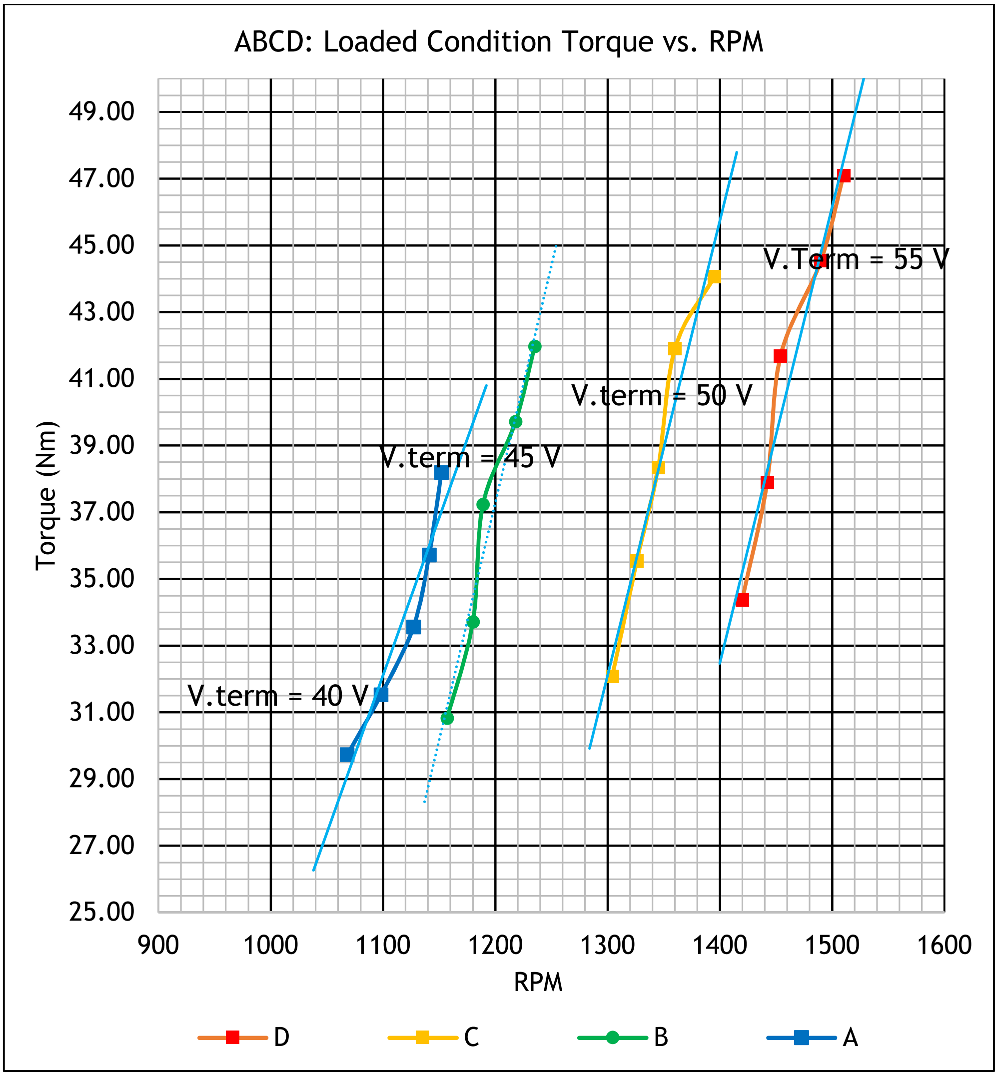


Figure 4.5. Loaded Condition Torque vs. RPM Graph (I.F 0.38 A)

Series from A to D, *Figure 4.5* shown different terminal voltage starting point with constant field voltage of 0.38 ampere. The input voltage increasing from 10 to 30 volt will deliver an increase of terminal voltage as shown in *Table 4.3*. Its condition represents in graph of terminal Torque (Nm) versus speed (RPM). Shown the torque and RPM is increasing along with starting voltage condition. The light blue trendlines indicates the maximum error of served data collecting comes in scenario C 4^{th} point that shown 1.5 Nm above the trendline located in 40.5 Nm. It marks 3.7% of error in scenario C operating condition.

4.11. LOADED CONDITION P.OUT VS. RPM

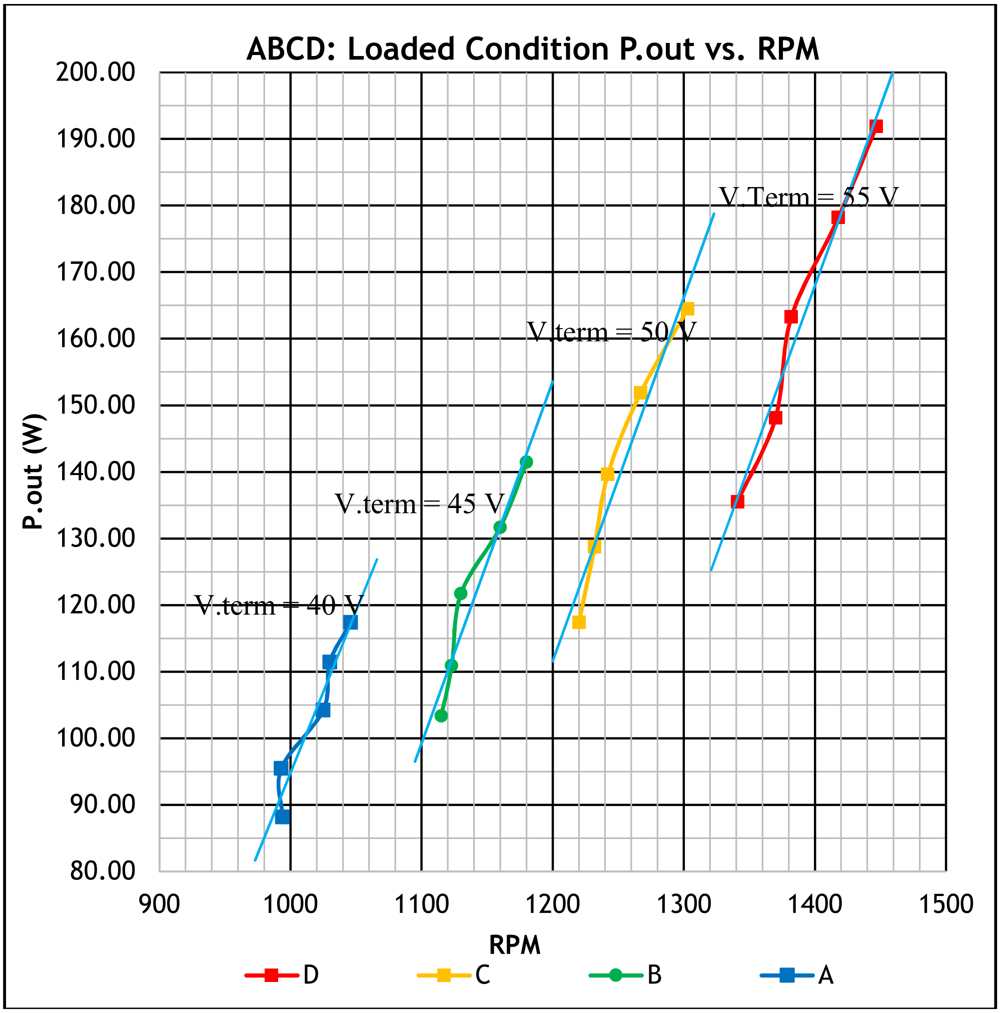


Figure 4.6. Loaded Condition P.out vs. RPM Graph (I.F 0.32 A)

Progression from A to D, *Figure 4.6*shown different terminal voltage starting point with constant field voltage of 0.32 ampere. The input voltage increasing from 10 to 30 volt will deliver an increase of terminal voltage as shown in *Table 4.3*. Its condition represents in graph of output power (W) versus speed (RPM). Shown the torque and RPM is increasing along with starting voltage condition. The light blue trendlines indicates the maximum error of served data collecting comes in scenario C 3^{rd} point that shown 7.5 watt above the trendline located in 132.5 watt. It marks 5.66% of error in scenario C operating condition.

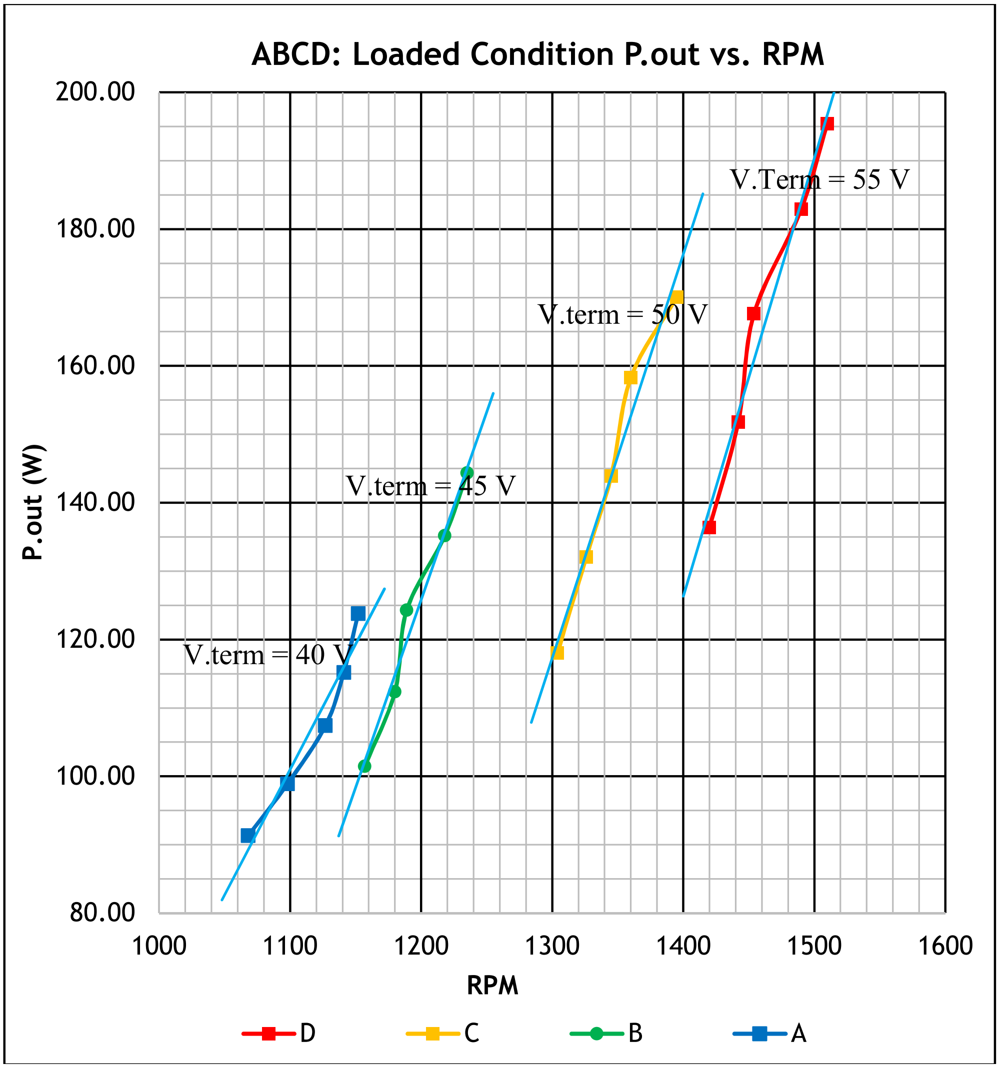


Figure 4.7. Loaded Condition P.out vs. RPM Graph (I.F 0.38 A)

Progression from A to D, *Figure 4.7*shown different terminal voltage starting point with constant field voltage of 0.38 ampere. The input voltage increasing from 10 to 30 volt will deliver an increase of terminal voltage as shown in *Table 4.3*. Its condition represents in graph of output power (W) versus speed (RPM). Shown the torque and RPM is increasing along with starting voltage condition. The light blue trendlines indicates the maximum error of served data collecting comes in scenario C 3rd point that shown 5 watt above the trendline located in 152.5 watt. It marks 3.28% of error in scenario C operating condition.

4.12. Motor Propeller Matching

4.12.1. Basic Principal Dimension

Modeling process of the propeller curve based on one specific vessel. It comes as an example just to show the representation of the DC motor characteristic due to the propeller curve. Hereby the technical specification of the vessel. The original detail of the vessel attached in the *Enclosure E*.

Table 4.10. Example Vessel Specification

TYPE: DRY BULK CARRIER		
Gross Tonnage	3980	ts
Net Tonnage	2474	ts
Displacement	8575	kt
DWT	6437.94	kt
Draught (T) Max.	6.98	m
Speed (v) Max.	12	knots
LOA	105.61	m
LPP	98.6	m
Breadth	16.33	m
Height	8.4	m
M/E BHP_{MCR}	3900	HP
M/E Speed	230	RPM
Propeller Blade	4	blades
Propeller Diameter	3.3	m

4.12.2. Propeller Curve

The motor propeller matching can be gain with the propeller curve and the motor envelope. The certain propeller curve is to be fitted to the motor envelope created with loaded condition P.out vs. RPM graph. The propeller curve is the summary of calculation which being calculated and fitted with assumption information of sister ship principal dimension. Shown below the propeller consideration and propeller curve constructed by P.out (BHP) vs. RPM graph.

Table 4.11. Propeller Consideration (Refer to Enclosure H)

Type	P / D_O	P / D_B	$1 / J_O$	$1 / J_B$	η_O	η_B	D_O (m)	D_B (m)	Power (HP)	Cavitation
B4-40	0.625	0.660	3.120	3.058	0.47	0.47	3.27	3.20	3657	10%
B4-55	0.625	0.670	3.110	2.240	0.47	0.47	3.26	3.19	3630	NO
B4-70	0.665	0.690	3.050	2.989	0.46	0.46	3.19	3.13	3709	NO
B4-85	0.710	0.740	2.960	2.901	0.44	0.43	3.10	3.04	3925	NO
B4-100	0.770	0.785	2.850	2.793	0.42	0.42	2.98	2.92	4047	NO

Table 4.12. B4-55 Propeller Curve Data (Refer to Enclosure I)

V_S (knots)	V_A (knots)	n_{PROP} (rps)	n_{ENG} (rpm)	K_Q	Q (kNm)	DHP (HP)	SHP (HP)	BHP_{SCR} (HP)	n_{ENG} (%)	BHP (%)
9	5.85	2.57	154	0.020	53	858	876	876	67	31
10	6.50	2.90	174	0.020	68	1238	1263	1263	76	44
11	7.15	3.28	197	0.021	88	1820	1857	1857	86	65
12	7.80	3.63	218	0.021	110	2500	2551	2551	95	89
13	8.45	4.12	247	0.022	146	3778	3855	3855	107	134

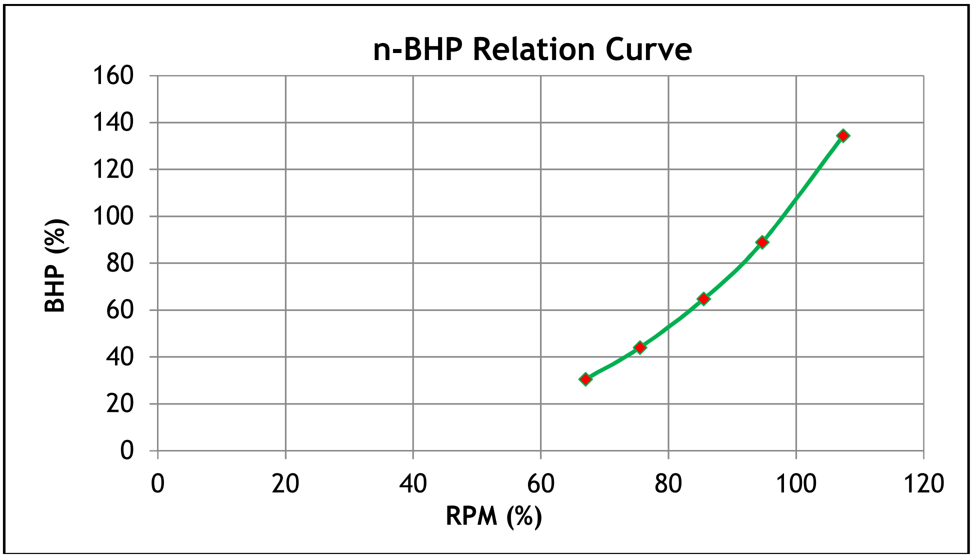


Figure 4.8. B4-55 Propeller Curve Graph

The graph above shown the BHP vs. RPM of the propeller in percentage value. Its value represents the comparison of certain point to its maximum capacity. It means each point is under 100% of power and RPM, but the highest (the top one) point show its position is above 100% of power and RPM capacity.

4.12.3. MATCHING DIMENSIONAL ANALYSIS

There is no ambiguity in propeller curve dimensional perspective. It is constructed by the power (kW) and speed (RPM) of its engine which shaped by its power demand in certain operating condition or load. Each point within the propeller curve based on the speed required comes along with specific resistance a torque required to be produced in it. Meanwhile, different point of view applied for the motor envelope. Its axis comes in the same way as propeller curve, but in different capacity. DC motor is not serving an information of its maximum capacity in field voltages 50 volts, neither 60 volts.

Its capacity is possible to be expand until its maximum field voltage and terminal voltage based on certain technical specification of the motor itself. Unlike the motor envelope, propeller curve has certain maximum value of percentages based on its maximum capacity of the engine driven. It is essential to assume the maximum point of each motor envelope, with field voltage 60 volts data as the highest point (100%) and field voltage 50 volts is in accordance to 60 volts as maximum percentage. Table below serves the sample of field voltage 60voltsassumption to gain percentages value of the motor envelope.

Table 4.13. Motor Envelope Percentages Assumption for V.F. 60 Volt

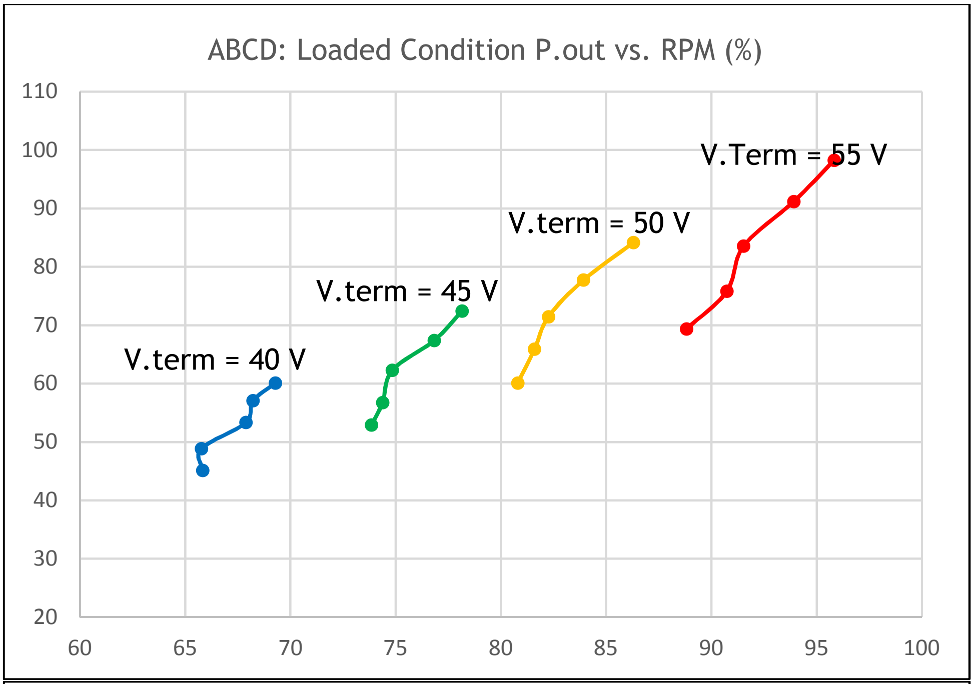
	A: V.Arm start 40		B: V.Arm start 45		C: V.Arm start 50		D: V.Arm start 55	
No.	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)
A-1	1068	91.32	1157	101.47	1304	118.01	1420	136.33
A-2	1098	98.90	1180	112.37	1326	132.05	1442	151.76
A-3	1127	107.42	1189	124.29	1345	143.89	1454	167.60
A-4	1141	115.18	1218	135.17	1360	158.25	1490	182.88
A-5	1152	123.78	1235	144.33	1395	170.09	1510	195.43

	A: V.Arm start 40		B: V.Arm start 45		C: V.Arm start 50		D: V.Arm start 55	
No.	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)
A-1	71	47	77	52	86	60	94	70
A-2	73	51	78	57	88	68	95	78
A-3	75	55	79	64	89	74	96	86
A-4	76	59	81	69	90	81	99	94
A-5	76	63	82	74	92	87	100	100

It can be seen that the highest point in certain constant field voltage is to be the maximum value of its percentages assumption. This condition creates the possibility to match the propeller curve and motor envelope in same dimensional condition, which in this specific case of laboratory state, is percentage of required power (kW) and speed of its main driver or motor (RPM). The graphical representation of the tables above is within the next sub-chapter named motor envelope.

4.12.4. Motor Envelope

The motor envelope developed from the variable of the calculated collected data of DC Motor. The loaded condition P.out vs. RPM graph can be represent in percentage value like shown in the figure below.



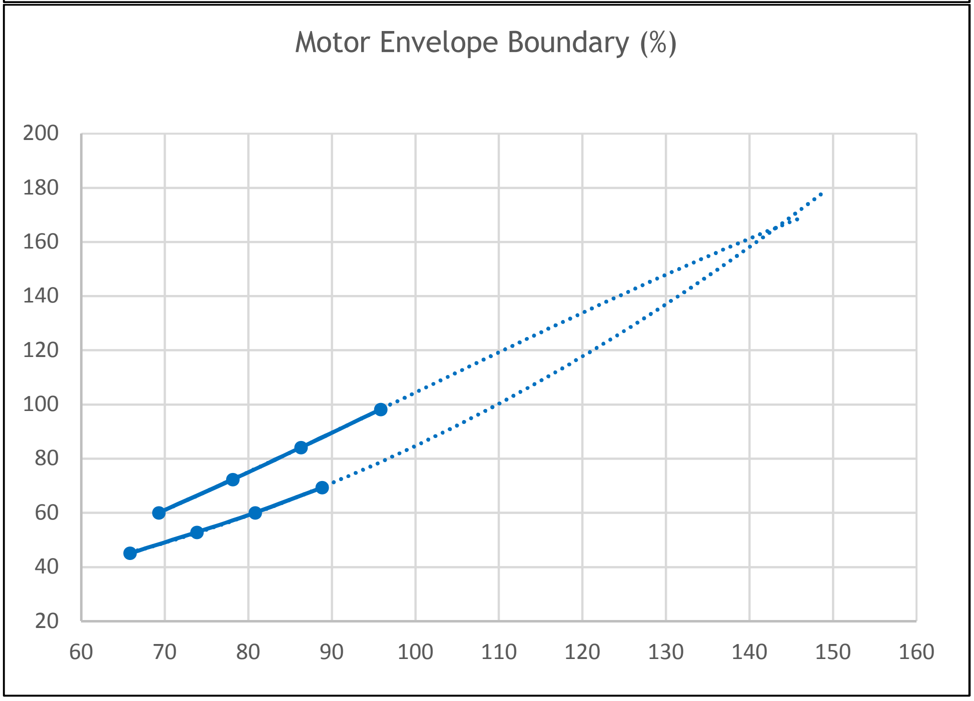
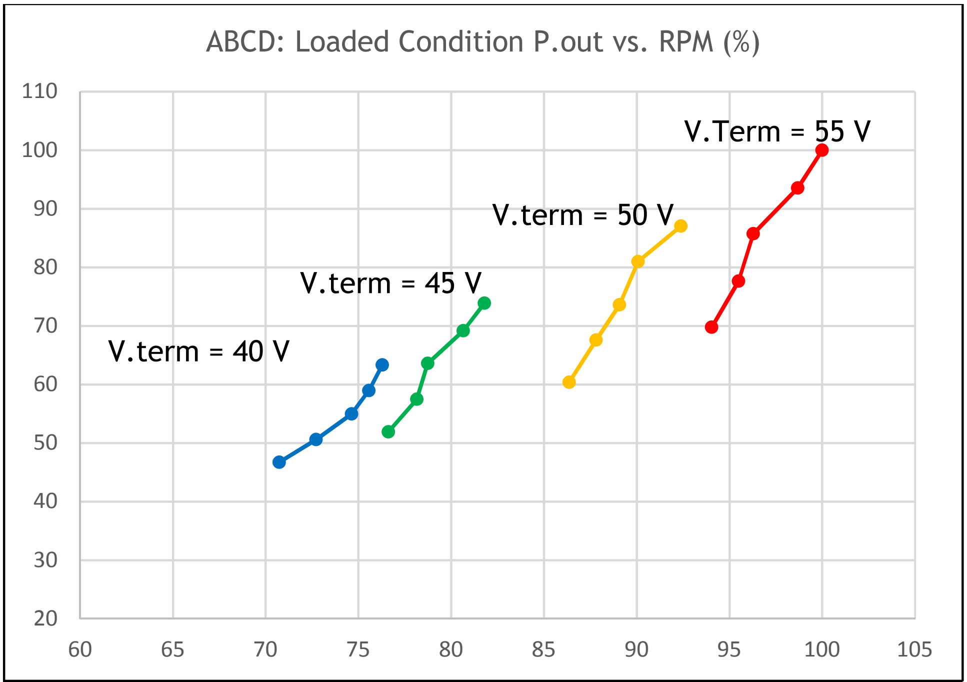


Figure 4.9. Loaded Condition P.out vs. RPM Graph (%) (V.F 50 V)



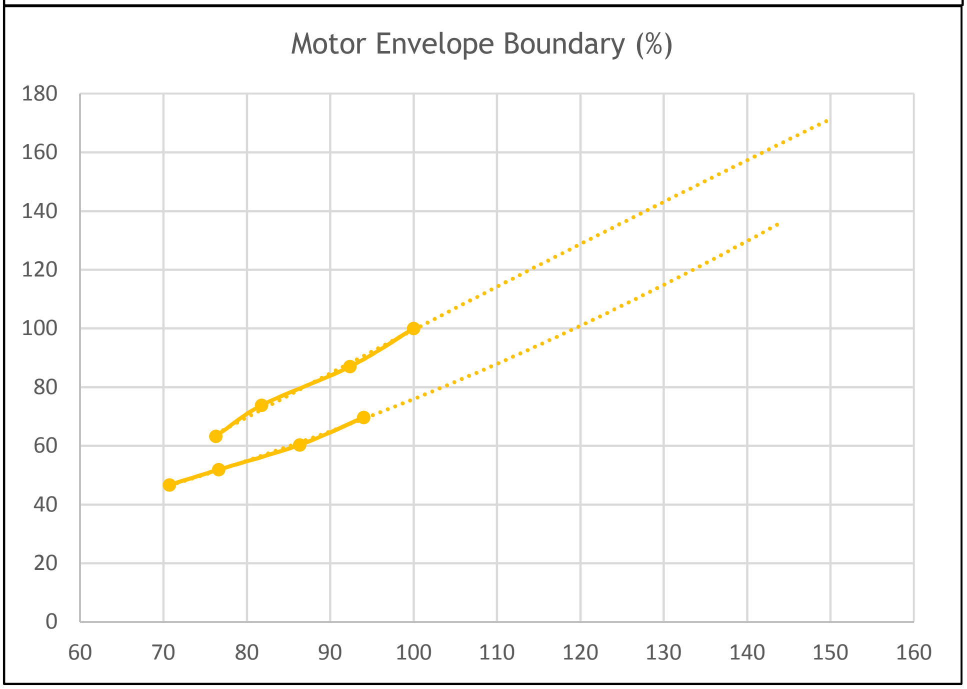


Figure 4.10. Loaded Condition P.out vs. RPM Graph (%) (V.F 60 V)

4.12.5. Matching Curve

The propeller curve is to be shaped to the motor envelope of field voltage 50 volt and 60 volt. Shown below the matching with those graph.

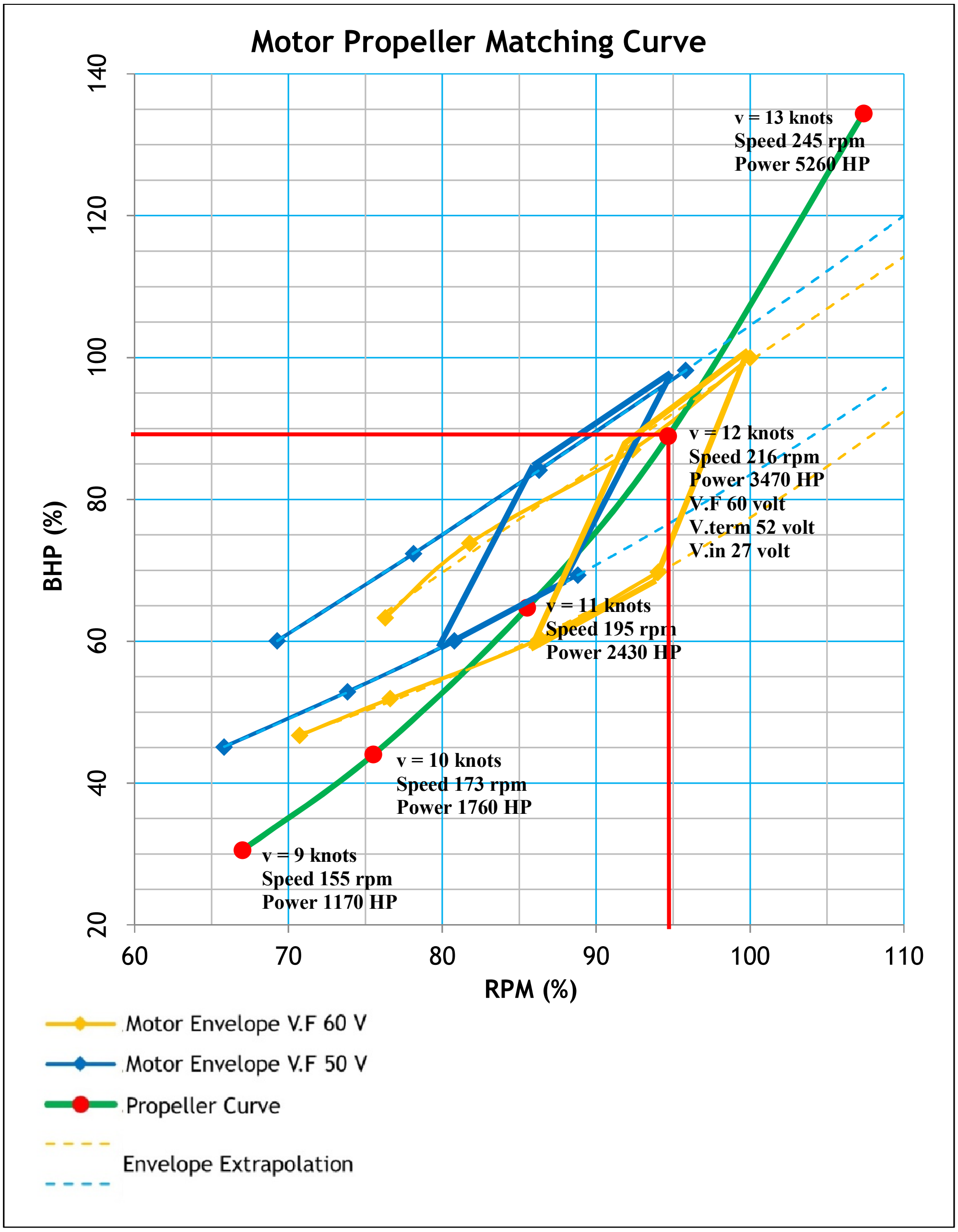


Figure 4.11. Motor Propeller Matching (I.F 0.32 and 0.38 A)

The motor envelope developed from the variable of the calculated The *Figure 4.11*shows the motor and propeller matching in percentage of speed (RPM) in X axis and rated power (kW) in Y axis. The percentage of speed and power of the motor comes from the comparison of the value of each point to collected data. It does not represent the 100% of the motor real power due to comparison purposes only.

Meanwhile, the percentage of speed and power of the propeller comes from the engine propeller matching calculation with an assumption ship particular data referred to one example of vessel. With condition of field voltage 60 volt as maximum and terminal voltage starting from 40 to 55 volt, propeller curve cross over certain section in motor envelope.

The orange area stands for 60 volt field voltage condition with constant current of 0.38 ampere and 30 volt input voltage. It can be seen the rated speed of the vessel in 12 knots is acceptable inside its operating area. Whilst the blue area stands for 50 volt field voltage condition. It comes in constant current of 0.32 ampere and 30 input voltage. One stop speed below rated speed, which define with 11 knots, is critically still within its operating area. The matching curve indicates that the certain propeller, in this case B4-55 is fitted in 60 volt field voltage operating area. It capable to serves the service speed of the vessel within around 12 knots.

The extension line in the graph is the trendline extrapolation of the motor envelope created by the pattern serves by the collected data with condition of field voltage of 50 volt and 60 volt and terminal voltage gradually from 40 until 55 volt.It shows the possible path created by the motor in constant field voltage and further increase of terminal voltage. It is legibly that the motor capable to serves until more than 110% or 20 points further in this field voltage condition. That condition would be acceptable for another types of propeller which carries different speed-power curve characteristic and or even same types of propeller in larger power demand.

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CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The task is to analyze the correlation of separately excited DC motor as main propulsion in engine propeller matching, or in this specific case named motor propeller matching. Within the laboratory scale, it combines the characteristic of DC motor merged to the product of engine propeller matching; the propeller curve.Using the perspective of dimensional, motor propeller matching can be acquired. It results an answer to the problem formulation of this study in the way of laboratory scale. Respective conclusion stated by these points below.

V.1.1. TORQUE CHARACTERISTIC OF DC MOTOR

Torque produced by the DC motor is in the same magnitude with the speed (RPM). The higher the speed have shaped the value of the torque.

V.1.2. TERMINAL VOLTAGE AND FIELD CURRENT AFFECT TO POWER AND SPEED OF DC MOTOR

The speed (RPM) itself is possible to be increase due to the addition of input voltage. It is in the same manner affect theterminal voltage (V.term) and field current (I.F). The current, whether terminal or field, regulated directly to its voltages. Whilst, the terminal and field current will change according to input voltage. Then, all magnitude of those variables will affect respectively the power. It can be explained by variables constructed the power is current and voltage, from both, terminal and field.

V.1.3. TORQUE GRAPHIC CHARACTERISTIC BETWEEN POWER AND RPM

Torque is the product of the speed (RPM), but in addition dependence to electromotive force (emf) and terminal current (I.term). The graphical result of torque vs. terminal current is likely in polynomial form. The same way with torque vs. RPM curve. Indeed, it is possible to comprehend the tendency of the torque vs. RPM to X^2 graphical representation. Besides, the torque vs. terminal current progression to linear curve. Torque versus RPM graph shown error in proportion its trendline curve. In the graph of 50 volt of field voltage and constant 0.32 ampere field current shows maximum error of 5.4%. Whilst 60 volt of field voltage and constant 0.38 ampere field current shows maximum error of 3.7%. It indicates the higher the field voltage in accordance to its maximum input voltage of operation, the lower the error acquired.

V.1.4. VARIABLE INPUTS IMPACTS THE GRAPHIC OF TORQUE CHARACTERISTIC BETWEEN POWER AND RPM

In the same manner as previous points stated. The input and terminal voltages adjusts all variables and results. In this study, different field voltage creates different pattern of motor envelope. Its manner to propeller curve occurs total different results. With field voltage of 50 volts, the ranges of motor envelope immoveable in the point of 150% of present speed and 160%. While field voltage of 60 volts serves larger ranges of motor envelope which possible to reach further than 50 volts curve. It concluded that the higher the field voltage, with the same input voltage, could produces different result due to the increasing of other variables, such as; current and voltage, of terminal and field. Noticed that the capacity of the motor in this study, laboratory scale, is much limited than actual study case scale. Apart from that condition, the extensive ranges of motor envelope or motor working condition area can affect the matching section with certain propeller curve based on certain propeller type.

5.2. RECOMMENDATION

Stands from this study results, followings are several recommendations for future possible research.

a. Actual study case based to gain an actual result of DC motor in DC network characteristic as main propulsion system.
b. The greater extent of terminal voltage and field current ranges in aim to gain a wider pattern of DC motor characteristic. It can be defines particular definition of error (bias) within the operation condition.
c. Another types of electric motor are strongly possible as the main object of characteristic analysis and comparability in respective of DC motor.

BIBLIOGRAPHY

Adji, Surjo, “Engine Propeller Matching”, ITS Resistance and Propulsion System Study Material, 2008

Chapman, Stephen, “Electric Machinery Fundamentals 5th Edition”, McGraw-Hill Higher Companies, ISBN 978-0-07-352954-7, New York, USA, 2005.

Doorduin, Willem, “The Use of Electric Motors for The Propulsion of Seagoing Vessels”, Rotterdam Mainport University of Applied Sciences (RMU), 2013

Fitzgerald, A. E.; Kingsley, Charles; &Umans, Stephen, “Electric Machinery 6th Edition”, McGraw-Hill Higher Education Publishing, ISBN 0-07-366009-4, New York, USA, 2003.

Hughes, Edward, “Electrical and Electronic Technology 10th Edition”, Pearson Education Inc., ISBN 978-0-13-206011-0, London, 2008.

Hughes, Austin, “Electrical Motors and Drives 3rd Edition”, Elsevier Ltd., ISBN 978-0-7506-4718-2, Oxford, 2006.

PT. Perusahaan PelayaranGurita Lintas Samudera, “MV. FITRIA PARAMITRA”, PT. Perusahaan PelayaranGurita Lintas Samudera,*glsship.com*, 2014.

Theraja, B. L.; Theraja, A. K.; &Tarnekar, S. G., “A Textbook of Electrical Technology Vol. I and II”, S Chand & Company Ltd., ISBN 81-219-2440-5, New Delhi, India, 2005.

Tupper, E. C., “Introduction to Naval Architecture 4th Edition”, Elsevier Ltd., ISBN 0-7506-6554-8, Oxford, 2004.

Wildi, Theodore, “Electrical Machines, Drives, and Power Systems 6th Edition”, Pearson Education Inc., ISBN 0-13-177693-2, New Jersey, 2006.

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ENCLOSURE A

ZERO LOAD CONDITION DATA COLLECTION (FIELD VOLTAGE: 50 V and 60 V)

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Table E.A.1. Zero Load Condition (V.F 50 V)

Zero Load Condition						
Con.	V.F (V)	I.Arm (A)	I.F (A)	RPM	Varm (V)	V.in (V)
A	50	2.61	0.32	957	40	10~30
B	50	2.37	0.32	1070	45	10~30
C	50	2.57	0.32	1178	50	10~30
D	50	2.68	0.32	1330	55	10~30

Table E.A.2. Zero Load Condition (V.F 60 V)

Zero Load Condition						
Con.	V.F (V)	I.Arm (A)	I.F (A)	RPM	Varm (V)	V.in (V)
A	60	2.7	0.37	1016	40	10~30
B	60	2.58	0.38	1122	45	10~30
C	60	2.63	0.37	1278	50	10~30
D	60	2.61	0.38	1399	55	10~30

The table above providing proportion information to construct *Table 4.2* within the report.

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ENCLOSURE B

LOADED CONDITION DATA COLLECTION AND POST CALCULATION (FIELD VOLTAGE: 50 V)

Table E.A.3. Loaded Condition Scenario A (V.F 50 V)

A: Loaded Condition (V.Arm starting 40, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.55	0.32	40	50
A-1	10	0.1	2.8	0.32	41	50
A-2	15	0.1	3.04	0.32	42	50
A-3	20	0.2	3.37	0.32	43	50
A-4	25	0.2	3.61	0.32	44	50
A-5	30	0.2	3.76	0.32	45	50

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	957	0	0	0	0
A-1	10	994	130.80	11.2	31.36	11.26
A-2	15	993	143.68	12.16	36.97	11.26
A-3	20	1025	160.91	13.48	45.43	11.26
A-4	25	1030	174.84	14.44	52.13	11.26
A-5	30	1046	185.20	15.04	56.55	11.26

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	29.80	31.66	2.64	88.18	67.4%
A-2	15	29.84	34.45	2.63	95.45	66.4%
A-3	20	29.52	36.60	2.72	104.22	64.8%
A-4	25	29.56	39.07	2.73	111.45	63.7%
A-5	30	29.96	40.62	2.77	117.39	63.4%

The table above providing essential information to construct *Figure 4.2*, *Figure 4.4, and Figure 4.6*within the report.

Table E.A.4. Loaded Condition Scenario B (V.F 50 V)

B: Loaded Condition (V.Arm starting 45, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.37	0.32	45	50
A-1	10	0.13	2.85	0.32	46	50
A-2	15	0.2	3.05	0.32	47	50
A-3	20	0.28	3.4	0.32	48	50
A-4	25	0.38	3.72	0.32	49	50
A-5	30	0.42	4.04	0.32	50	50

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	Ia^2.Ra	If^2.Rf
A-0	0	1070	0	0	0	0
A-1	10	1115	147.10	11.4	32.49	11.26
A-2	15	1123	159.35	12.2	37.21	11.26
A-3	20	1130	179.20	13.6	46.24	11.26
A-4	25	1160	198.28	14.88	55.35	11.26
A-5	30	1180	218.00	16.16	65.29	11.26

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	34.60	33.35	2.96	103.35	70.3%
A-2	15	34.80	35.65	2.98	110.88	69.6%
A-3	20	34.40	39.04	3.00	121.70	67.9%
A-4	25	34.12	41.27	3.08	131.66	66.4%
A-5	30	33.84	43.70	3.13	141.45	64.9%

The table above providing essential information to construct *Figure 4.2*, *Figure 4.4, and Figure 4.6*within the report.

Table E.A.5. Loaded Condition Scenario C (V.F 50 V)

C: Loaded Condition (V.Arm starting 50, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.57	0.3	50	50
A-1	10	0.1	2.84	0.3	50.9	50
A-2	15	0.17	3.11	0.3	52.2	50
A-3	20	0.23	3.42	0.3	53	50
A-4	25	0.29	3.77	0.3	54	50
A-5	30	0.31	4.15	0.3	55	50

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	1178	0	0	0	0
A-1	10	1220	159.56	11.36	32.26	9.90
A-2	15	1232	177.34	12.44	38.69	9.90
A-3	20	1242	196.26	13.68	46.79	9.90
A-4	25	1267	218.58	15.08	56.85	9.90
A-5	30	1303	243.25	16.6	68.89	9.90

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	39.54	34.71	3.23	117.39	73.6%
A-2	15	39.76	37.85	3.27	128.75	72.6%
A-3	20	39.32	40.83	3.29	139.57	71.1%
A-4	25	38.92	43.68	3.36	151.83	69.5%
A-5	30	38.40	46.13	3.45	164.46	67.6%

The table above providing essential information to construct *Figure 4.2*, *Figure 4.4, and Figure 4.6*within the report.

Table E.A.6. Loaded Condition Scenario D (V.F 50 V)

D: Loaded Condition (V.Arm starting 55, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.68	0.3	55	50
A-1	10	0.13	2.95	0.3	56	50
A-2	15	0.21	3.25	0.3	57	50
A-3	20	0.29	3.64	0.3	58	50
A-4	25	0.36	4.04	0.3	59	50
A-5	30	0.44	4.41	0.3	60	50

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	1330	0	0	0	0
A-1	10	1341	180.20	11.8	34.81	9.90
A-2	15	1370	200.25	13	42.25	9.90
A-3	20	1382	226.12	14.56	53.00	9.90
A-4	25	1418	253.36	16.16	65.29	9.90
A-5	30	1447	279.60	17.64	77.79	9.90

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	44.20	36.67	3.56	135.49	75.2%
A-2	15	44.00	39.37	3.63	148.10	74.0%
A-3	20	43.44	43.15	3.66	163.22	72.2%
A-4	25	42.84	46.03	3.76	178.17	70.3%
A-5	30	42.36	48.69	3.84	191.91	68.6%

The table above providing essential information to construct *Figure 4.2*, *Figure 4.4, Figure 4.6, and Figure 4.9*within the report.

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ENCLOSURE C

LOADED CONDITION DATA COLLECTION AND POST CALCULATION (FIELD VOLTAGE: 60 V)

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Table E.A.7. Loaded Condition Scenario A (V.F 60 V)

A: Loaded Condition (V.Arm starting 40, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.7	0.37	40	60
A-1	10	0.2	2.84	0.37	41	60
A-2	15	0.1	3.1	0.37	42	60
A-3	20	0.2	3.42	0.37	43	60
A-4	25	0.2	3.7	0.37	44	60
A-5	30	0.2	4.05	0.37	45	60

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	1016	0	0	0	0
A-1	10	1068	138.64	11.36	32.26	15.06
A-2	15	1098	152.40	12.4	38.44	15.06
A-3	20	1127	169.26	13.68	46.79	15.06
A-4	25	1141	185.00	14.8	54.76	15.06
A-5	30	1152	204.45	16.2	65.61	15.06

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	29.64	29.73	2.83	91.32	65.9%
A-2	15	29.60	31.52	2.91	98.90	64.9%
A-3	20	29.32	33.56	2.99	107.42	63.5%
A-4	25	29.20	35.71	3.03	115.18	62.3%
A-5	30	28.80	38.19	3.05	123.78	60.5%

The table above providing essential information to construct *Figure 4.3*, *Figure 4.5, and Figure 4.7*within the report.

Table E.A.8. Loaded Condition Scenario B (V.F 60 V)

B: Loaded Condition (V.Arm starting 45, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.58	0.38	45	60
A-1	10	0.2	2.68	0.38	46	60
A-2	15	0.26	3.02	0.38	47	60
A-3	20	0.29	3.42	0.38	48	60
A-4	25	0.39	3.79	0.38	49	60
A-5	30	0.44	4.08	0.38	50	60

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	1122	0	0	0	0
A-1	10	1157	146.08	10.72	28.73	15.88
A-2	15	1180	164.74	12.08	36.48	15.88
A-3	20	1189	186.96	13.68	46.79	15.88
A-4	25	1218	208.51	15.16	57.46	15.88
A-5	30	1235	226.80	16.32	66.59	15.88

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	35.28	30.82	3.07	101.47	69.5%
A-2	15	34.92	33.71	3.13	112.37	68.2%
A-3	20	34.32	37.23	3.15	124.29	66.5%
A-4	25	33.84	39.71	3.23	135.17	64.8%
A-5	30	33.68	41.96	3.27	144.33	63.6%

The table above providing essential information to construct *Figure 4.3*, *Figure 4.5, and Figure 4.7*within the report.

Table E.A.9. Loaded Condition Scenario C (V.F 60 V)

C: Loaded Condition (V.Arm starting 50, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.63	0.37	50	60
A-1	10	0.07	2.78	0.37	51	60
A-2	15	0.13	3.18	0.37	52	60
A-3	20	0.18	3.51	0.37	53	60
A-4	25	0.25	3.96	0.37	54	60
A-5	30	0.31	4.32	0.37	55	60

No.	V.in (V)	RPM	P.in (W)	Ia.Ra	Ia^2.Ra	If^2.Rf
A-0	0	1278	0	0	0	0
A-1	10	1304	163.98	11.12	30.91	15.06
A-2	15	1326	187.56	12.72	40.45	15.06
A-3	20	1345	208.23	14.04	49.28	15.06
A-4	25	1360	236.04	15.84	62.73	15.06
A-5	30	1395	259.80	17.28	74.65	15.06

No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	39.88	32.06	3.46	118.01	72.0%
A-2	15	39.28	35.53	3.52	132.05	70.4%
A-3	20	38.96	38.35	3.57	143.89	69.1%
A-4	25	38.16	41.91	3.61	158.25	67.0%
A-5	30	37.72	44.05	3.70	170.09	65.5%

The table above providing essential information to construct *Figure 4.3*, *Figure 4.5, and Figure 4.7*within the report.

Table E.A.10. Loaded Condition Scenario C (V.F 60 V)

D: Loaded Condition (V.Arm starting 55, V.F constant in 50 V)						
No.	V.in (V)	I.L (A)	I.Arm (A)	I.F (A)	V.Arm (V)	V.F (V)
A-0	0	0	2.61	0.38	55	60
A-1	10	0.14	2.92	0.38	56	60
A-2	15	0.29	3.31	0.38	57	60
A-3	20	0.29	3.73	0.38	58	60
A-4	25	0.36	4.15	0.38	59	60
A-5	30	0.43	4.48	0.38	60	60
No.	V.in (V)	RPM	P.in (W)	Ia.Ra	$Ia^2.Ra$	$If^2.Rf$
A-0	0	1399	0	0	0	0
A-1	10	1420	186.32	11.68	34.11	15.88
A-2	15	1442	211.47	13.24	43.82	15.88
A-3	20	1454	239.14	14.92	55.65	15.88
A-4	25	1490	267.65	16.6	68.89	15.88
A-5	30	1510	291.60	17.92	80.28	15.88
No.	V.in (V)	Ea (W)	Torque (Nm)	RPS	P.out (W)	Efficiency
A-0	0	0	0	0	0	0
A-1	10	44.32	34.37	3.77	136.33	73.2%
A-2	15	43.76	37.88	3.82	151.76	71.8%
A-3	20	43.08	41.68	3.86	167.60	70.1%
A-4	25	42.40	44.54	3.95	182.88	68.3%
A-5	30	42.08	47.09	4.00	195.43	67.0%

The table above providing essential information to construct *Figure 4.3*, *Figure 4.5, Figure 4.7, and Figure 4.10*within the report.

ENCLOSURE D

MOTOR ENVELOPE PERCENTAGE ASSUMPTION (FIELD VOLTAGE: 50 V and 60 V)

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Table E.A.11. Motor Envelope Percentage Assumption (V.F 50 V)

	A: V.Arm start 40		B: V.Arm start 45		C: V.Arm start 50		D: V.Arm start 55	
No.	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)
A-1	994	88.18	1115	103.35	1220	117.39	1341	135.49
A-2	993	95.45	1123	110.88	1232	128.75	1370	148.10
A-3	1025	104.22	1130	121.70	1242	139.57	1382	163.22
A-4	1030	111.45	1160	131.66	1267	151.83	1418	178.17
A-5	1046	117.39	1180	141.45	1303	164.46	1447	191.91

	A: V.Arm start 40		B: V.Arm start 45		C: V.Arm start 50		D: V.Arm start 55	
No.	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)
A-1	66	45	74	53	81	60	89	69
A-2	66	49	74	57	82	66	91	76
A-3	68	53	75	62	82	71	92	84
A-4	68	57	77	67	84	78	94	91
A-5	69	60	78	72	86	84	96	98

Table E.A.12. Motor Envelope Percentage Assumption (V.F 60 V)

	A: V.Arm start 40		B: V.Arm start 45		C: V.Arm start 50		D: V.Arm start 55	
No.	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)
A-1	1068	91.32	1157	101.47	1304	118.01	1420	136.33
A-2	1098	98.90	1180	112.37	1326	132.05	1442	151.76
A-3	1127	107.42	1189	124.29	1345	143.89	1454	167.60
A-4	1141	115.18	1218	135.17	1360	158.25	1490	182.88
A-5	1152	123.78	1235	144.33	1395	170.09	1510	195.43

	A: V.Arm start 40		B: V.Arm start 45		C: V.Arm start 50		D: V.Arm start 55	
No.	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)	RPM	P.out (W)
A-1	71	47	77	52	86	60	94	70
A-2	73	51	78	57	88	68	95	78
A-3	75	55	79	64	89	74	96	86
A-4	76	59	81	69	90	81	99	94
A-5	76	63	82	74	92	87	100	100

The table above providing essential information to construct *Figure 4.9 and Figure 4.10*within the report.

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ENCLOSURE E

ASSUMED VESSEL SPECIFICATION

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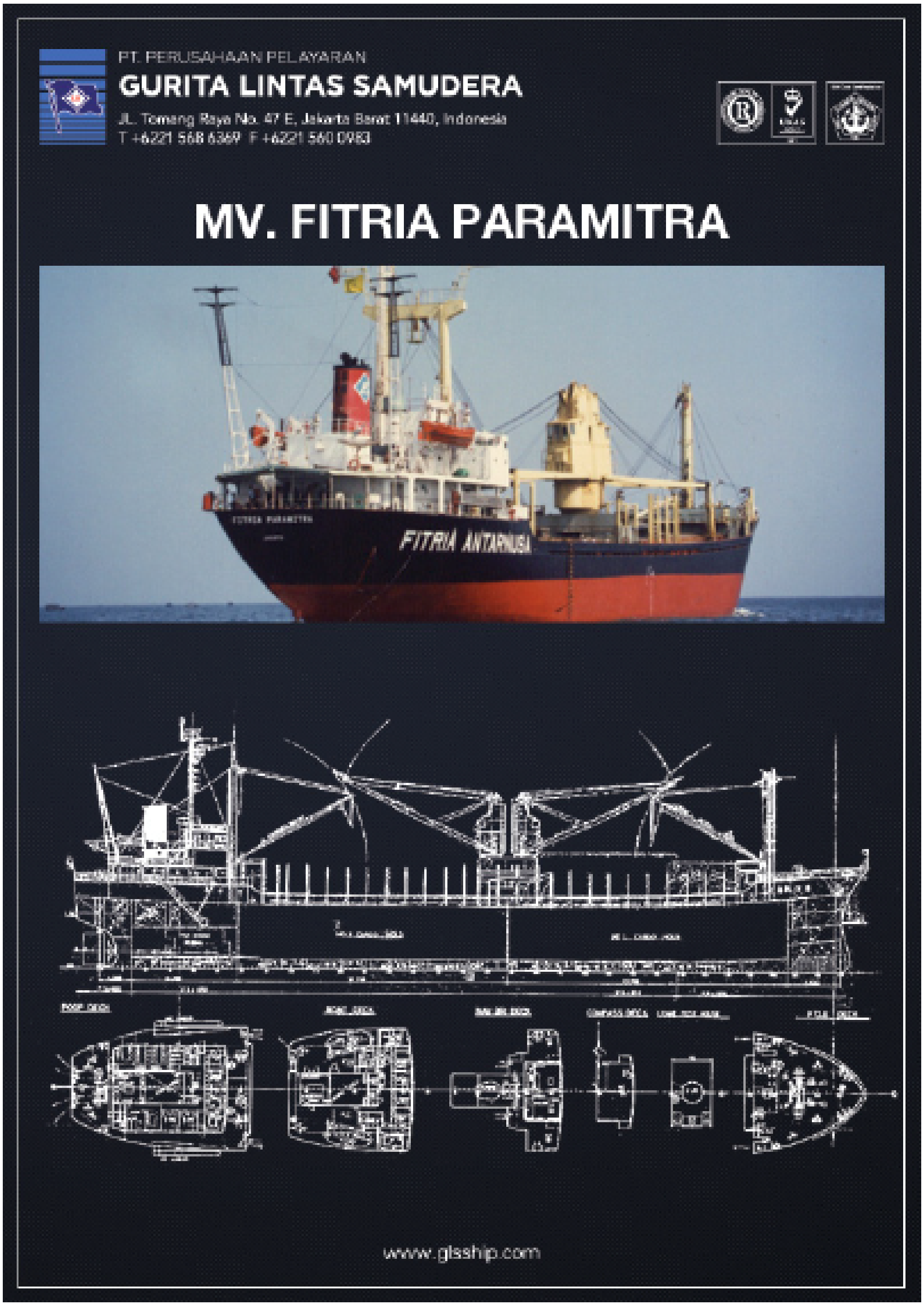

Figure E.A.1. MV. FitriaParamitra (*glsship.com*)

Table E.A.13. MV. FitriaParamitra General Specification

Name of vessel		: **MV. FITRIA PARAMITRA**
Nationality		: Indonesia
Official Number		: 1997 Ba. No. 959 / L
Port of Registry		: Jakarta
Call Sign		: Y F P B
When Build		: 1983
Builder		: Nishi Ship Building Co. Ltd Japan
Material		: Steel
Gross Tonnage		: 3980 ts
Net Tonnage		: 2474 ts
Displacemet		: 8575.00 kt
Dead Weight All Told		: 6437.94 kt
DWCC		5800.00 kt
Grain Space	#1	: 4284.42 m3
Grain Space	#2	: 4004.75 m3
Total		: 8527.96 m3
Bale Space	#1	: 4049.67 m3
Bale Space	#2	: 4004.75 m3
Total		: 8054.42 m3
Draft Maximum		: 6980 m
Speed		: abt 12 knots
Consumption		
MFO		: 9.0 ts
MDO at Sea		: 0.80 ts / day / at Sea
MDO at Port		: 1.20 ts / day / at Port
Length Over All		105.61 m
Length Between Perpendicular		: 98.60 m
Breadth		: 16.33 m
Depth		: 8.40 m
Deck		: SINGLE
Bulkheads		: THREE (3)
Holds		: TWO (2)
Hatches Dimensions #1		: 27.25 m x 8.40 m x 1 m
all hatches Pontoon #2		: 28.60 m x 8.40 m x 1 m
Holds Dimensions #1		37.15 m x 15.80 m x 7 m
Holds Dimensions #2		: 35.75 m x 15.80 m x 7 m
Class Character		: BKI

Table E.A.14. MV. FitriaParamitra Technical Specification

INMARSAT-C ID No.	: 452500032	
IMO Number	: 8313099	
Derricks	: 25 ts x 2 set 15 ts x 2 set	
Main Engine	: Mitsubishi Akasaka 6UEC 37/88 H	
M/E Dimension	: 450 MM x 850 MM x 6Cyl	
Brake Horse power	: 3900 PS	
RPM	: 230 Rpm	
Maker	: Akasaka Diesel Co. Ltd	
When Made	: 1983, Japan	
Auxiliary Engine	: Yanmar 6 RAL-T	
Generator AC	: 445 Volt x 60C/S x 200 KVA x 1200 RPM x 2 set	
Propeller		
Number of Blade	: 4 (four)	
Material	: Manganese Bonze (Cast)	
Diametre	: 3.300 mm	
Pitch	: 2.267 mm	
Maker	: Ichihaci Propeller	
When Made	: July, 12nd 1983	
Boiler	: Composide System, Hort Exhauset Gas Tube	
Number	1 (one) Set	
Heating Surface	:	
Working Pressure	: 8.0 kg/cm2	
Fuel	: Heavy Fuel	
Maker	: Nishida Marine Boller	
When Made	: May, 17 1983	
Life Boat	: Two (2) sets	
No. of Person	: 25 Person	
Nav. Equipment	: Gyro Compass Auto Pilot Radars of Eleclog Echo Sounder Loran Fax Rec NSD-1585	
Capacity of Cargo Hold	Capacity	
	CBM	CF
BALE		
#1 Hold & Hatch ; Length 37.15 m	4049.67	143014.09
#2 Hold & Hatch ; Length 35.75 m	4004.75	141427.74
Total	8054.42	284441.83
GRAIN		
#1 Hold & Hatch ; Length 37.15 m	4284.42	151304.29
#2 Hold & Hatch ; Length 35.75 m	4243.54	143860.61
Total	8527.96	301164.9

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ENCLOSURE F

ASSUMED VESSEL RESISTANCE CALCULATION (SERVICE SPEED 12 KNOTS)

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PRINCIPLE DIMENSION (DRY BULK CARRIER: MV. FITRIA PARAMITRA)						
Length Between Perpendicular	L_{PP}	98.6	m	=	323.487	ft
Length of Waterline	L_{WL}	101.6	m	=	333.329	ft
Breadth Moulded	B	16.33	m	=	53.5755	ft
Depth Moulded	H	8.4	m	=	27.5587	ft
Draught	T	6.98	m	=	22.9	ft
Ship Speed	V_S	12	knots	=	6.17336	m/s
Volume Displacement (Simpson)	▼	8575	m^3			
Mass Displacement	▲	8789	ton			
Waterplane Area Coefficient	C_{WP}	0.8	(assumed from Introduction to Naval Architecture 4th Ed., 1975, pp. 37)			
Block Coefficient	C_B	0.8	(assumed from Introduction to Naval Architecture 4th Ed., 1975, pp. 37)			
Midship Coefficient	C_M	0.98	(assumed from Introduction to Naval Architecture 4th Ed., 1975, pp. 37)			
Prismatic Coefficient (Longitudal)	C_P	0.8	(assumed from Introduction to Naval Architecture 4th Ed., 1975, pp. 37)			
Prismatic Coefficient (Vertical)	C_P	0.8	(assumed from Introduction to Naval Architecture 4th Ed., 1975, pp. 37)			

RESISTANCE AND POWER CALCULATION

Wet Surface Area

$$S = 1.025 \cdot L_{PP} \cdot ((C_B \cdot B) + (1.7 \cdot T)) \quad (m^2)$$
$$= 2519.55 \quad m^2$$

Sv.Aa.Harvald, Ship Resistance and Propulsion; page133

Froude Number and Reynold Number

$$F_N = V_S / \sqrt{(g \cdot L_{WL})} = 0.196$$

where $g = 9.81$ m/s

$$R_N = V_S \cdot L_{WL} / v = 3.33E+08$$

where $v = 1.8831E-06$ m^2/s

Frictional Coefficient

This coefficient shall be include in calculation given that friction produced by the hull and water contact resistance can not negligible.

$$C_F = 0.075 / (\text{Log } R_N - 2)^2 = 0.0018$$

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.119

Residual Coefficient

This coefficient should be include in calculation given that the wave resistance can not negligible.
(in actual condition, residual resistance consist of wave resistance and viscosity resistance)

$$L_{WL} / ▼^{1/3} = 4.96381589$$

The value of L_{WL} / $▼^{1/3}$ is not in the guldhammer diagram, the result can be found with interpolation.

L_{WL} / $▼^{1/3}$	10^3 C_R
4.5	1.6
4.964	**1.42375**
5	1.41

with v/(L^1/2) 0.667

$$10^3 C_R = 1.42374996$$
$$C_R = 0.001424$$

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.120-128

B / T Correction

B / T = 2.33954155

The *guldhammer method* require B / T ratio equal to 2.5, in this case correction is needed.

C_R Correction: $10^3 C_{R2}$ = $10^3 C_R + (0.16 \cdot ((B / T) - 2.5) / 1000)$
= 1.424
C_{R2} = 0.001

Ship Body Correction

Residual coefficient cam be increase in full loaded ship approximately 3-5%

C_R Correction: $10^3 C_{R3}$ = C_{R2} + (3% C_{R2})
= 0.00147

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.131-132

Additional Resistance Coefficient

This coefficient should be include in calculation given that the hull roughness can not negligible.

$10^3 C_A$ = 0.16
C_A = 0.00016

L_{PP} (m)	$10^3 C_A$
<100	0.4
150	0.2
160	0.16
200	0

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.132

Additional Wind Resistance Correction

This coefficient shall be include in calculation given that the wind resistance can be negligible.

C_{AA} = 0.00007

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.132

Additional Rudder Resistance Correction

This coefficient shall be include in calculation given that the rudder resistance can be negligible.

C_{AS} = 0.00004

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.132

Total Resistance

Total resistance means total force against the force to produce ship speed.

		%
C_F	0.0018	50.378
C_{R3}	0.0015	41.906
C_A	0.0002	4.572
C_{AA}	0.0001	2.000
C_{AS}	0.0000	1.143
C_{TOTAL}	0.0035	100

R_T = $0.5 \cdot \rho \cdot V_S^2 \cdot S \cdot C_{TOTAL}$ (Newton) (with ρ = 1025 kg/m^3)
= 172205.191 Newton
= 172.205191 kNewton

$R_{T\text{-service}}$ = R_T + (10-20%) $\cdot R_T$ (Newton)
= R_T + (10%) $\cdot R_T$ (Newton)
= 189425.7 Newton
= 189.426 kNewton

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.132

$C_{T\text{-service.12}}$ = C_T + (10%) $\cdot C_T$
= 0.00384927

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ENCLOSURE G

ASSUMED VESSEL REQUIRED POWER CALCULATION (SERVICE SPEED 12 KNOTS)

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Effective Horse Power (EHP)

Effective horse power means power need to produce ship speed.

EHP	=	$R_{T\text{-service}} \cdot V_S$	(Watt)	
	=	1169393.86	W	(1 HP = 0.7355 kW)
	=	1169.394	kW	(1 kW = 1.3596 HP)
	=	1589.90789	HP	

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.135

Wake Friction (w)

Wake fraction means comparison between ship speed and water speed to the propeller.

$w = 0.5\ C_B - 0.05$

$= 0.35$

Van Lammeren, Resistance, Propulsion, and Steering of Ships; page 178

Thrust Deduction Factor (t)

$t = k \cdot w$

$= (0.7\text{-}0.9) \cdot w$

$= (0.76) \cdot w$

$= 0.266$

Principle of Naval Architecture; page 158

Hull Efficiency (η_H)

$\eta_H = (1 - t) / (1 - w)$

$= 1.12923$

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.136

Relative Rotative Efficiency (η_{RR})

Relative Rotative Efficieny for single screw propeller located between 1 to 1.1.

$\eta_{RR} = 1.05$

Principle of Naval Architecture; page 152

Propulsion Efficiency (η_O)

Propulsion efficiency means the efficiency of the propeller in open water test. (the value assumed)

$\eta_O = 0.55$

Propulsve Coefficient (Pc)

$Pc = \eta_H \cdot \eta_{RR} \cdot \eta_O$

$= 0.65450$

Delivery Horse Power (DHP)

Effective horse power means power delivered to propeller from propulsion system.

DHP	=	EHP / Pc	
	=	1786.69215	kW
	=	2429.18665	HP

Sv.Aa.Harvald, Ship Resistance and Propulsion; page.135

Shaft Horse Power (SHP)

Effective horse power means power delivered to shaft which nearest to the main propulsion system.

SHP	=	DHP / η_S	
where η_S	=	98% (for the ship that has engine room in stern side)	
	=	97% (for the ship that has engine room around midship)	
SHP	=	DHP / (0.98)	
	=	1823.15525	kW
	=	2478.76188	HP

Required Main Engine Power

The rotation is in range of necessary to use gearbox, then the gearbox efficiency (η_G) is equal to 0.98.

BHP_{SCR}	=	SHP / η_G	
	=	SHP / (0.98)	
	=	1860.3625	kW
	=	2478.76188	HP

Maximum power generation. (using engine margin between 80% to 85%)

BHP_{MCR}	=	BHP_{SCR} / (engine margin)	
	=	BHP_{SCR} / (0.8)	
	=	2325.45313	kW
	=	3098.45236	HP

Main Engine Information

Engine	=	Mitsubishi Akasaka 6UEC 37/88 H Dimension	
Power	=	3900	HP
	=	557.14	HP/Cylinder
Cylinders	=	6 (six)	
n	=	230	rpm

FROM ASSUMED VESSEL SPECIFICATION

Power Re-Calculating

BHP_{MCR}	=	2868	kW
	=	3900	HP
BHP_{SCR}	=	$BHP_{MCR} \cdot 0.8$	
	=	2295	kW
	=	3120	HP
SHP	=	$BHP_{SCR} \cdot \eta_G$	
	=	$BHP_{SCR} \cdot (0.98)$	
	=	2249	kW
	=	3058	HP
DHP	=	$SHP \cdot \eta_S$	
	=	$SHP \cdot (0.98)$	
	=	2204	kW
	=	2996	HP
EHP	=	$DHP \cdot Pc$	
	=	1442	kW
	=	1961	HP
THP	=	$EHP \cdot \eta_H$	
	=	1629	kW
	=	2215	HP

ENCLOSURE H

ASSUMED VESSEL PROPELLER CONSIDERATION

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Propeller's Diameter

The value of maximum diameter of propeller based to *draught (T)* in empty condition with ballast.

D_{max} = 3.3000 m **FROM ASSUMED VESSEL SPECIFICATION**

Advance Speed

Advance speed means the speed of water *delivered to propeller* through the friction of the ship's hull.

V_A = $(1-w) \cdot V_S$ (knots)
= 7.8 knots
= 4.013 m/s

BP Value

The value of BP is necessary to predict the type of propeller which will be use.

BP = $(n \cdot DHP^{0.5}) / V_A^{2.5}$ (British Unit)
= 74.0960

BP-δ Diagram

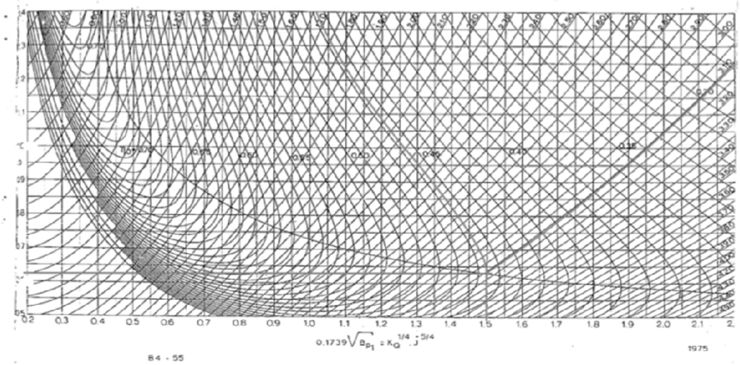
In purpose to read the diagram of *Wegningen B-Series*, BP value need to be convert.

$0.1739 \cdot \sqrt{}$ = **1.4969**
D_{max} = **3.3000** m

B4-55 PROPELLER CALCULATION

BP-δ Diagram Plot (Open Water)

Z = 4 Blades
A_E / A_0 = 0.55



P / D_O = 0.625
η_O = 0.4675
$1 / J_O$ = 3.11

δ_O Value

$1 / J_O$ = $0.009875 \cdot \delta_O$
3.11 = $0.009875 \cdot \delta_O$
δ_O = 314.937

D_O and D_B Value

D_O means the diameter of propeller which in open water test.

δ_O	=	$(n \cdot D_O) / V_A$		
D_O	=	$(\delta_O \cdot V_A) / n$		(feet)
	=	10.6805	ft	
	=	3.2554	m	

D_B means the diameter of propeller which in behind of the ship.

D_B	=	$0.98 \cdot D_O$		(single screw)			
	=	10.4669	ft				
	=	3.1903	m	<	3.3	m	(diameter compatible)

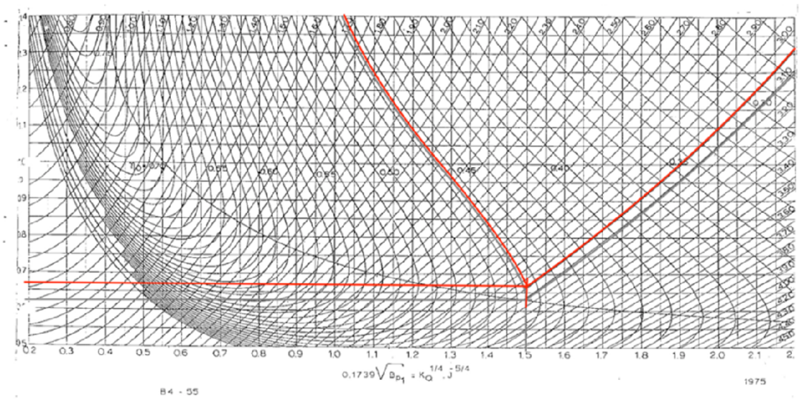
δ_B Value

δ_B	=	$(n \cdot D_B) / V_A$
	=	308.638

$1 / J_B$ Value

$1 / J_B$	=	$0.009875 \cdot \delta_B$
	=	3.0478

BP-δ Diagram Re-Plot (Behind)



P / D_B	=	0.67
η_B	=	0.465
$1 / J_B$	=	2.24

Thrust

Thrust means the thrust generated to the propeller.

T	=	$R_T / (1 - t)$		(Newton)
	=	258073	Newton	
	=	258.073	kNewton	
	=	58014.8	lbf	(Pound Force)

Relative Velocity

Relative velocity means the velocity of water through the propeller. (at 0.7 of propeller's radius)

V_R = $V_A + (2\pi \cdot 0.7 \cdot r_B \cdot n)$ (m/s)
= 30.8931 m/s

Area (A_0)

A_0 means area of propeller from face sight with no specific condition.

A_0 = $1/4 \cdot \pi \cdot (D_B)^2$
= 7.98973 m^2
= 86.0007 ft^2

Expansion Area (A_E)

A_E means area of propeller's blades from face sight with specific condition that the blades stretched.

A_E / A_0 = 0.55
A_E = $0.55 \cdot A_0$
= 4.39435 m^2
= 47.3004 ft^2

Projected Area (A_P)

A_P means area of projected propeller from face sight.

A_P = $(1.067 - (0.229 \cdot (P / D_B))) \cdot A_D$

where A_D = A_E (Expansion Area)

A_P = 4.01455 m^2
= 43.2122 ft^2

Mean Thrust Loading Coefficient

Mean thrust loading coefficient means the coefficient of mean thrust generated to the propeller.

τ_C = $T / (0.5 \cdot \rho \cdot V_R^2 \cdot A_P)$ (SI Unit) ($\rho = 1025$ kg/m^3)
= 0.13143

Cavitation Number

Cavitation number means the value in purpose to plot in cavitation diagram of Burill.

$\sigma_{0.7R}$ = $(188.2 + (19.62 \cdot h)) / (V_A^2 + (4.836 \cdot n^2 \cdot D_B^2))$ (SI Unit)

where h = distance between shaft center point to empty condition draught
= 3.1 m

$\sigma_{0.7R}$ = 0.3368

Bullier Diagram Plot

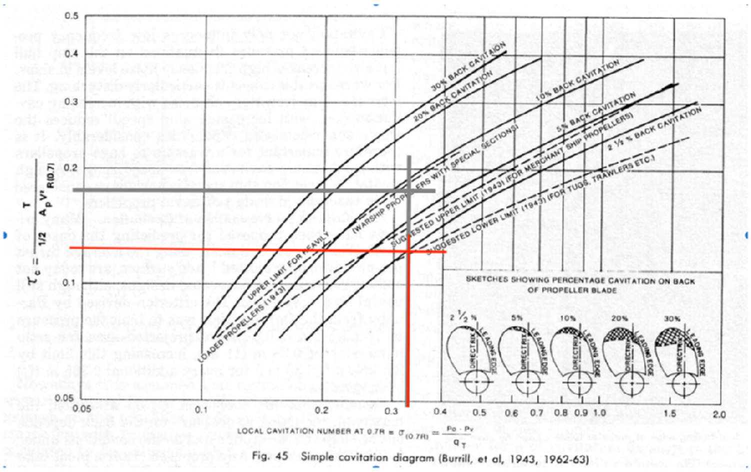


Fig. 45 Simple cavitation diagram (Burrill, et al, 1943, 1962-63)

The plot result show that the propeller is **not cavitation**

Power Re-Calculating according to η_B

EHP	=	**1442.47**	**kW**				
	=	**1961.18**	**HP**				
DHP	=	EHP / Pc		where	η_H	=	1.1292
	=	EHP / ($\eta_H \cdot \eta_{RR} \cdot \eta_B$)			η_{RR}	=	1.05
	=	**2616.26**	**kW**				
	=	**3557.07**	**HP**				
SHP	=	DHP / η_S		where	η_S	=	0.98
	=	**2669.66**	**kW**				(E/R in stern side)
	=	**3629.67**	**HP**				
BHP_{SCR}	=	SHP / η_G		where	η_G	=	1
	=	**2669.66**	**kW**				(not use gearbox)
	=	**3629.67**	**HP**				
BHP_{MCR}	=	BHP_{SCR} / (engine margin)					
	=	BHP_{SCR} / (1)					
	=	**2669.66**	**kW**				
	=	**3629.67**	**HP**	< **3900**	**HP**		**(power capable)**

The calculation above providing essential information to construct *Table.IV.11*within the report.

ENCLOSURE I

ASSUMED VESSEL KT-J CALCULATION (SERVICE SPEED 12 KNOTS)

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KT-J RELATION CURVE CALCULATION (12 KNOTS)

Propeller Load Characteristic (K_T)

K_T = $(0.5 \cdot C_{T\text{-service.12}} \cdot S / (1-t) \cdot (1-w)^2 \cdot D_B^2)\ (V_A / n \cdot D_B)^2$

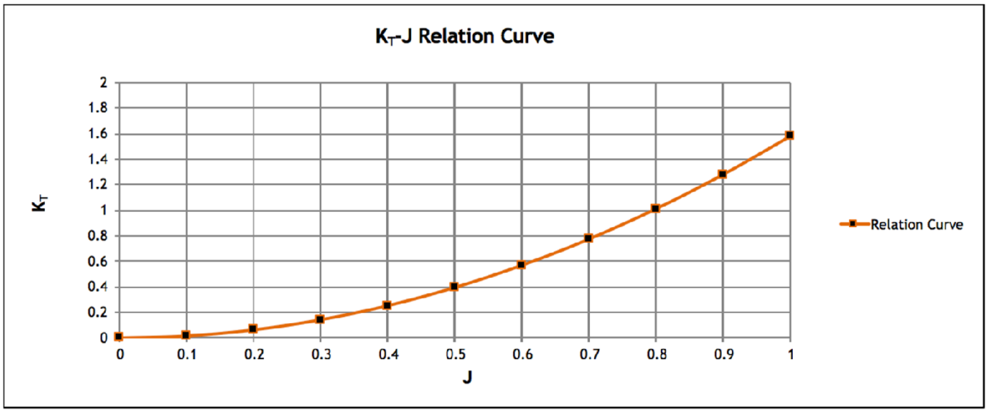
ß = $(0.5 \cdot C_{T\text{-service.12}} \cdot S) / ((1-t) \cdot (1-w)^2 \cdot D_B^2))$
= 1.57948

J^2 = $(V_A / n \cdot D_B)^2$
(will be various given that on the ship speed in practical condition is not constant)

K_T-J Relation Curve

By knowing ß value with J value various between 0 until 1, K_T value can be found.

J	J^2	K_T
0	0	0
0.1	0.01	0.01579
0.2	0.04	0.06318
0.3	0.09	0.14215
0.4	0.16	0.25272
0.5	0.25	0.39487
0.6	0.36	0.56861
0.7	0.49	0.77394
0.8	0.64	1.01087
0.9	0.81	1.27938
1	1	1.57948



K_Q K_T J Diagram Re-Drawing

The value of **P/D_B** (0.67) is not exist in diagram, then re-drawing process can be done with interpolation process.

P / D_B = 0.6

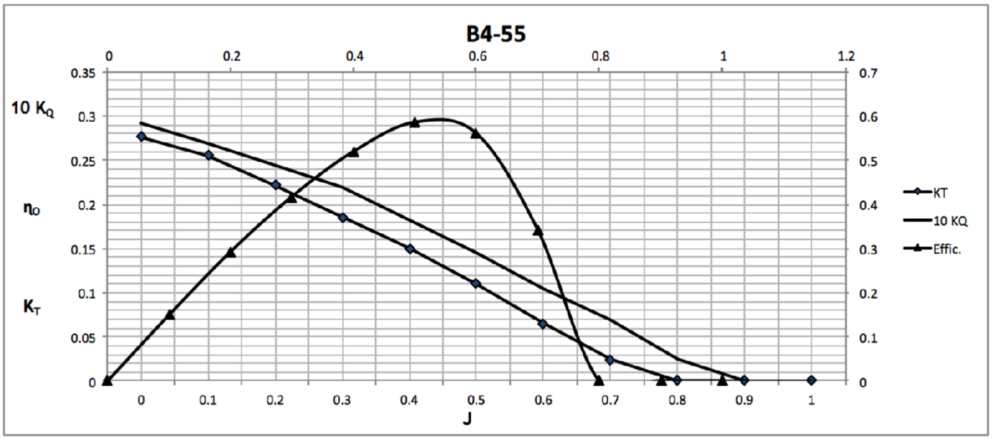
J	K_T	$10K_Q$	η_O
0	0.245	0.24	0
0.1	0.22	0.22	0.16
0.2	0.19	0.195	0.31
0.3	0.15	0.17	0.435
0.4	0.115	0.14	0.53
0.5	0.075	0.11	0.565
0.6	0.03	0.07	0.435
0.7	0	0.045	0
0.8	0	0	0
0.9	0	0	0
1	0	0	0

P / D_B = 0.7

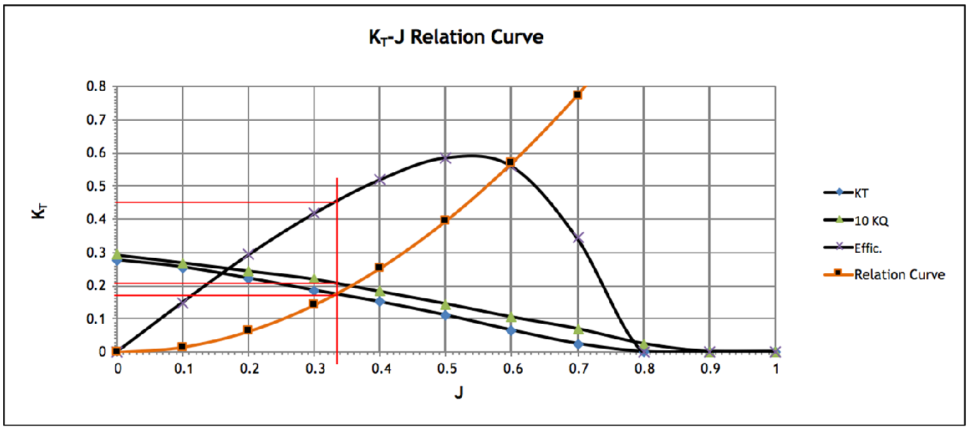
J	K_T	$10K_Q$	η_O
0	0.29	0.315	0
0.1	0.27	0.29	0.145
0.2	0.235	0.265	0.285
0.3	0.2	0.24	0.41
0.4	0.165	0.2	0.515
0.5	0.125	0.16	0.595
0.6	0.08	0.12	0.615
0.7	0.035	0.08	0.49
0.8	0	0.035	0
0.9	0	0	0
1	0	0	0

P / D_B = 0.67

J	K_T	$10K_Q$	η_O
0	0.2765	0.2925	0
0.1	0.255	0.269	0.1495
0.2	0.2215	0.244	0.2925
0.3	0.185	0.219	0.4175
0.4	0.15	0.182	0.5195
0.5	0.11	0.145	0.586
0.6	0.065	0.105	0.561
0.7	0.0245	0.0695	0.343
0.8	0	0.0245	0
0.9	0	0	0
1	0	0	0



K_Q-K_T-J Diagram Plot



J	=	0.335
K_T	=	0.175
10 K_Q	=	0.2075

Propeller Rotation

J	=	V_A / (n_{PROP} · D_B)		(SI Unit)
n_{PROP}	=	V_A / (J · D_B)		
	=	3.630	rps	

Torque

Q	=	$K_Q \cdot \rho \cdot D_B^5 \cdot n_{PROP}^2$		(Nm)	(ρ = 1025 kg/m^3)
	=	109664.14	Nm		
	=	109.66414	kNm		

Delivery Horse Power (DHP)

DHP	=	$2\pi \cdot Q \cdot n_{PROP}$	
	=	2499774.3	W
	=	2499.7743	kW

Shaft Horse Power (SHP)

SHP	=	DHP / (0.98)	
	=	2550.7901	kW

Brake Horse Power (BHP_{MCR})

BHP_{SCR}	=	SHP / η_G	
	=	2550.7901	kW

The calculation above providing essential information to construct *Table.IV.12* and *Figure 4.8*within the report.

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The author was born on 14th September 1994 in Jakarta. His father's name is Iman Satria Ardiana and his mother's name is Putu Eridani Bukian. The author has completed the formal education in TK Al-Falah, SD Al-Falah, SMP Global Mandiri, and Labschool Jakarta. The author continued his study for bachelor degree in Double Degree Programme of Marine Engineering (DDME) of Institut Teknologi Sepuluh Nopember (ITS) and Hochschule Wismar, with student registration number is 4213101038. During His study program, the author took an area of expertise in Marine Electrical And Automation System (MEAS) Laboratory. During His Study program, besides the formal academic activities the author also follow several non academic activities, namely LKMM Pra TD FTK ITS 2013, committee of 32nd Marine Engineering ITS "Homecoming Day" 2014, Basic ship survey and inspection professional training course IMAREST 2016, The author has done the first on the job training in PT. Jasa Armada Indonesia, Jakarta, and the second on the job Training in PT. ABB Sakti Industri, Jakarta.