A STUDY OF 2-STROKE MARINE DIESEL ENGINE CHARACTERISTIC BASED ON CONDITION BASED MAINTENANCE

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ABSTRACT

In today's environment, generating revenues for any industry is important. Profit margins are shrinking and often the difference between a profit and a loss can be as simple as preventing loss and improving efficiencies. Locating sources of energy waste, identifying failure conditions in electrical and mechanical systems all contribute to helping improve the bottom line. The ability of a vessel to operate depends on the ability of the ship main propulsion produces optimum power and translated through the transmission system to the propeller shaft. Marine diesel engine is the prime mover, which is synonymous in the shipping industry. Most important of criterion for boost the profit margin are the reliability, availability, repair, installation costs, operating costs, flexible and engine size. Failure to optimize the performance of the engine will tremendously reduce the profit margin. The condition based maintenance (CBM) is the option for engine's owner to gain the profit margin with shrinking the performance of the engine. CBM is the new method for performing maintenance and it was applied in various industries such as aviation industries, marine industries and commercial sector. Wave spectrum analysis using Ultrasonic wave sensor is one of the CBM method that can be applied for early identifying the excessive friction. In this study, both condition based maintenance and wave spectrum analysis be utilized together for identifying the engine performance without involving major and complex procedure. This study approved that once the engine is operating within the operating limit (maximum exhaust gas temperature is 350˚C, maximum inlet lubricating oil temperature is 55˚C and maximum inlet fuel oil temperature is 50˚C.) and that wave spectrum show the decrement of wave amplitude, the engine is in good condition and no major maintenance required. If the working parameter is out of the range, and significant friction detected using wave spectrum analysis, then the maintenance is required. Therefore, both condition based maintenance and wave spectrum analysis is a good combined method to identify the engine performance and able to reduce the maintenance cost that using the conventional maintenance schedule.

ABSTRAK

Fenomena perindustrian perkapalan hari ini, menjana pendapatan adalah satu element penting. Sering berlaku margin keuntungan mengecil dan perbezaan antara keuntungan dan kerugian dan ia boleh dielakkan semudah mencegah kerugian dan meningkatkan kecekapan. Mencari sumber sisa tenaga, mengenal pasti keadaan kegagalan dalam sistem elektrik dan mekanikal semua menyumbang untuk membantu meningkatkan keuntungan. Keupayaan kapal untuk beroperasi bergantung kepada keupayaan pendorongan utama kapal menghasilkan kuasa optimum dan diterjemahkan melalui sistem penghantaran untuk aci kipas. Enjin diesel marin adalah penggerak utama yang sinonim dalam industri perkapalan. Kriteria paling penting untuk meningkatkan margin keuntungan adalah kebolehpercayaan, ketersediaan, pembaikan, kos pemasangan, kos operasi, fleksibel dan enjin saiz. Kegagalan untuk mengoptimumkan prestasi enjin dengan ketara akan mengurangkan margin keuntungan. Penyenggaraan berdasarkan keadaan (CBM) adalah pilihan bagi pemilik enjin untuk mendapatkan margin keuntungan dengan mengecut prestasi enjin. CBM adalah kaedah yang baru untuk menjalankan penyelenggaraan dan ia telah digunakan dalam pelbagai industri seperti industri penerbangan, industri marin dan sektor komersial. Gelombang analisis spektrum menggunakan sensor ultrasonik gelombang adalah salah satu kaedah CBM yang boleh digunakan untuk mengenal pasti awal geseran berlebihan. Dalam kajian ini, kedua-dua keadaan berdasarkan penyelenggaraan dan analisis spektrum gelombang digunakan bersama-sama untuk mengenal pasti prestasi enjin tanpa melibatkan prosedur utama dan kompleks. Kajian ini menunjukkan bahawa apabila enjin beroperasi dalam had operasi (maksimum suhu gas ekzos ialah 350˚C, maksimum suhu kemasukan minyak pelincir ialah 55˚C dan maksimum suhu kemasukan bahan api ialah 50˚C.) dan spektrum gelombang menunjukkan susutan amplitud gelombang, enjin dalam keadaan baik dan tiada penyelenggaraan utama diperlukan. Jika parameter yang bekerja di luar julat, dan geseran yang ketara dikesan menggunakan analisis spektrum gelombang, maka

penyelenggaraan yang diperlukan. Oleh itu, kedua-dua kaedah, keadaan berdasarkan penyelenggaraan (CBM) dan spektrum gelombang analisis adalah kaedah gabungan yang baik untuk mengenal pasti prestasi enjin dan dapat mengurangkan kos penyelenggaraan yang menggunakan jadual penyelenggaraan konvensional.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In today's environment, generating revenues for any industry is important. Profit margins are shrinking and often the difference between a profit and a loss can be as simple as preventing loss and improving efficiencies. Locating sources of energy waste, identifying failure conditions in electrical and mechanical systems all contribute to helping improve the bottom line. In some cases it can be a dramatic improvement.

The ability of a vessel to operate depends on the ability of the ship's main propulsion produces optimum power and translated through the transmission system to the propeller shaft. Marine diesel engine is the prime mover, which is synonymous in the shipping industry. Most ships nowadays worldwide using marine diesel engine as the prime mover. In addition, there are also the ships that use steam turbines, gas turbines, generators and nuclear power generators. But the election of a ship's main engine is influenced by several factors; the most important of these is the reliability, availability, repair, installation costs, operating costs, flexible and engine size. Failure to make the appropriate selection and optimum engine will cause the shipping company will pay a very high.

However, the factors that most concern to all shipping companies now is to control the increase in operating costs, including the cost of maintenance and spare parts costs. Therefore, all shipping companies are now focusing on the development and improvement in analytical methods, operations, diagnosing fault conditions, monitoring performance, optimize performance and engine control (H.M. Abdul - Kader, 2009).

Approach as above is to minimize the risk of failure of equipment in line with rising maintenance costs. Therefore, these factors have prompted efforts latest technology helps provide a method of monitoring or monitoring and evaluation of mechanical systems for the purpose of replacing conventional methods such as waiting until the failure of either local or comprehensive and replace parts according to the scheduled routine (Mohd Zaki Nuawi 2008).

Operation and monitoring of marine diesel engine mid-sized and large have to be thorough and detailed. Therefore, knowledge and understanding of the engine operating system vital to ensure that procedures are carried out in the process engine is operating properly. Engine performance monitoring can also help reduce maintenance costs, but this method requires extensive experience by marine engineers and conventional than the latest technological methods.

Monitoring engine by using modern technology can now extend the life of the engine. The life of marine diesel engines is very important, this is caused by the life of the engine is affected by the operation of a ship. According to the International Maritime Organization (IMO) the life of a ship is allowed to operate about 20-to-30 years. Throughout the life of the ship's main engines operate vessels will also operate around the life of the same.

Accordingly, in the life of the main engine has to be concerned about the reliability in operation around 7000 hours per year and a maximum of 210,000 hours up to 30 years. Throughout the life of the repair costs such as parts are very important.

The study discussed in this dissertation is based on the hypothesis that the ultrasonic signal propagation structure capable of being used as a media monitoring in the operation of the engine. Through this study, the signals in the frequency range of ultrasonic sound generated by the engine during operation can be discerned. The ultrasonic sound signals can be generated through contiguity, interactive and friction between the piston ring and the inner walls of the combustion chamber (liner).

The monitoring process is studied through the operation of marine diesel engine 2-stroke type scavenge aligned. Engines will be charged and improved load through hydro dynamometer periodically. Hence, the observation of ultrasonic signals will be done at different speeds in each load applied. Observations wave or ultrasonic signals was performed using instrumentation such as Ultraprobe 10000 to record the signal in the form of time domain.

In this study also observed the use of ultrasound signals from the engine operation in the monitoring process is used. Thus, all the advantages, strengths and weaknesses obtained through this method will be described in this dissertation. The instruments electronically translate ultrasound frequencies through a process called heterodyning, down into the audible range where they are heard through headphones and observed as intensity and or dB levels on a display panel. The newer digital instruments utilize data management software where information is data logged on the instrument and downloaded to a computer for analysis. An important feature of the spectral analysis software, in addition to viewing sound samples in spectral, time and waterfall screens, is the ability of users to hear the sound sample as it is played.

1.2 Problem Statement

Generally marine diesel engine operates the fluctuations piston movement causing contact and friction between the cylinder block and piston rings mounted on the piston. This shift would produce sound waves in the range of ultrasonic waves (M.Z. Nuawi et al. 2008). Ultrasonic waves generated during the period of operation of the engine caused a wave propagating in the structure of the engine cylinder and the outer frame of the engine. Resonant pressure propagation effects of this structural framework distortion engine will experience a very artistic and cannot be identified with the naked eye. Through a combination of structure and propagation effects distortion framework will form the engine knocking noise in the engine (S.C. Behrens & J.F.Bohme 2001).

In addition, the propagation of vibration on the cylinder structure also occurs as a result of noise when the combustion process occurs. This is because the resulting noise is caused by the explosion of spontaneous combustion. However, the frequency and extremely loud noise will cause damage to the engine, especially on the surface of the piston. Extremely loud noise also produces acoustic waves and is usually measured using a pressure signal (S. Carsten-Behrens & J.F. Bohme 2001).

Research related to structural shifts and wear engine component run many currently. Among the research developed through monitoring oil and diagnostic programs using information technology and computer. This research method is done by analysing a sample of lubricating oil in the engine momentarily before the machine stops operating. Through this method also some information technology and computer equipment required such as video cameras, ferroscope, televisions, computers and printers. But apart from the above equipment requires the system should also be developed with special software with high costs.

Apart from that there are also technology developed over 38 years of acoustic emission technology development. Through this technology related studies twisting and shifting components developed. However acoustic emission technology requires an acoustic sensor mounted on the operating components, thus monitored and do diagnostics. Wavelength of about 100 kHz to 1MHz recorded and analysed through time domain waveforms (D. Mba & Raj B.K.N.Rao 2006).

Review vibration signal to a 2-stroke marine diesel engine on ships found that the vibration signal monitoring and diagnostics are also among the diagnostic methods that are often run on internal combustion engines. Through this diagnostic method, the sensor is mounted on the cylinder jacket to measure and record vibration signals generated in the engine. However, this method still has the disadvantage caused by vibration and noise signals generated when a fault occurs when it is too late and the resulting sound is able to be detected by hearing human.

Method using ultrasonic signal propagation structure is a method that is suitable for monitoring the operation of the engine. This is because the ultrasonic signal is parallel direction and then the result of the directive, the signal-noise ratio (SNR) obtained better next use appropriate signal filtering (Mohd Zaki Nuawi 2008).

The increment of maintenance cost was significantly increase the life cycle cost and it might interrupt the efficiently and return of investment in any particular asset, as in this project is the 2-stroke marine diesel engine. The condition based maintenance could be one of the option to reduce the maintenance cost and increase the efficiently of the marine engine.

1.3 Objectives of the Study

The objective of this project are:

(i) to evaluate the engine performance based working parameter.
(ii) to identify the ultrasonic wave signature using Ultraprobe 10000.
(iii) to propose the solution to minimize the maintenance cost.

1.4 Scope and Limitations of Research

The scope of this project are:

(i) The parameters are analysed based on the standard parameter provided by the original equipment manufacturer of the 2-stroke marine diesel engine.
(ii) The study on ultrasonic wave signature is based on the output result of Ultraprobe 10000.
(iii) The data collection is based on the existing 2-stroke marine diesel engine at Marine Lab, Politeknik Ungku Omar.
(iv) Four load step used in this study which is 0, 928, 1044, 1160 kg.
(v) Three speed step used in this study which is 185 rpm, 235 rpm and 255 rpm.

1.5 Organization of Thesis

This section is intended to brief a summary of the thesis layout. Its five chapters were organized in this thesis with following the scopes. This thesis first gives a brief overview of the background of study, problem statements, objectives and scopes and limitations of research.

Chapter 2 begins with a literature review related to the internal combustion engine, type diesel engine, marine diesel engine, the basic theory of acoustic waves, and ultrasound technology in surveillance and monitoring of the engine, the ultrasonic signal processing method as written in Chapter 2: Literature Review.

After that a test rig developed by utilizing marine diesel engine 2-stroke engine used in the teaching and learning process in the Marine Engineering Department, Ungku Omar Polytechnic, Ipoh. The research methodology set out in Chapter 3: Methodology.

Chapter 4 discusses on the experimental results and discussions of the study. All the results obtained from observation of the ultrasonic signal during engine operation will be displayed. The study goes on to make an analysis and discussion of the results of the observation process the signal. A comparison of the signals obtained from monitoring the engine is processed in the time domain and frequency domain results discussed.

Finally, Chapter 5 pointed out and summarizes the results of the research and some recommendation are also provided in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Heat Engine

Heat engine can be divided into two main categories: internal combustion engines and internal combustion engines outside. The internal combustion engine is an engine that produces work through the process of combustion of the fuel in the combustion chamber. Fuels used by internal combustion engines now include petrol, diesel, gasoline and gas engines. Fuel reacts with air in the combustion process to generate energy and power.

While outside combustion engine is an engine combustion chamber process undergo separate and combustion products will be sent to the generator or turbine. Among the types of engines in this category is the steam turbine and gas turbine. Both of types engine using steam and hot gas as a medium to drive a turbine to produce work.

However, both the heat engine above categories must meet the following requirements for producing good engine and is capable of high current operation:

(i) Fuel and air to be supplied to the engine with the appropriate proportion and correct.

(ii) Fuel and air must be compressed before or after the mixing process occurs.

(iii) Mixture of fuel and air needs to be burned and the resulting combustion engine components will move through the development process.

(iv) The exhaust gas must be removed from the engine during the development process to provide input combustion chamber receives air.

2.1.1 Marine Diesel Engine

The internal combustion engine or heat engine has been tested in early 1888. The marine diesel engine was invented by Dr. Rudolf Diesel in a decade. Thereafter, the first 4-stroke engine marine diesel engine was invented by Sulzer which is capable of producing 20 horsepower at 60 revolutions per minute. Diesel engines are known by the name of compression ignition engines due to technical reasons. Generally, the marine diesel engines can be categorized into three main categories: low speed (< 200 rpm), medium speed (200-1000 rpm) and high speed (> 1000 rpm).

However, the competition in designing marine diesel engines, 2-stroke and 4-stroke which each tries to produce engines with high output, lightweight engines and small and low rates fuel consumption. Some physical constraints that need to be prioritized in the selection of marine engines, namely:

(i) Engine capacity to operate in a state where the position of the vessel hull of uncertain when ship in rolling position.

(ii) Marine engine systems should be designed to allow the engine to withstand the water temperatures of at least 35 $^{\circ}C$ and 40 $^{\circ}C$ ambient temperatures around - 45 $^{\circ}C$.

(iii) Marine engine is also able to withstand corrosion caused by sodium namely through the inlet air moisture and vanadium contained in the fuel.

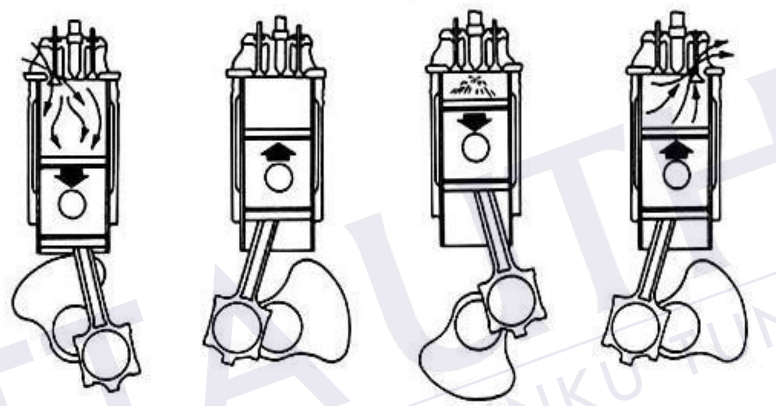
(iv) The marine engine noise to comply with the maximum noise level allowed by the International Standards Organization (ISO) of 75 dBA in the engine control room, while 90 dBA in the engine room.

(v) Marine engines must also withstand vibration resulting from the rotation of the propeller shaft, transmission and component damage.

Diesel engine or fuel compression engines operating under higher compression ratio than the fuel ignition engines. Most marine diesel engine 2-stroke and 4-stroke engine is currently working on modern Diesel Cycle or Dual Combustion Cycle. Dual-combustion cycle is the cycle that combines Diesel Cycle and Otto cycle. Hence, Dual-Combustion Cycle start burning fuel injection and earlier, ie around 20 $^{\circ}$ before top dead center (TDC) (S.S. Hou 2004). Diesel engine which initially operated using diesel-cycle has been developed to operate in a dual combustion cycle. Efficiency of Dual-cycle diesel engine is higher than compared with Diesel Cycle and Otto cycle.

2.1.2 Marine Diesel Engine 4-Stroke and 2-Stroke

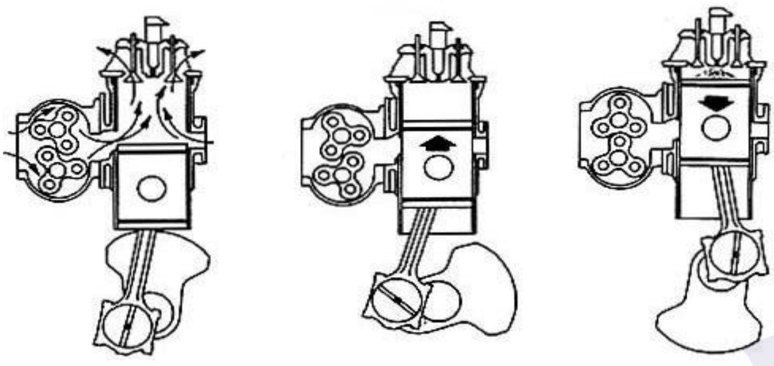
Marine diesel engine 4-stroke operation by completing two rounds of the crankshaft or piston moves up and down four times to complete a four-stroke cycle. Air is sucked through the inlet valve to assist the combustion in the combustion chamber and discharged through the exhaust valve during the exhaust stroke as shown in Figure 2.1.



(a) (b) (c) (d)

Figure 2.1: Marine Diesel Engine 4-Stroke; (a) intake (b) compression (c) power (d) exhaust
(http://www.dieselduck.info/machine/01%20prime%20movers/diesel_engine/diesel_engine.02.htm)

When the piston is at top dead center (TDC) inlet valve opens and air is sucked into the combustion chamber and piston then down to the bottom dead center (BDC). The BDC inlet valve is closed and the air in the combustion chamber is compressed by the piston moves up to TDC. During the process of compressed air, temperature and air pressure in the combustion chamber increases. Fuels (diesel) injected in the combustion chamber and combustion occurs by generating a high-pressure gas. At this point the piston is pushed down to the BDC. On the exhaust stroke valve opens and the piston moves up to TDC again to push exhaust gases out. While marine diesel engine 2-stroke crankshaft makes one round to complete one cycle round. At the beginning of the process air is at low pressure. Air will entering the combustion chamber through a hole scavenges will push out the exhaust gas through the exhaust vent or exhaust valve. When the piston is at TDC and the exhaust hole scavenge will be closed as shown in Figure 2.2.



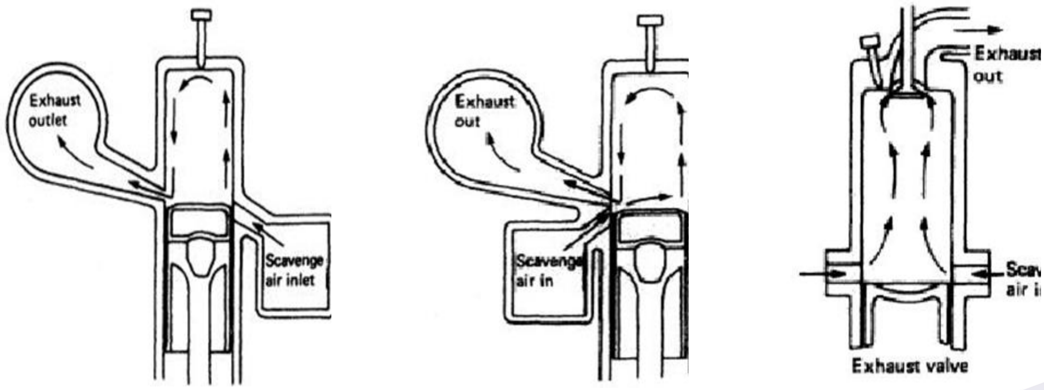
(a) (b) (c)

Figure 2.2: Marine Diesel Engine 2-Stroke; (a) exhaust and intake (b) compression (c) power
(http://www.dieselduck.info/machine/01%20prime%20movers/diesel_engine/diesel_engine.01.htm)

Piston at BDC and then down to the exhaust vent will open first, followed by scavenge hole. When the hole is open scavenge air will enter the combustion chamber by pushing the exhaust gas out through the exhaust vent. At the end of the piston stroke will rise to TDC and compressing air at high pressure and temperature suitable for combustion.

There are differences among marine diesel engine 4-stroke and 2-stroke air input during the process. 4-stroke diesel engines are using the inlet valve to allow air to enter the combustion chamber. While the 2-stroke diesel engines using scavenge hole for supplying air into the combustion chamber. Scavenge methods on marine diesel engine 2-stroke is divided into three types, namely the type of cross flow, loops and uniflow as illustrated in Figure 2.3. These three types of scavenge method each have advantages and disadvantages. Cross flow type method requires piston skirt to prevent air and exhaust gases out when the piston is at TDC. While the loop is designed for low air temperatures and high temperature exhaust gas through holes adjacent to each other. This is necessary to avoid differences in temperatures far wall liner.

Scavenge uniflow type is a method that is more efficient and widely used in marine diesel engines.



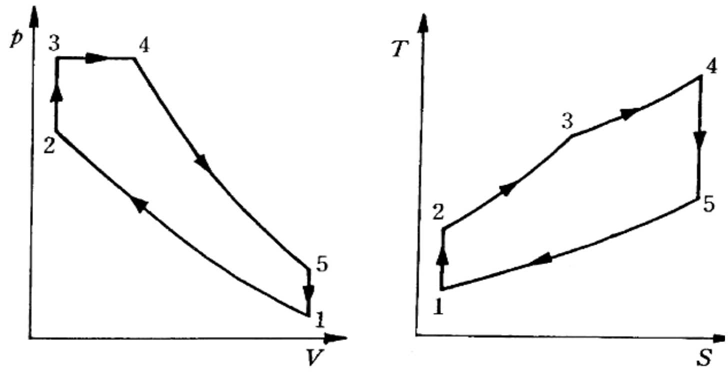
(a) (b) (c)

Figure 2.3: Types of scavenge 2 stroke marine diesel engine; (a) cross flow (b) loop and (c) Uniflow (http://www.brighthubengineering.com/marine-engines-machinery/41089-scavenging-in-marine-engines/#)

2.1.3 Air Standard Dual Cycle

Air standard dual cycle combustion is applied to the thermodynamic cycle marine diesel engine 2-stroke. Air standard cycle is described with reference to air as a medium and converted to heat effect of the reaction gas in the combustion process (N.E.Chell 1999).

The internal combustion engine which operates on the air standard dual cycle air will go through the compression stroke and the expansion of adiabatic and reversible. When air compression and expansion process reversible form of friction between the piston and cylinder wall occur. But the friction that exists is minimal due to the smooth surface of the cylinder wall and lubricated (S.S. Hou 2004). Figure 2.4 shows (a) and (b) diagram; Specific volume versus pressure and T-s; Entropy versus temperature for the thermodynamic Air standard dual cycle.



(a) (b)

Figure 2.4: (a) *P-v* Diagram; (b) *T-s* Diagram for Air Standard Dual Cycle (http://www.brighthubengineering.com/marine-engines-machinery/9605-theoretical-cycles-in-marine-diesel-engines-the-dual-cycle/)

Referring to the P-v diagram and T-s diagrams above, process 1-2 is an isentropic compression process between BDC to TDC; 2-3 is a process of constant volume process and heat is supplied; 3-4 process is a process of constant pressure and heat is supplied; 4-5 process is isentropic expansion process and process 5-1 is the process of heat or exhaust fans. Heat is supplied in the system through the process of combustion of fuel and air. While the T4 cycle temperature is the maximum temperature achieved during this cycle and pressure process constant. Work per unit of mass is generated by the cycle,

$$W=C_V\,(T_3+T_2) + C_p(T_4-T_3) - C_V(T_5-T_1) \tag{1}$$

W is the work per unit of mass; C_V is the specific heat at constant volume; Cp is the specific heat at constant pressure; T1, T2, T3, T4 and T5 are in the process of temperature cycles 1 to 5. In the case of isentropic process 1-2 and 4-5,,

$$T_2 = T_1 .\, r_c^{k-1} \text{ and } T_5 = T_4\left(\frac{\beta}{rc}\right)^{k-1} \tag{2}$$

and k is the ratio of specific heats (Cp / C_V); r_c is the compression ratio (V_1 / V_2) and β is the ratio of the cuts (V_4 / V_3). While heat per unit mass that is supplied in the cycle is in a state of constant volume - 2-3 process, Q_1 and the constant pressure situation - the process 3-4, Q_2 as follows,

$$Q_1 = C_V (T_3 - T_2) \text{ and } Q_2 = C_p (T_4 - T_3) \tag{3}$$

Therefore the amount of heat supplied to the cycle, Q_{in} is,

$$Q_{in} = C_V (T_3 - T_2) + C_p (T_4 - T_3) \tag{4}$$

2.1.4 Power Efficiency of Marine Diesel Engine.

Selection of an internal combustion engine, not only through the physical aspects of the external or even covering aspects of the engine's ability to produce output translates to the ability level of the operation of the vehicle. Similarly often when to determine in the selection of the engine for a ship. Factor is the engine's ability to produce optimum power and is compatible with the size of the vessel and type of vessel operations are concern.

Term of power is used in the identification of marine diesel engines and internal combustion engines in which the word "power" is referring to indicated power and brake power generated by the engine (J. Lambs, 1986). Generally, the power generated by the combustion process in the engine cylinder and translated by the mechanical movement of the crankshaft to move the ship propeller.

Indicated power generated for each cylinder of the engine. While the engine brake power is the ability to resist engine shaft rotation to test the ability of the engine to work in the loaded condition. The method used in making the measurements indicated a power marine diesel engine is to use pressure indicator equipment or engine indicator. Figure 2.5 shows the engine indicator which is capable of recording any changes in pressure in each cylinder when the engine operates.

Engine indicator mounted on the indicator cock on the cylinder of the engine. The pressure inside the cylinder will react on a small piston contained within the body of the indicator. Small piston pushes the piston rod and will move the spring. Stylus arm will move the smaller piston movement into filter paper that there is a wall around the drum.

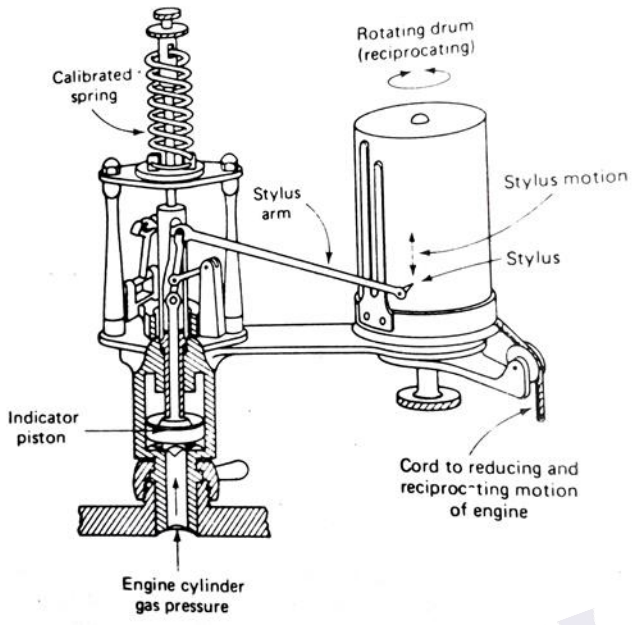


Figure 2.5: Engine Indicator
(Burghardt Kingsley, Marine Diesels, 1981)

Indicators cable will be connected to the moving parts of the engine that has the same movement with the movement of the piston engine fluctuations. Figure indicated engine will be recorded on the filter paper with the movement of the stylus which is connected to the hub. Indicated the resulting diagram illustrates the difference in pressure that exists inside the cylinder. While the area under indicator diagram describes the power generated for each cylinder. There are two types of diagrams that can be recorded through the above methods indicator diagram and phase diagram of the engine as shown in Figure 2.6 and 2.7.

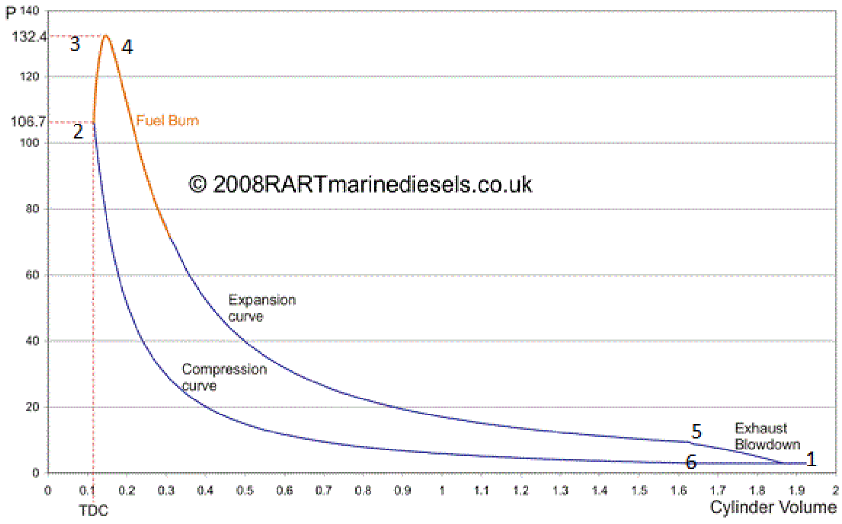


Figure 2.6: Indicated Power Diagram 2-Stroke Marine Diesel Engine (http://www.marinediesels.info/Theory/actual_diesel_cycle.htm)

Figure 2.6 illustrated the Indicated Power Diagram above can be produced by applying a string indicator to mechanism that moves with the movement of the piston engine. A process that could be interpreted from the diagram above as follows:

Point 1 : BDC

Point 2 : Compression process end

Point 3 : Combustion begin

Point 4 : Fuel injection end

Point 5 : Exhaust vent open

Point 6 : Compression begin

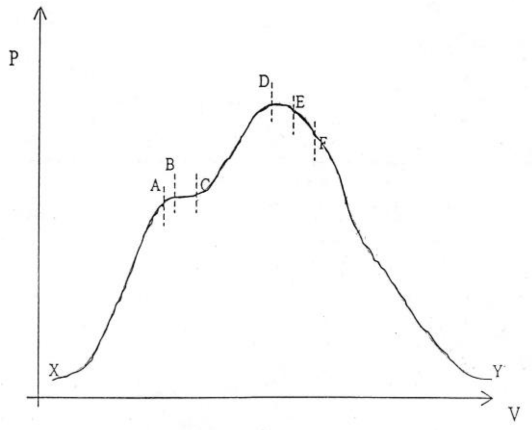


Figure 2.7: Phase Diagram (*P-v*) 2 Stroke Marine Diesel Engine

While the phase diagram of marine diesel engine 2-stroke above can be generated by manually pulling the strings indicators. Definition of cycle parts labelled on the Table 2.1.

Table 2.1: Definition of cycle parts

Point A :	Fuel injection began; at this point the fuel pump is ready to deliver fuel to injector .
Point A-B:	Period for flame retardation - a delay is caused by the expansion of the fuel piping system and delay time to send pressure to the fuel injectors.
Point B :	The needle valve open fuel injector and fuel entering the cylinder.
Point B-C:	Delay flame - due to the quality of fuel, air pressure and temperature, fuel injection pattern, size and number of injector nozzles.
Point C :	Flame begins - the flame resulting from the reaction of fuel with temperature and high pressure.
Point C-D:	The length of the combustion process - the temperature and the pressure increased to the maximum level.
Point D-E:	Duration of combustion - the piston moves past TDC and begins to descend to BDC.
Point E-F:	Part burning - burning only on this condition react with residual fuel left.
Point X-A:	Compression Stroke
Point F-Y:	Exhaust Stroke

Through the indicator diagram, indicated power can be determined by measuring the area of the diagram. Area of the diagram measured using a planimeter or half ordinate method as shown in Figure 2.8.

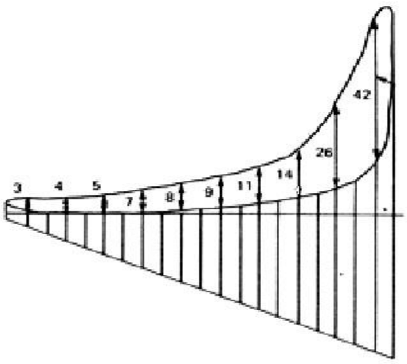


Figure 2.8: Method of calculation area of the indicator diagram – ordinate the distribution half

Indicated area of the diagram can be easily obtained through readings on the gauges are planimeter. While through the half-ordinate diagram is divided into several parts. Min height will be more accurate figure by the number of parts more. The calculation is done manually by the following equation:

$$\text{High Mean Indicated Diagram} = [\text{total ordinate half}] \;/\; [\text{number of sections}] \quad (5)$$

$$\text{Mean effective pressure, Pm} \left(\frac{\text{N}}{\text{m}^2}\right) = [\text{Mean high indicated diagram}]\text{x } [\text{coefficient of spring}] \quad (6)$$

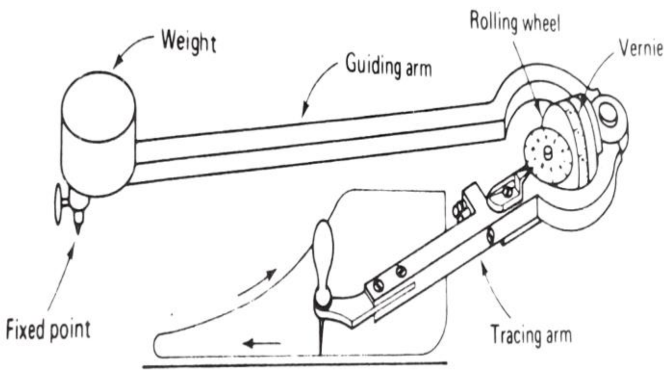


Figure 2.9: Polar Planimeter
(Burghardt Kingsley, Marine Diesels, 1981)

Through extensive measurement indicator diagram using a planimeter calculation mean indicate pressure can be determined as follows:

$$Pm = [S / a] \times l \qquad (7)$$

where,

Pm = mean effective pressure, kPa

S = coefficient of spring, kPa /m^2

a = area of indicator diagram, m^2

l = length of indicator diagram, m

The equation for determining the indicated power diagram diesel engine 2 stroke:

$$i.p = Pm \times L \times A \times N \times n \qquad (8)$$

where,

Pm = mean indicator diagram, kW

L = stroke, m

A = sectional area of the bore, m^2

N = engine speed, rpm

n = number of cylinder

For the measurement of engine braking power is based on an analysis of hydro dynamometer. Marine diesel engine 2-stroke engines tested performance will connect the crankshaft with hydro dynamometer. Engines that operate round the shaft will transfer power to the dynamometer. There is water in the hydro dynamometer will resist and prevent the engine shaft rotation. Engine brake power is determined using the following equation:

$$b.h.p = T \times \omega \qquad (9)$$

where,

$b.h.p$ = brake power, kW

T = torque, Nm

ω = angular velocity, rad/s

Potential engine is determined by an analysis of some parameters such as mechanical efficiency, thermal efficiency, volumetric efficiency, air and fuel ratio, the mean piston speed, fuel consumption rate, and the rate of air consumption and use of specific fuel consumption.

Mechanical efficiency of the engine is measured efficiency of friction between moving components in the engine. Mechanical efficiency is determined by the ratio between the brake power and indicated power as follows (D.A. Taylor 1999):

$$\eta_m = \text{brake power} / \text{indicated power} \quad (10)$$

While the mean piston speed is the ability of the piston moves from TDC or BDC and to the maximum half-stroke. Min is determined as follows:

$$\text{Mean piston speed} = [2 \text{ x stroke}] / [\text{time for around crankshaft}] \quad (11)$$

The ratio of air and fuel consumption is determined by measuring the amount of air and fuel that is used when the engine is operating at a specific period of time. However, the rate of air consumption is very difficult to determine and analyse in detail. Practically in engine combustion process, air containing oxygen 21% and 79% Nitrogen in volume. Equation of air and fuel ratio as follows:

$$\phi = [F/A]_{actual} / [F/A]_s \quad (12)$$

where,

$[F/A]_{actual}$ = actual fuel air ratio

$[F/A]_s$ = stoichiometric fuel air ratio

The rate of fuel consumption in the engine when the engine is operating in a certain period . The equation used is:

$$\dot{m}_f = \frac{V \text{ x } \rho f}{t} \quad (13)$$

where,

$\dot{m}_f$ = rate of fuel consumption, kg/s

v = volume of fuel, m^3

ρf = density of fuel, kg/m^3

t = period of engine operation, s

But there are other methods that can be used are to take readings of the flow rate of fuel consumption directly on the flow meter. The specific fuel consumption is also a fuel consumption rate required to produce a unit of engine power. The engine has a fuel consumption of the low is more economical. Specific fuel consumption equation is:

$$s.f.c = \frac{\dot{m}}{b.h.p} \quad (14)$$

where,

s.f.c = specific fuel consumption

$\dot{m}$ = rate of fuel consumption, kg/s

b.h.p = brake power, kW

Engine capacity to determine the effective thermal energy supply for use with optimum thermal energy is determined by the following equation:

$$\eta_{th} = \frac{\text{work done per second}}{\text{heat supplied from the fuel per second}} \quad (15)$$

Heat supplied to the engine depending on the fuel calorific value (C.V.) is used, i.e. the amount of heat energy obtained per unit mass of fuel when the burned at constant pressure conditions. Thermal energy is supplied, $\dot{m}f$ x C.V.

2.2 Wave Theory

2.2.1 Introduction

Waves can be classified into two types of mechanical waves and electromagnetic waves, this division is referring to the wave propagation medium. Mechanical wave is the wave propagation in the medium requires. Examples of mechanical waves are sound waves, surface waves and water waves on a string. While the electromagnetic wave is a wave that does not require a medium in its propagation. Examples of electromagnetic waves are light, radio waves, TV waves, X-rays and gamma rays.

Acoustics is the science of sound also covers the generation, transmission and sound effects. Sound is not only a natural phenomenon that occurs in the air and the sound can only be heard but can also be generated through physical analogue principles. Acoustic wave is a mechanical wave that propagates through the medium of liquid, gas or solid (propagation structure).

Elastic waves can be generated at a range of 0.1 to 1 MHz in surface materials change shape as a result of the reaction friction and wear of materials (R.M.Douglas et al. 2006). Acoustic waves can also be generated by a vibrating or oscillating source. Oscillation or vibration at some point will generate waves that can propagate to the whole medium (M.Z.Nuawi 2008).

The machines operate fluctuations such as the internal combustion engine will cause the acoustic waves can be generated by processes that occur in such combustion engines, piston movement, sound of valve, the flow of gas and liquid reaction and mechanical movement of the engine components (M.H.E.l- Ghamry et al. 2002). The cause of generating acoustic waves in an internal combustion engine will also produce waves of noise and vibration in the engine. Wave noise and low frequency vibration it will also spread through sources that are hard to detect even using signal sensors.

Figure 2.10 shows the wave cycle that has characteristics such as wavelength, frequency and velocity. The time required to complete one cycle is normal, T. While the total time for the cycle in one second is the frequency, f, and is measured in units of hertz (Hz). The distance between the peak to peak or valley to valley distance between the waves is called the wavelength, λ (R.C.Stanley 1968).

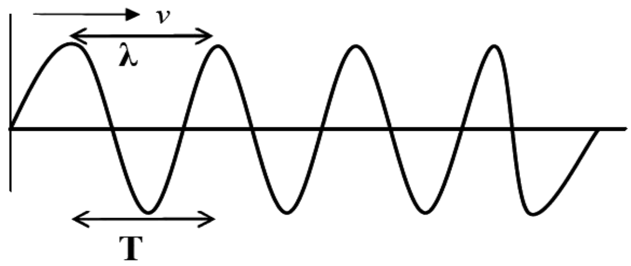


Figure 2.10: Wave Cycle

If a source of vibration frequency per second, *f* travels at a distance f λ in one second is defined as the velocity, v. Wave velocity can be connected via the equation:

$$v = f\lambda \quad (16)$$

where,

λ = wavelength, m

v = wave velocity, m/s

f = wave frequency, Hz

2.2.2 Sound Wave

Propagation of sound waves or mechanical waves through a solid medium pressure is changing. Figure 2.11 shows the movement of sound waves that are reflected by the wave motion of the particles in the cylinder-piston system briefly. Particles move forward and backward waves in the direction of wave propagation. The rate of pressure change in a variable that can determine the frequency of the wave. Through the concept of particle movement in pressurized sound waves inside the cylinder, these factors lead to the propagation of sound propagating structure. Sound can propagate through the transmission structure and propagation of air.

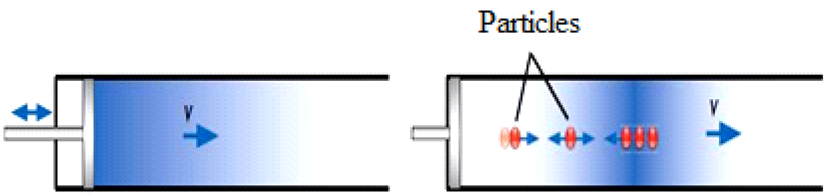


Figure 2.11: Longitudinal wave propagation in the cylinder-piston system

2.2.3 Velocity of Sound

Disturbance or movement of sound propagation through a medium at a certain speed will cause the molecular wave will transfer energy from one point to the next. If interference exists small in size, it is constant and depends only on the content of the physical medium. For large disturbance it depends on the size of the disturbance. The velocity of sound in the gas can be connected via the equation:

$$c = \sqrt{\frac{\gamma P}{\rho}} \tag{17}$$

where,

c = velocity of sound

γ = the specific heat for gas

P = min pressure

ρ = density of gas

While the velocity of sound propagating through the liquid can be connected in common area:

$$c = \sqrt{\frac{B}{\rho}} \tag{18}$$

where,

B = modulus of elasticity adiabatic

ρ = density of liquid

The velocity of sound propagating in solid was linked by following equation:

$$c = \sqrt{\frac{E}{\rho}}$$

(19)

where,

E = modulus Young's elasticity

ρ = density of solid

The difference in speed of sound waves that propagate on the type of material at a temperature of 20 ℃ and 1 atmosphere shown below in Table 2.1.

Table 2.2: Differences velocity of sound waves in different types of materials

Medium	Density (kg/m^3)	Velocity (m/s^2)
Air	1.21	343
Carbon Dioxide	1.84	267
Hydrogen	0.084	1330
Nitrogen	1.17	349
Oxygen	1.33	326
Fresh Water	998	1483
Sea Water	1025	1522

2.2.4 Sound Pressure

Sound pressure level is 0 dB sensitivity range of the ear (2x10^{-5} Nm-2) to 120 dB (20 Nm^{-2}). But the daily noise audible range and normal environment is between 35 dB to 90 dB. While pressure for audio-acoustic sound is to refer to the 2x10^{-5} Nm^{-2} and sound pressure in water is 10^{-1} Nm^{-2}.

From equation decibels,

$$20 \log_{10} n^{1/2} = 20 \log_{10} \left(\frac{p1}{p2}\right) \tag{20}$$

where p1 is the absolute value of 20 $\log_{10} n^{1/2}$ and p^2 is 2x10^{-5} Nm^{-2} is the root mean square value for minimum pressure of human hearing. Therefore, the sound pressure level is,

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