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Prediction Performance of Two Stroke Semi Free Piston Diesel Engine with Dual Piston System

[1]Aguk Zuhdi Muhammad Fathallah, [2]Ian Bimatara, [3]Rosli Abu Bakar

[1]Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember (ITS) Surabaya Indonesia
[2]Graduated of Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember (ITS) Surabaya Indonesia
[3]Faculty of Mechanical Engineering, Univesiti Malaysia Pahang, Malaysia

fathalaz@gmail.com

Abstract. The design of the semi-free piston two-stroke diesel engines has been successfully implemented. Before the engine is built, it is necessary to predict its performance. Prediction is done by using the simulation method. This method is considered the most effective because it does not fabricate the machine first. Modelling and simulation are done using application software. Simulation modelling covers all parts of the engine, namely the intake system, block, injection system, and then exhaust system. Engine performance predictions are based on speed variations as well as load variations. Validation is done with a conventional machine. The difference between the two engines lies in friction losses, where the free piston concept is to reduce friction losses. The simulation results are engine performance such as torque, power, bsfc, bmep, and combustion processes such as heat release, pressure, and ignition delay. The difference in the performance of the semi-free piston compared to a conventional engine with the same combustion chamber size. Prediction results state that the difference in performance is very significant.

1. Introduction

The use of internal combustion engines in today's era relies on conventional engines. The conventional engine in this case is quite widely used as transportation media or industrial supporting media. The conventional engine that is very often used is the diesel engine. Currently, diesel engines have the highest level of efficiency. But in the future, there will be a need for engines that have higher efficiency.

Based on several studies that have been carried out, linear engines have better performance when compared to conventional internal combustion engines. The difference in performance occurs because the working principle is slightly different. The design of a linear engine can reduce the frictional force received and consequently can improve performance such as power, torque, and fuel consumption can be better. [1, 2]

The difference in working principle between linear engines and conventional engines lies in the return cycle to the top dead centre [6]. In conventional engines is using the basic mechanism of the crank rotation system. The process to the top dead centre on a conventional engine occurs because the power received from the combustion process pushes the piston and is transmitted by the connecting rod to rotate the crankshaft. While the semi-free piston linear engine with dual-piston in the process of

return cycle to top dead centre is caused by the return pressure obtained from the combustion of another combustion chamber (opposite piston chamber).

From the difference in the return cycle process, the frictional force received by the linear engine is smaller because there is no frictional force generated by the crank system. So that the semi-free piston linear engine with a dual-piston system provides greater efficiency than conventional engines.[1]. Fathallah and Barus [3] have succeeded in designing a semi-free piston linear engine; this research is to predict its performance. This study also adopted the data used in the study. Before the engine is further developed, it is necessary to predict its performance in advance.

2. Research Methodology

2.1. Engine Modelling
To predict engine performance, a model is needed. Modelling is adjusted to the type and main dimensions of the engine. Things that need to be modelled are the design of the combustion chamber, power transmission system, input and output, and fuel injection system. In this study, performance predictions are compared with free pistons with conventional engines that have the same combustion chamber dimensions. The difference between a free piston and a conventional engine lies in the power transmission system (rotational motion and linear motion). This study used professional software. There are two models developed, namely the free piston model and the conventional engine as a comparison to measure its performance. Figure 1 is the result of designing a semi-free piston, dual-piston, and two-stroke diesel engine. The main dimensions of the machine can be seen in table 1.

Fredriksson and Denbratt [7] in their simulation reported that the combustion process of fuel with low fuel quality causes a poor combustion process. There are recommendations for increasing the compression ratio because a high compression ratio will improve ignition for the better. A higher compression ratio provides increased engine speed, power, and efficiency. Based on this report the design of the semi-free piston has been recommended.
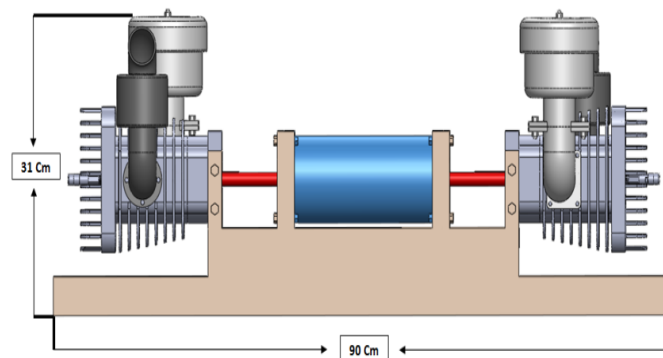

Figure 1. *Semi-free Piston two stroke, dual piston diesel engine*

Table 1. Specifications of semi free piston diesel engine

Engine Name	Linear Engine
Type engine	Diesel Engine
Stroke	2 stroke
Bore	53 mm
Stroke	60 mm
Compression ratio	1 : 21
Cooling System	Air Cooler

2.2. Modeling of Conventional Engine
Conventional engine modelling is done using the software. Where linear engine modelling refers to the design of Fathallah and Barus [3], with the most complete size possible so that the results obtained can be analyzed as much as possible. By doing a conventional engine design without any

modification, FMEP's prediction follows Fathallah and Bakar [1] by utilizing the formulas of Ferguson and Kirkpatrick [4]. The difference in the use of the formula lies in the choice of formula between the Otto and Diesel cycles. The results of FMEP calculations for both semi-free piston linear engines and conventional engines are shown in table 2. In modelling and simulation, there are steps that must be carried out so as to produce valid data for analysis. The stages for modelling are as follows:

2.2.1. Design measurement
The first thing to do before doing the modelling and simulation is to measure the diesel engine components that have been designed. This is done because the application requires detailed data related to the dimensions of engine parts and environmental conditions to create an accurate model. Measurements are as accurate as possible in order to obtain the results of the smallest error.

2.2.2. Modelling by part
The model must be made and divided into several parts so that it is easy to provide input on each component in the engine component that has been designed. Figure 2 is a schematic model of the simulation engine. In the case of engine modeling, both conventional and semi-free pistons are the same. The difference between the two lies in the data input on the FMEP. In this study, it is defined that the difference between the two engines lies in the magnitude of the friction loss in the engine. As has been done the calculation of friction at various speeds, as presented in table 2. The table above has been calculated at full load (100 loads) at each speed.
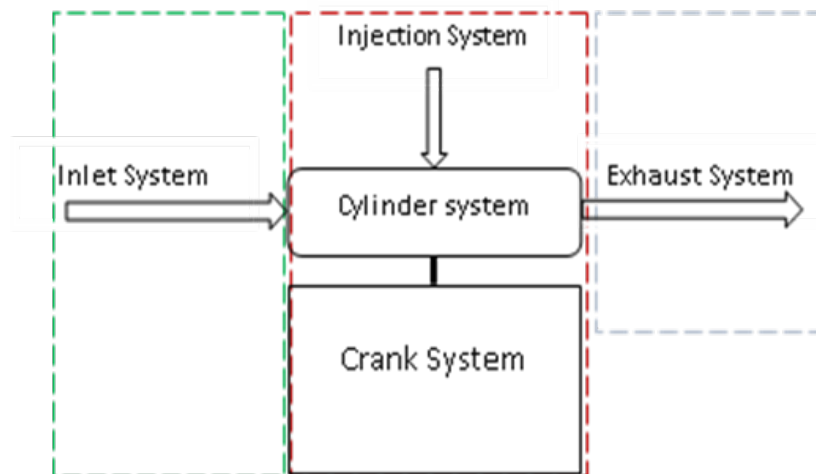

Figure 2. Schematic modeling of the engine

Table 2. FMEP for both Conventional Total Engine and Semi free Piston

Speed (Rpm)	Piston Speed (m/s)	FMEP of Conventional Engine (Bar)	FMEP of Semi Free Piston (Bar)
600	1.29	1.556	1.426
1200	2.58	2.343	2.083
1800	3.87	3.212	2.822
2400	5.16	4.099	3.580
3000	6.45	4.995	4.346
3600	7.74	5.898	5.116
4200	9.03	6.797	5.889
4500	9.68	7.249	6.276
4800	10.32	7.703	6.663
5400	11.61	8.612	7.438

2.2.3. Defining Objects

For model design, diesel engine parts must be made by entering data according to the required parameters. This is called object definition. Basically, the model is divided into 3 main systems, including the intake system, the combustion chamber including the fuel injection system along with the transmission system, and the exhaust system.

2. 3. Modelling of Linear Engine

The steps are similar to those performed in conventional engine modelling, but modify the formula for friction loss (FMEP). As shown in table 2, there is a difference in the amount of FMEP between conventional engines and semi-free pistons. This study also observed the load variable, so that the model needs to be added an alternator to variety the partial load. The alternator is mounted on the crank of the model system.

2.3.1. Running Simulation

After the modelling process along with data input is complete, the model is ready to be simulated. Conventional engines and linear engines are simulated with variable speed and load. So that the data is obtained in the form of power, torque, SFOC, and combustion characteristics such as heat release, pressure, and ignition delay.

2.3.2. Validation

Since the engine is still new, it is a bit difficult to validate it. This research is done by validating the conventional engine model. The validation method adopted the one suggested by Rask and Sellnau [5]. To reduce the cost and time of powertrain development encourages the development of more advanced calibration techniques. Whereby simply validating the simulation results, the accuracy is declared acceptable. Invalidating the newly designed engine, Rask and Sellnau used GT Power engine simulation software and the engine model was validated through limited dynamometer testing. This research has also been modelled using an alternator (dynamometer) by providing a limited load at each constant rotating speed. This study measures the specific power, torque, and fuel consumption of conventional engine models. These three performances are used to measure the performance of the semi-free piston engine.

3. Results and Discussion

The simulation is carried out based on the semi-free piston linear engine that has been designed in previous studies. Every time the simulation is run, the simulator software generates several output files containing the simulation results in various formats. Most of the output is available in data processing applications, which can be used to view graphs and analyze the output. After the simulation is complete, a report summarizing the simulation can be generated. Simulations carried out at various speeds were also carried out using different loads, ranging from 20%, 40%, 60%, 80%, 100%, and 20% overload. This is done to find out in more detail the engine performance characteristics.

3.1. Prediction of Engine Performance

Performance matters are fuel requirements, power, torque, and average effective pressure. The four indicators are predicted to be compared in this study. The presentation can be seen in the sub-section on engine performance.

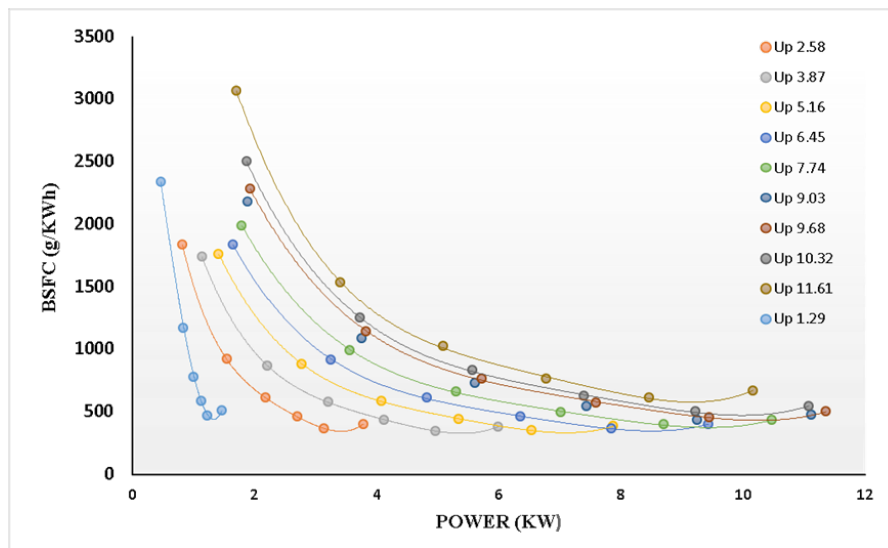*3.1.1. Prediction of specific fuel consumption characteristics.*

Figure 3. Fuel consumption at each piston speed to power

Specific fuel oil consumption (SFOC) is one indicator of engine performance. In this prediction, the SFOC for power at each revolution generated by the model is shown in Figure 3. Very high fuel consumption occurs in engines with low power output and tends to decrease fuel consumption at higher power, but fuel consumption increases again at higher power outputs.
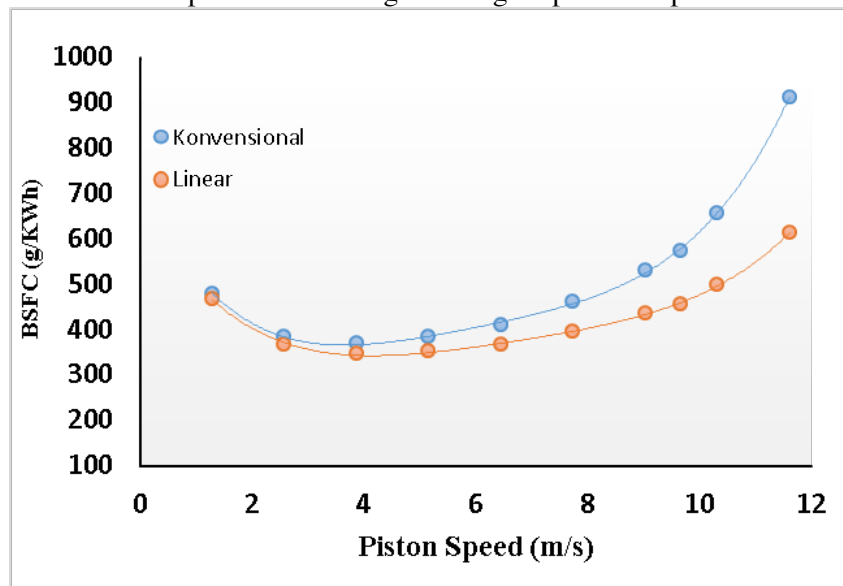

Figure 4. Graph of SFOC Vs piston speed

The SFOC of an engine is one of the most important indicators of engine performance. The SFOC prediction generated from the linear engine is better than the conventional engine. The SFOC difference in linear engines at each piston speed is about 2.21% to 37% less than in conventional engines. The smallest SFOC produced by the two engines is at a speed of 3.87 m/s where the conventional engine is 370.54 g/kW-h and the linear engine is 347.57 g/kW-h. The SFOC trend on the variable speed can be seen in figure 4.

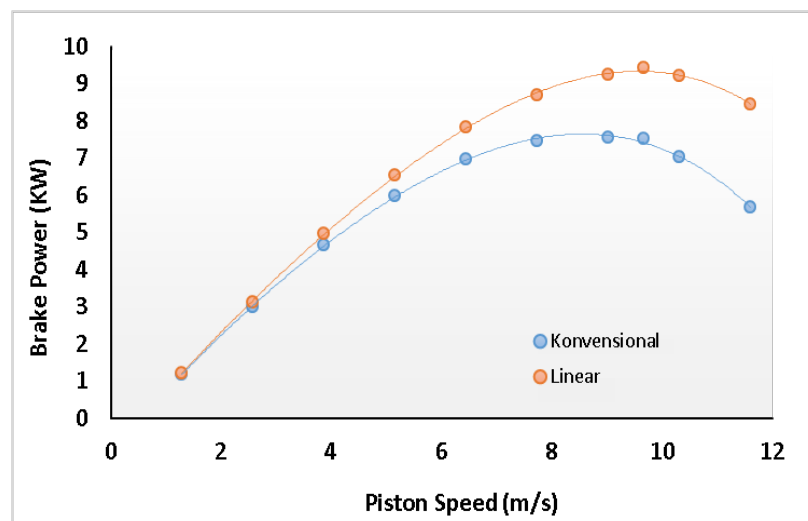### 3.1.2. Prediction of Engine Power Characteristics
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Figure 5. Graph of brake power vs piston speed

The power value can be increased by reducing the frictional force that occurs in the engine. The difference in power between a conventional engine and a semi-free piston engine can be seen, that a semi-free piston engine has less friction which results in greater power. In the variable speed, there is a significant difference between the conventional engine and the semi-free-piston engine. This increase in power is obtained from the elimination of friction by eliminating the rotary motion of the engine. The greater the friction, the lower the power generated. The difference in these characteristics can be seen in Figure 5. At a speed of 9.68 m/s, the conventional engine only reaches a power of 7.53 kW while the semi-free piston engine reaches a power of 9.45 kW.

3.1.3. Prediction of Engine Torque Characteristics
Torque is one of the most important indicators to determine engine performance. Figure 6 shows a graph of the torque characteristics of the semi-free piston engine which tends to look larger than the torque produced by a conventional engine. The highest torque characteristics are produced by the semi-free piston engine and the conventional engine is at a speed of 3.87 m/s, at which time the torque produced by the semi-free piston engine is 26.37 N-m. While on the conventional engine the largest torque produced is 24.74 N-m.
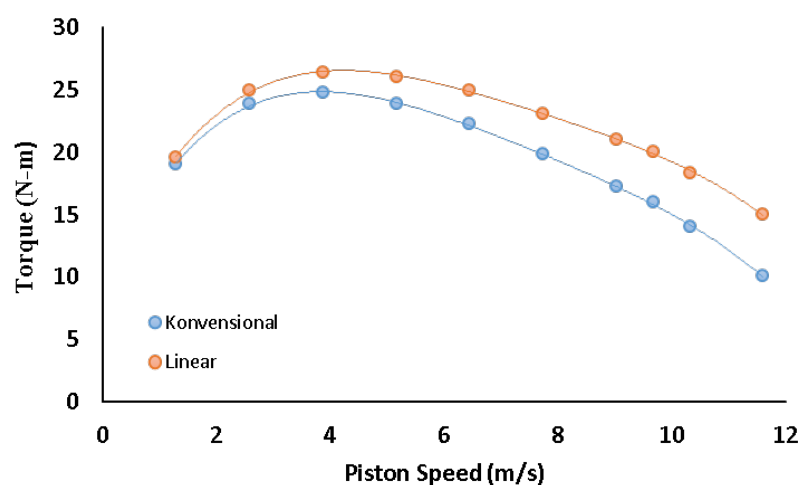

Figure 6. Graph of brake torque Vs engine speed

3.1.4. Prediction of Engine Mean Effective Pressure Characteristics

Figure 7 shows the mean effective pressure (MEP) generated from the simulation. When the piston speed is 3.87 m/s, the MEP of the linear engine is at 6.25 bar while on the conventional engine it is only 5.87 bar. Both MEP values are the highest of all piston speeds.
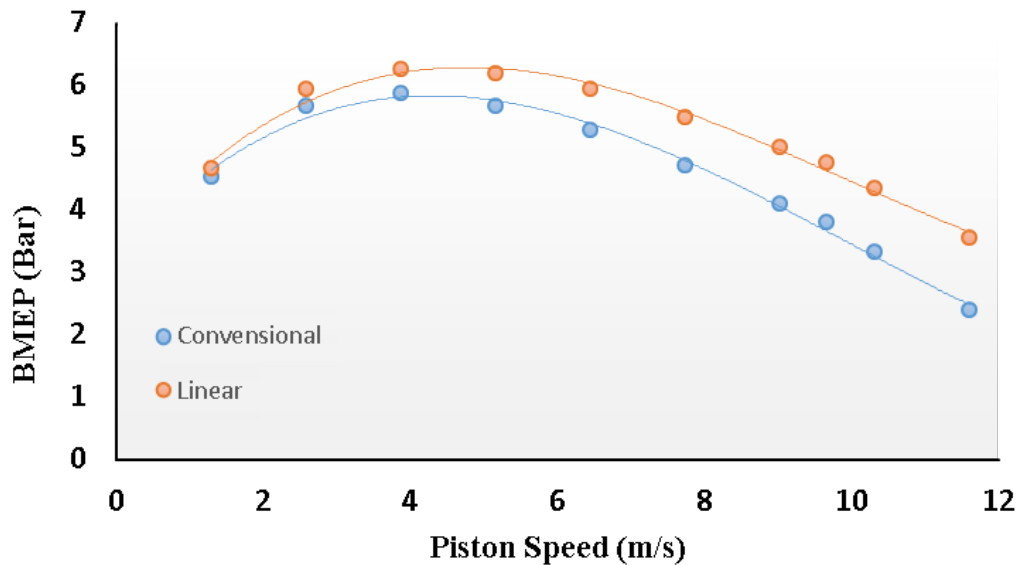

Figure 7. Mean effective pressure Vs engine speed

3.2. Combustion Process

In studying the combustion process related to performance predictions, only pressure and ignition delay characteristics are presented. Theoretically, the combustion process has no effect on performance. Performance is affected by friction because the philosophy of the free piston is to reduce friction.

3.2.1.Pressure characteristics

In the dual-piston, there are 2 cylinders, namely the left and right, in this study the left cylinder was taken (cylinder no. 1). Figure 8 shows a graph of the pressure in the cylinder which is an indicator of the combustion process with variations in load, the highest pressure occurs at 100% load (full load) and occurs around the top dead centre. It is in this area of the upper dead centre that a lot of fuel is burned so that the pressure reaches its maximum peak. The highest pressure value is 106.2 bar at a crank angle of 6.84 degrees. The pressure drops as the piston moves down when the combustion process also ends. The trend of increasing pressure is very clear even though the increase in load is not very significant when the pressure changes.
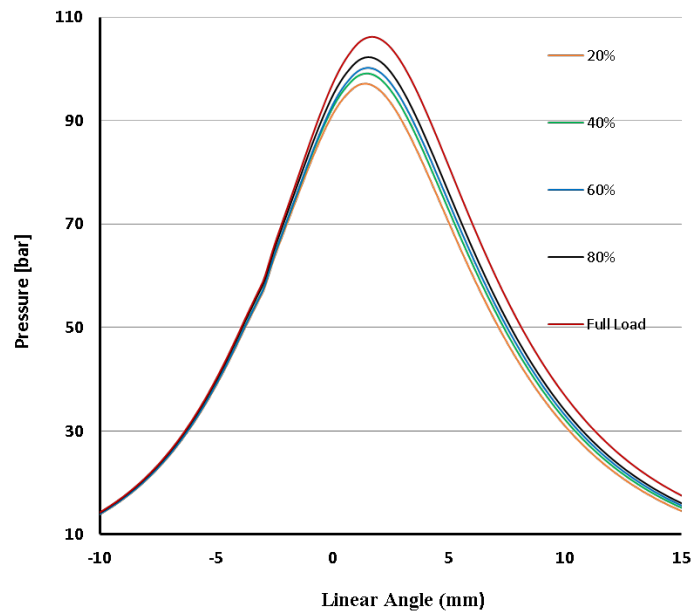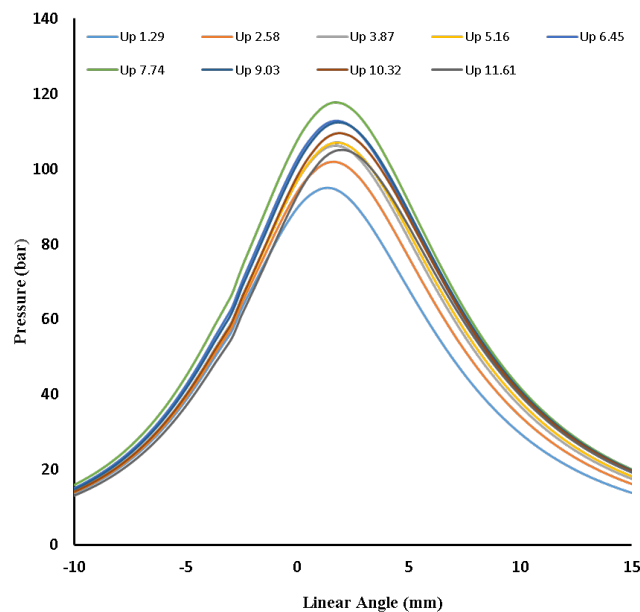
Figure 8. Pressure in cylinder model 1

Figure 9. Pressure in cylinder 1 with variable speed

Figure 9 shows that with variations in speed, the highest pressure in cylinder number 1 occurs at a piston speed of 7.74 m/s then tends to decrease at low speeds, and occurs in the top dead centre region because at this stage at high speeds it has an impact on increasing very significant pressure. To increase the speed, extra fuel is needed which has an impact on increasing combustion energy. The highest pressure value is 117.69 bar at a crank angle of 6.84 degrees.

From the observations of the two combustion processes, namely the speed variable and the load variable, both have an impact on increasing the maximum pressure of the combustion process. Studying the existing trends, the increase in engine speed is more significant than the increase in engine pressure.

3.2.2. Ignition delay Characteristics

Ignition delay is one that affects the start to the end of combustion, so it can affect the performance of an engine. Ignition delay is a process to prepare the reaction between fuel and air. A good ignition is a short one, so there is no need to build up the amount of fuel injected into the cylinder. Figures 10 and 11 show the ignition delay value for piston speed and engine linear loading.
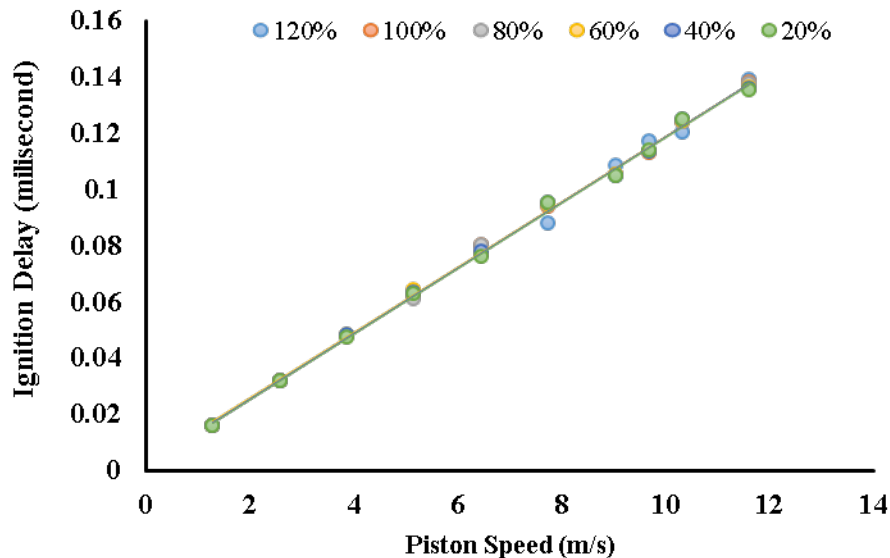

Figure 10. Ignition delay graph on cylinder 1 with variable speed

Studying the ignition delay based on the characteristics in Figures 10 and 11, it appears that engine speed has a very significant effect on the delay of the ignition engine. The faster the engine speed could be impacting the increase in the delay period of ignition (see figure 10). The impact of a long delay period on this increase in velocity is shown in the pressure diagram (see Figure 9). Pressure is also very significant to variable speed. This implies that increasing engine speed has an impact on hard combustion, and there may be knocking on any engine if the speed continues to be increased. On the other hand, the increase in load does not significantly affect the ignition delay. There is a correlation between the compression ratio and the peak pressure in the cylinder vs the injection time, and by adjusting the harmonious design, the optimum design will be obtained. [8]. A thought-through optimizing the combustion process by operating a variable compression pressure will result in a good combustion process. This thinking is still a concept that needs intensive research implementation. [9]
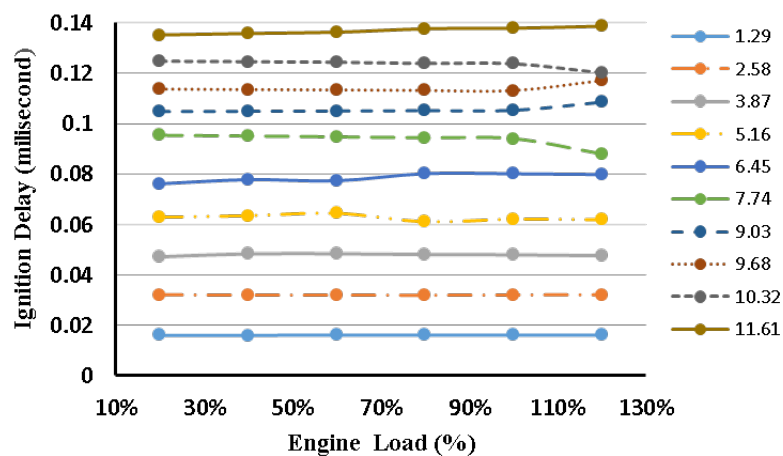

Figure 11. Graph of ignition delay on cylinder 1 with variable load

4. Conclusion
From the simulation results, it is found that the semi-free piston engine modified through reverse engineering produces better performance. The increase in performance produced by the semi free-piston engine is caused by a significant reduction in engine friction relative to conventional engines. The average frictional force is reduced by 10 – 25% of the friction produced by a conventional engine. The performance predictions and the combustion process are as follows:

1. From the running simulation, the lowest SFOC produced by both types of engines is at 3.87 m/s where the conventional engine is 370.54 g/kWh and the semi-free piston engine is 347.57 g/kWh.
2. The power achieved at a speed of 9.68 m/s from the conventional engine is 7.53 kW, while the semi-free piston engine reaches 9.45 kW.
3. The largest torque of both engines is achieved at a speed of 3.87 m/s; the results are 24.74 N-m and 26.37 N-m respectively for conventional engines and semi free-piston engines.
4. The mean effective pressure (MEP) produced is at a speed of 3.87 m/s respectively 5.87 bar and 6.25 bar for conventional engines and semi-free piston engines.
5. The highest pressure on the engine type is the same at 100% load (full load) of 117.69 bar at a crank angle of 6.84 OCA.

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