SIMULATION OF FOUR STROKE FREE PISTON DIESEL ENGINE

HAFNIZAR BIN MUHAMAD SHAHARUDDIN

UNIVERSITI MALAYSIA PAHANG

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HAFNIZAR BIN MUHAMAD SHAHARUDDIN

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SUPERVISOR DECLARATION

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature	:	....
Supervisor	:	Prof Madya Dr. ROSLI B ABU BAKAR
Position	:	Lecturer/Supervisor
Date	:	10 November 2008

Signature	:	....
Co-Supervisor	:	Mr INDRA RANU KUSUMA
Position	:	Co-Supervisor
Date	:	10 November 2008

Signature	:	....
Name of Panel	:	
Position	:	
Date	:	

STUDENT DECLARATION

I declare that this entitle "*simulation of four stroke free piston diesel engine*" is the result of my own research expect as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature: …………………………..
Name : Hafnizar bin Muhamad Shaharuddin
Date : 10 November 2008

To my beloved father Mr. Shaharuddin Bin Abdul Manap

To my beloved mother Mrs. Sarina Binti Hj Sulaiman

Sisters and brothers

All my friends

May Allah bless all of you

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ABSTRACT

Free-piston engines are under investigation by a number of research groups worldwide due to their potential advantages in terms of fuel efficiency and engine emissions. Some prototypes have emerged, mainly aimed for vehicle propulsion, and have reported favourable performance compared to conventional technology. This paper describes the design of a four stroke free piston diesel engine. The simulation is described, and extensive simulation results are presented, giving insight into engine operating characteristics and performance. The operating characteristics of the free-piston engine was found to differ significantly from those of conventional engines, giving potential advantages in terms of fuel efficiency and emissions formation due to fast power stroke expansion.

ABSTRAK

Linear enjin merupakan enjin yang masih didalam penyelidikan para penyelidik di seluruh dunia kerana potensinya dalam menjimatkan bahan bakar dah mengurangkan pencemaran. Beberapa rekaan telah dibuat terutamanya untuk kegunaan kenderaan dan telah diketahui mempunyai potensi yang lebih baik berbanding enjin biasa. Projek ini bertujuan untuk mereka bentuk dah mengkaji potensi linear enjin. Linear enjin yang digunakan untuk menjayakan projek ini adalah jenis Empat Lejang linear diesel enjin. Cara linear enjin beroperasi adalan berbeza berbanding enjin biasa dan memberikan kelebihan pada penjimatan menggunakan bahan bakar serta mengurangkan pencemaran kerana lejangnya yang lebih pantas.

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Hp	-	Horse power
g	-	Gravity
V	-	Velocity
M	-	Mass
T	-	Torque
F	-	Force
b	-	Distance from rotor to load cell
P	-	Brake power
N	-	Engine speed

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CHAPTER 1

INTRODUCTION

1.1 Introduction

It is generally accepted today that the internal combustion engine represents a main source of power production. The most common mechanical configuration of an internal combustion engine is represented by the traditional slider-crank mechanism, which permits the conversion of the reciprocal linear motion of the piston to the rotational motion of the crankshaft. Another mechanical configuration of an internal combustion engine is represented by the rotary engine known as the “Wankel” engine. This engine offers a more compact size than the reciprocating engines and multifuel capability. Having fewer moving parts than reciprocating engines, they have a lower weight and therefore high specific power density. However these engines have their own weaknesses and these is represented by the leakage encountered at the interface between the rotor apex seals and housing. Most piston engines are of the slider-crank mechanism type, but there is a second class of piston engines, termed free-piston or linear engines, in which the engine's pistons reciprocate freely without the use of a rotating crankshaft or flywheel.

1.2 Problem Definition

A large amount of literature discusses the problem of friction in internal combustion engines in conventional rotating engines. In a linear engine, the situation is already simplified compared to a rotating engine, because there is no crankshaft. Except for the effect of gravity (which is negligible compared to the side thrust in a slider-crank engine), there is no side thrust on the piston, therefore the piston does not move in the cylinder in radial direction. The sources of friction force in a linear engine are friction between the piston rings and the cylinder liner and friction between the piston skirt and the cylinder liner. This phenomenon makes the linear engine having more advantage than rotating engine because less force needed to against the friction and make it fuel economic.

1.3 Objective

i. Modify the design of conventional diesel engine become linear engine.
ii. Study the simulation of linear engine through GT power software.
iii. Compare the performance between the linear engine and conventional engine.

1.4 Scope

i. Literature review about linear engine.
ii. Modify and sketching the linear engine using Computer Aided Design (CAD).
iii. Analysis the linear engine using GT power software.
iv. Analysis and documentation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With a reference from various source such as books, journals, notes, thesis and internet literature review has been carry out to collect all information related to this project. This chapter discussed about history, basic concept, application and configuration of linear engine. The researches about advantages of linear engine compare to the rotational engine from internet to collect all information. The literature reviews in this project it will focusing and more information about the application on the types of linear engine.

2.2 History of free piston engine

Nowadays, the development of free piston engine has become the center of interest in the development of high quality internal combustion engine. The development of free piston engine generator is used as auxiliary power unit of a Hybrid Electric Vehicle. The function of auxiliary power unit is to supply the power for electric motor and to recharge the batteries [2]. The number of Free Piston Engine has been already proposed since in 1928. However, the majority of them are not commercially successful. During that time, the technology of free piston cannot compete with the rapid advancement of Internal Combustion Engine (ICE). It can be seen from technical literature of free piston engine that describe only a particular design and provide an introduction to free-piston engine principles.

Until in the late 1940s, it is reported by General Motors and Ford Motor Company that the free piston gas generator was installed in a number of stationary power plants and some marine installations as vessel propulsion. Then, the General Motor Research (GMR) modified twin gasifier to power an automobile for the first time. The engine was named “Hyprex” engine that a 250 Hp (186kW) in ward compressing engine. Hyprex was installed in the XP-500 experimental car, as shown in Figure 2.1. The 1956 General Motors XP 500 concept car's power plant is a low-temperature turbine [2].

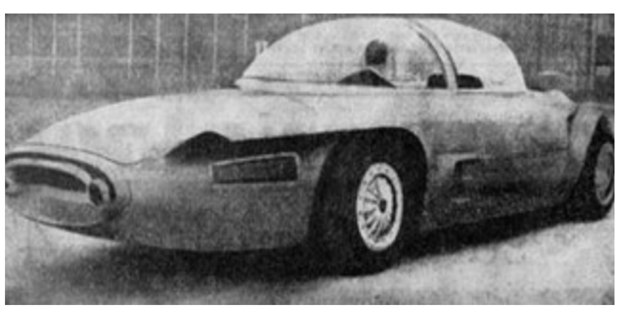

Figure 2.1: General Motor XP 500

Opposing pistons within a single cylinder, and connected to no crank shaft, vent their exhaust gasses into the turbine. The purpose of having the combustion chamber outside the turbine is to lower the temperature of the gasses, thus allowing the use of low cost materials and fuels. Unfortunately, the Hyprex could not compete with traditional engines and it was abandoned (Amann C.A, 1999).

The free-piston engine linear generator is the most recent application of the free-piston concept. Hybrid vehicles are presumed to be the ultimate use for these engines (Van Blarigan et al., 1998). For example, Van Blarigan et al. (1998) propose the free-piston linear alternator depicted in Figure 2.2 to generate approximately 30kW and use Homogeneous Charge Compression Ignition Combustion (HCCI).

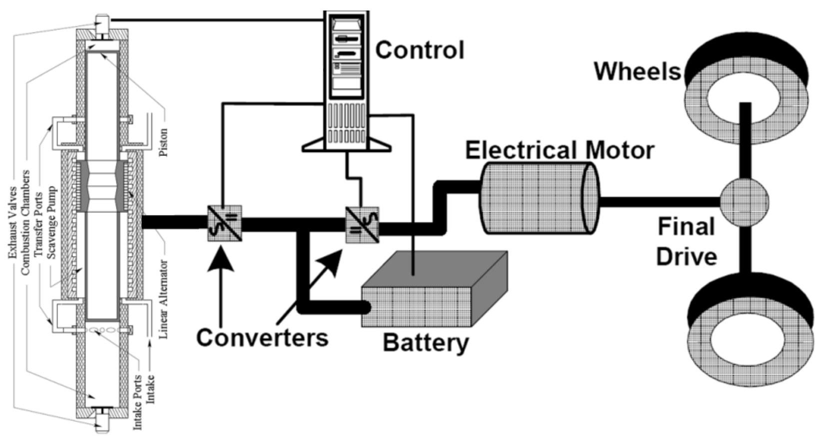

Figure 2.2: The free piston engine generator in HEV [4]

One should note however, that a prototype is primarily concepts. Consequently data such as force-load characteristics of linear alternators are not known. Consequently particulars and design requirements such as starting, stroke control, and load response of free-piston linear-generators are not known. Although, the work of Goldsborough and Van Blarigan (1999) suggests that the design and control of a free-piston linear-alternator employing HCCI combustion is a challenge.

2.3 Basic concept of linear engine

In a linear engine, there is no crankshaft that would define the piston's motion or its top and bottom dead center [2][3][7]. Instead, the piston speed and position is the result of the forces acting on the translator and top and bottom dead centers can vary from cycle to cycle. The alternating mass consists of the pistons, piston rings, piston pins, pin retainers, connecting rod, the moving components of the electric machine, and the fastener components. The forces acting on the translator are: inertial force, friction force, gas forces (compression and expansion), and load force.

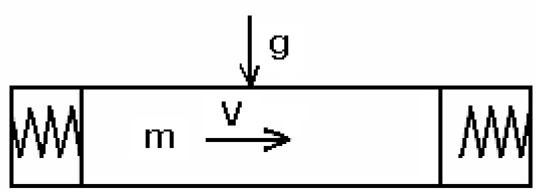

Figure 2.3: The linear engine can be thought of a mass spring system [5].

The linear engine can be thought of as a simple mass-spring system as shown in figure 2.3. The mass represents the combined mass of the translator, the two springs represent the gas being compressed in the cylinders and the exciting force represents the gas forces during expansion or compression. The gap between the translator and the spring on the right hand side represents the range where ports are open in both cylinders at the same time. The exhaust port is already uncovered in the expansion cylinder, letting the expansion pressure blow-down. At the same time, ports are still uncovered in the compression cylinder therefore compression has not started yet.

In a linear engine, the problem of friction is already simplified compared to a rotating engine, because there is no crankshaft. Except for the effect of gravity (which is negligible compared to the side thrust in a slider-crank engine), there is no side thrust on the piston, therefore the piston does not move in the cylinder in radial direction. The sources of friction force in a linear engine are friction between the piston rings and piston skirt with the cylinder liner [1][4].

Two types of gas forces act on the piston-load assembly compression and expansion. Because the engine operates on a two-stroke cycle, compression takes place in one cylinder while expansion takes place in the other and vice versa. Because the engine is symmetrical, the modeled processes taking place in the two cylinders are identical, happening with a half cycle time shift between them.

2.4 Applications of linear engines

There were three main applications of linear engines

i. used as gasifiers along with gas turbines
ii. used to drive linear positive displacement hydraulic pumps
iii. used coupled with linear alternators

2.4.1 Gasifier

Linear engine gasifiers have various sizes and arrangements, but they all fulfilled the same role: they were combusters for gas turbines [5]. A gasifier engine pumps clean air and its own exhaust into a tank from where the warm, pressurized mixture of air and exhaust is led to the inlet of the gas turbine. The free piston engine used as a gasifier is shown in Figure 2.4.

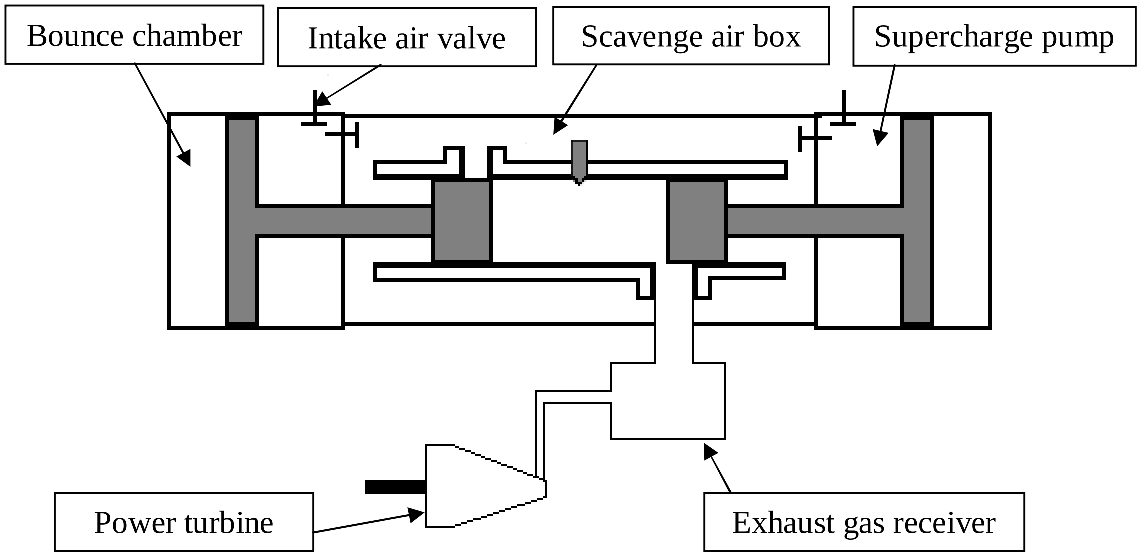

Figure 2.4: Free Piston Engine used as a Gasifier [6]

The particular design shown in Figure 2.4 is an opposed piston arrangement with a common combustion chamber in the middle and bounce cylinders at the two ends. The bounce cylinders are basically air springs that accumulate energy during expansion and return it during compression. The energy stored in the air springs is used to compress the air in the combustion cylinder during combustion. When proper compression is reached fuel is injected into the combustion chamber where it autoignites and presses the pistons outward compressing air in the bounce chambers and sucking air into the space under the large piston pump. When the ports are revealed exhaust exits the cylinder and fresh air from the air box flows through the cylinder to the air tank. The pistons start moving inward, as the result of decreased pressure in the combustion chamber and the high pressure in the bounce chamber. Compression starts when intake and exhaust ports are covered by the pistons and with the same motion the piston displaces the air from the space under the pump pistons to the pressure box and the cycle starts again.

2.4.2 Hydraulic or pneumatic pump

Linear engines can be connected to positive displacement, linear, hydraulic or pneumatic devices such as piston or membrane pumps to generate pressure or flow supply for hydraulic or pneumatic actuators or motors. Several different designs and arrangements were developed and simulated for various purposes. For example, the single piston and dual pistons configuration was a typical application [5].

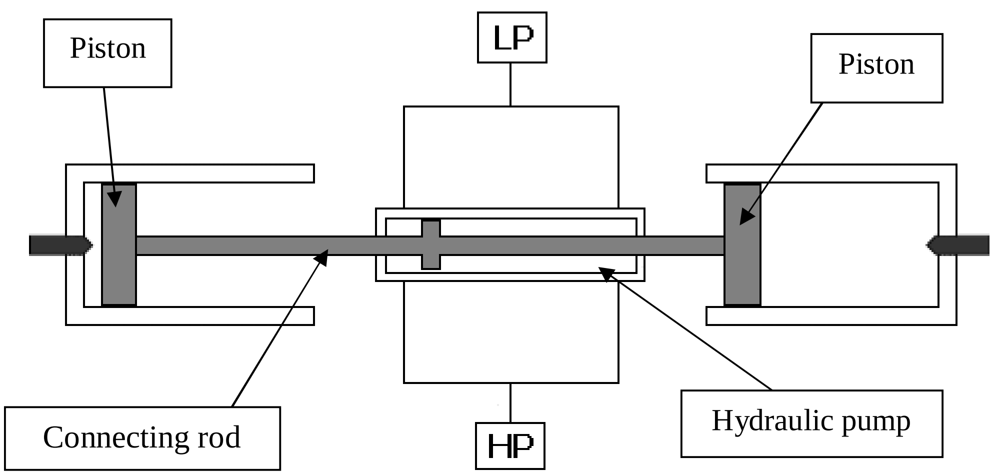

Figure 2.5: Dual piston hydraulic pump [6]

The engine was a dual-piston, two-stroke, loop scavenged diesel linear engine that drove a hydraulic pump located between the cylinders. As it was a dual piston two-stroke design, the engine did not require assistance from the hydraulic pump to sustain operation. The engine applied a Ganser-Hydromag common rail injection system. The engine was started using the hydraulic pump as a hydro-motor.

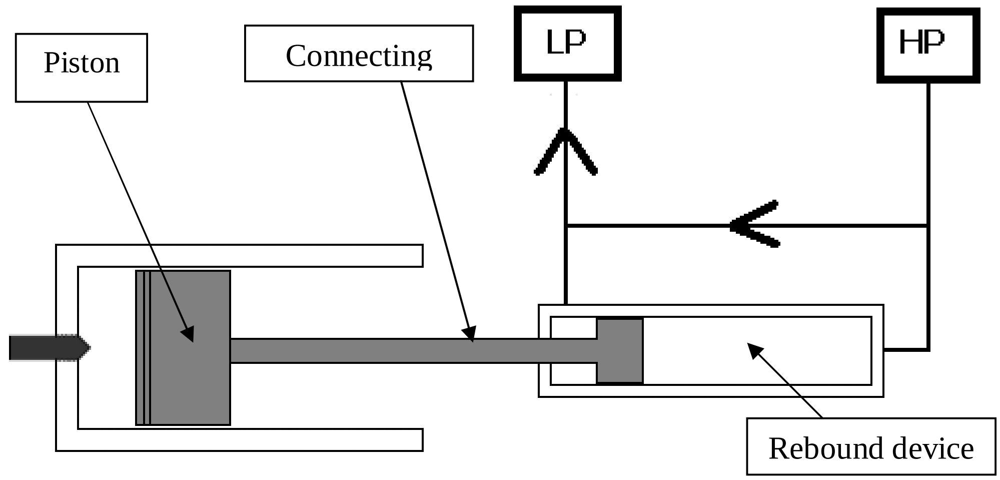

Figure 2.6: Single piston hydraulic pump [2]

Figure 2.6 shows a single cylinder linear engine hydraulic pump. As it was a two-stroke single-cylinder design, a hydraulic accumulator was applied to store energy during the power stroke that was used to drive the piston during the compression stroke. The engine design used pulse-pause modulation to control the operational frequency. When the piston was on the power stroke, the hydraulic pump used its power to pump the fluid as a useful power output. At the same time, part of the power was used to build up pressure in the compression accumulator through a check valve. Because the engine design was a single cylinder engine there was nothing that would push the piston up to cause compression. The system stopped and stayed in a standby state until the frequency control valve opened and let the pressure of the accumulator act on the compression piston that moved the piston towards Top dead center compressing the air in the cylinder. After compressing the air, fuel was injected and combustion took place resulting in a power cycle, pumping fluid from the low-pressure side to the high-pressure side as well as to the hydraulic accumulator. The process was repeated at the opening of the frequency control valve.

2.4.3 Electric generator

A linear engine can be coupled with a linear generator to form an electric generator set. The generator set can be used as a stand-alone mobile power generator or as an auxiliary power unit of a hybrid vehicle. Previous research at West Virginia University (WVU) included the simulation of a four-cylinder four-stroke linear engine, the simulation of a two-cylinder two-stroke linear engine, and the development of a spark ignited two-cylinder two-stroke prototype linear engine. The linear engine prototype developed at WVU can be seen in Figure 2.7.

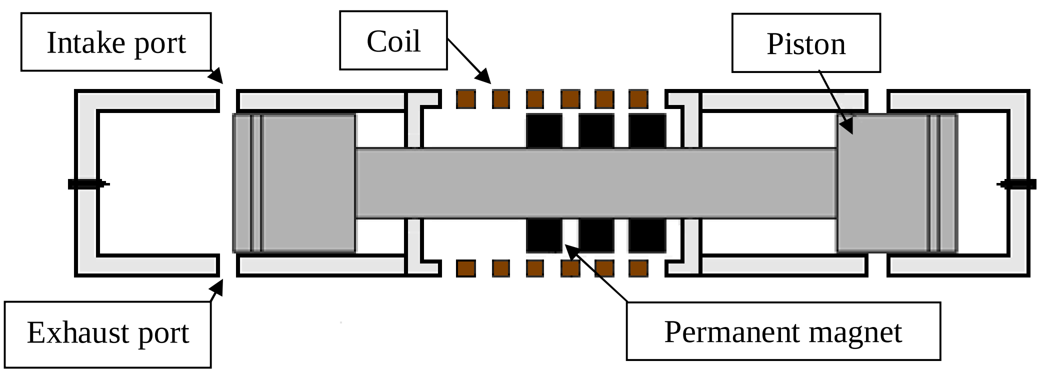

Figure 2.7: Illustration of the free-piston engine generator [2]

WVU's 1st generation linear engine was a dual-piston two-stroke model and it is spark ignited. The engine had 36.5 mm bore and a maximum stroke of 50 mm. A brushless permanent magnet DC alternator was used to apply load and gain power from the system. An engine prototype is reported to have achieved 316 W power output at 23.1 Hz, with 36.5 mm bore and 50 mm maximum stroke. High cycle-to-cycle variations are reported, particularly at low loads.

2.5 Linear engine configurations

The following linear engine configurations are achievable practically: Single piston, Double piston (dual piston, opposed piston), Four pistons (dual piston, opposed piston, complex piston configuration) and Multiple pistons (dual piston, opposed piston, complex piston configuration).

2.5.1 Single piston

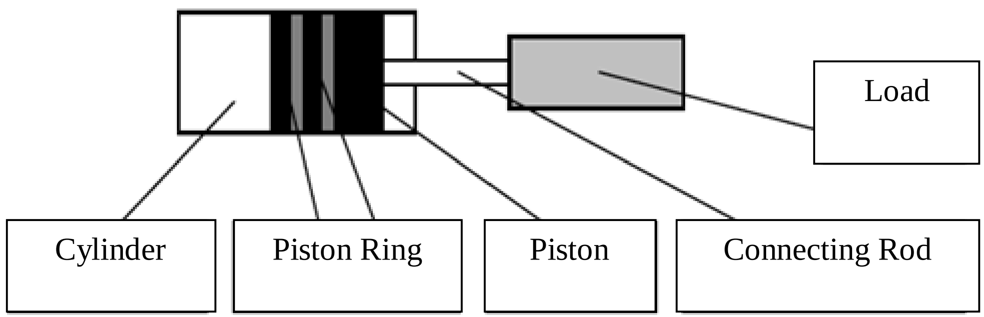

Figure 2.8: A single cylinder configuration

Figure 2.8 show a single cylinder configuration. At a minimum, two pistons must be linked together when using two-stroke engines and four pistons must be linked together when using four-stroke engines to ensure a power stroke for every stroke. An exception is when a double acting piston is used and the volume below the piston as well as the volume above it are both used for combustion. As a conclusion, a power stoke is needed for every half of a frequency cycle (revolution in conventional engines). However, if there are fewer cylinders in a design then an additional power source is required to move the piston(s) during its power consuming stroke(s). A hydraulic accumulator, a linear electric motor, or even a spring can be used to move the piston on the power consuming strokes resulting in continuous operation [8].

2.5.2 Double piston

2.5.2.1 Dual piston / Opposed piston

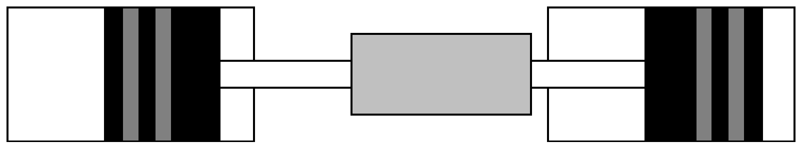

Figure 2.9: Dual piston linear engine configuration

Figure 2.10: Opposed piston linear engine configuration

Figure 2.9 and Figure 2.10 show the dual piston and the opposed piston arrangements for two cylinder linear engines respectively. Figure 2.9 shows two arrangements. One is where each piston has its own cylinder and the load is placed between them. The other is when the pistons are united and share a cylinder and load is applied on each side. In the latter one, the combustion takes place on the connecting rod side of the piston, making cylinder sealing a significant issue.

The dual piston version is desirable for two-stroke operation as it provides a power stroke for each stroke of the engine. Two cylinders for the dual piston arrangement two-stroke operation are sufficient to run the engine without an external energy source or an energy accumulator. However, the pistons, connecting rod, and the moving components of the load form a high reciprocating mass that causes undesired vibration. However, the opposed piston configuration would eliminate the vibration problem since the pistons always move in the opposite direction resulting in zero net force on the cylinders and the housing [8].

2.5.3 Four pistons

2.5.3.1 Complex piston configuration

Figure 2.11: Four cylinder complex configuration

Figure 2.11 shows a four-cylinder arrangement with complex dual and opposed pistons configuration. On the two-stroke cycle this engine will have a power stroke for each cycle and the reversed motion of the two piston-load assemblies will eliminate vibration.

2.5.3.2 Dual pistons / opposed piston

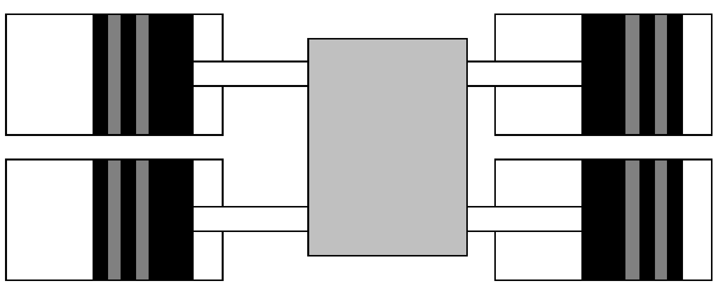

Figure 2.12: Four cylinder dual piston linear engine configuration

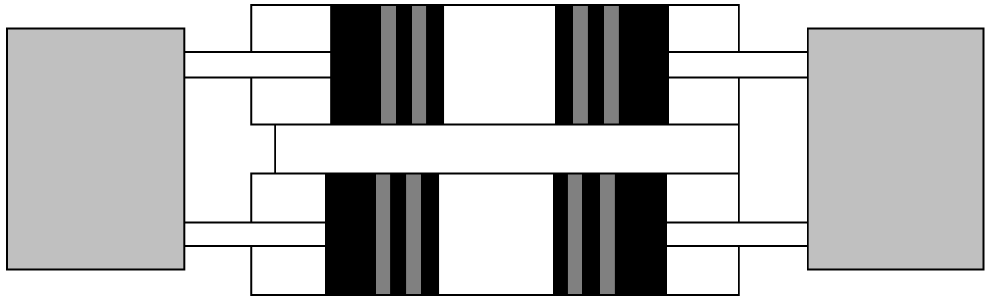

Figure 2.13: Four cylinder opposed-piston configuration

Figure 2.12 and Figure 2.13 show the dual and opposed piston arrangements respectively for four-cylinder linear engines. The cylinder that is on the expansion stroke moves the other cylinder(s). This creates a side thrust on the pistons that is undesirable.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Generally, this project involved in designing and analyzing. The design is four stroke four cylinder linear engines. The drawing process is designed by SolidWork. This design than has been analyzed using GT-power software. This was to compare the different between linear engine and conventional engine. In 3.1 below, it showed the methodology process.

3.2 Project Methodology

i. Literature review about linear engine
ii. Modify the design of conventional diesel engine become linear engine
iii. Study the simulation of linear engine through GT power software
iv. Compare the performance between the linear engine and conventional engine

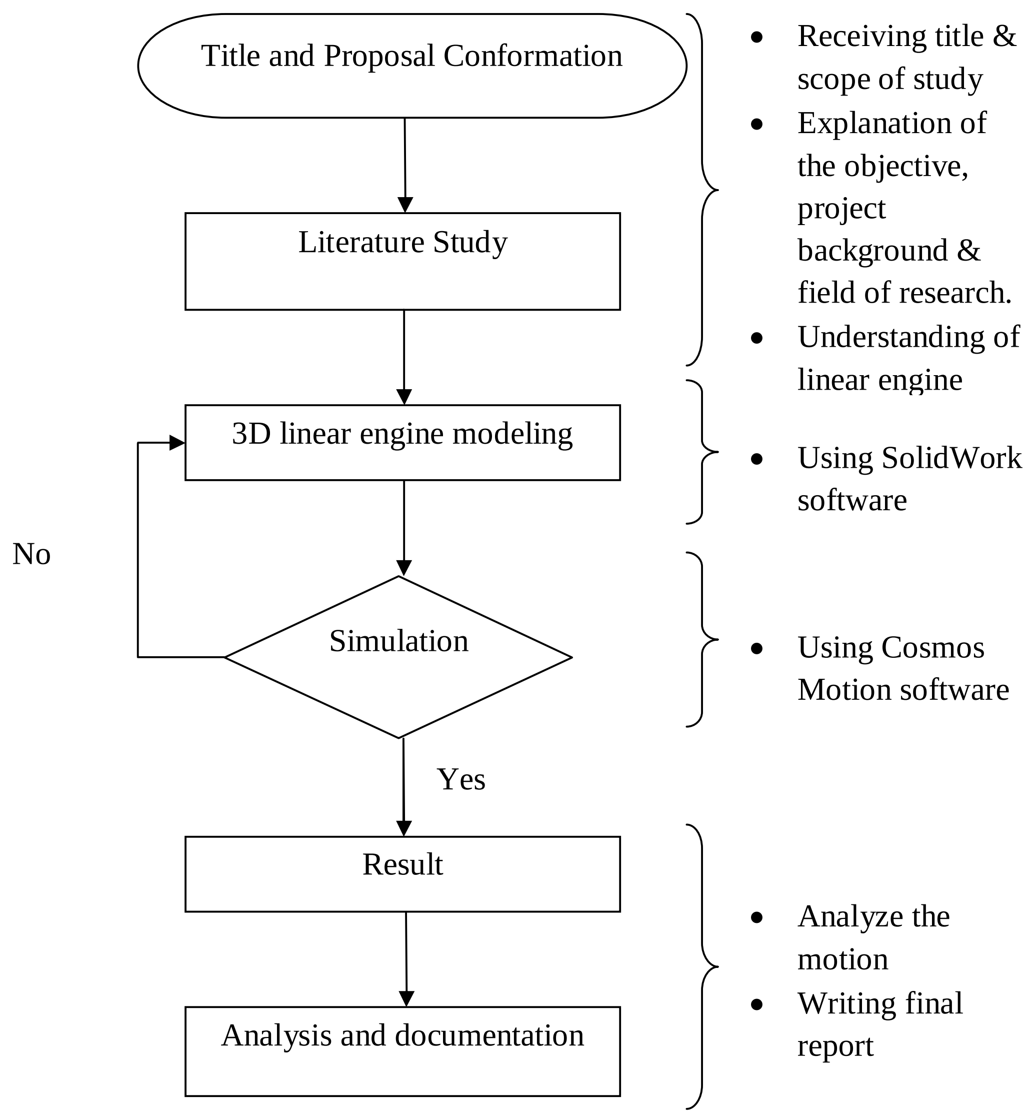

Figure 3.1: The flow chart of methodology

First of all, this project begins with receiving title that had selected and scopes of study from supervisor. The objective, project background and field of research were explained. Second Step was literature review and proposal confirmation. It is important to provide the understanding of linear engine. During this step, make a study, analysis and research about linear engine through other thesis, technical paper, web site, journal, books and many more. Then, the modification progress was start. This linear engine was design using Solid work 2008. First, we must determine how this linear engine can be modifying from conventional Diesel Engine. To become linear, two of the diesel engine must be arrange in opposed configuration and eliminate the entire crankshaft. Others parameters that need to consider were material usage, effect of vibration, reduce space, linear engine stability and wasting material.

After get the concept and idea of linear engine, then interpretation it into several designs. After having discussion with supervisor, the best and suitable design was chosen. The design was having four cylinder four stroke linear engines opposed in configuration. Figure in appendix show the detail of linear engine design. Simulation will be run by using GT-power software. The simulation wants to see the differential performance between linear and conventional engine. The performance such as the brake power, brake torque and brake specific fuel consumption is being analyzed.

3.3 Simulation using GT-power software

The main different between the linear engine and conventional engine is the elimination of rotating crankshaft. Because of the elimination, linear engine is known as the less friction engine. The model of four stroke four cylinder diesel engine is created using GT-power software.

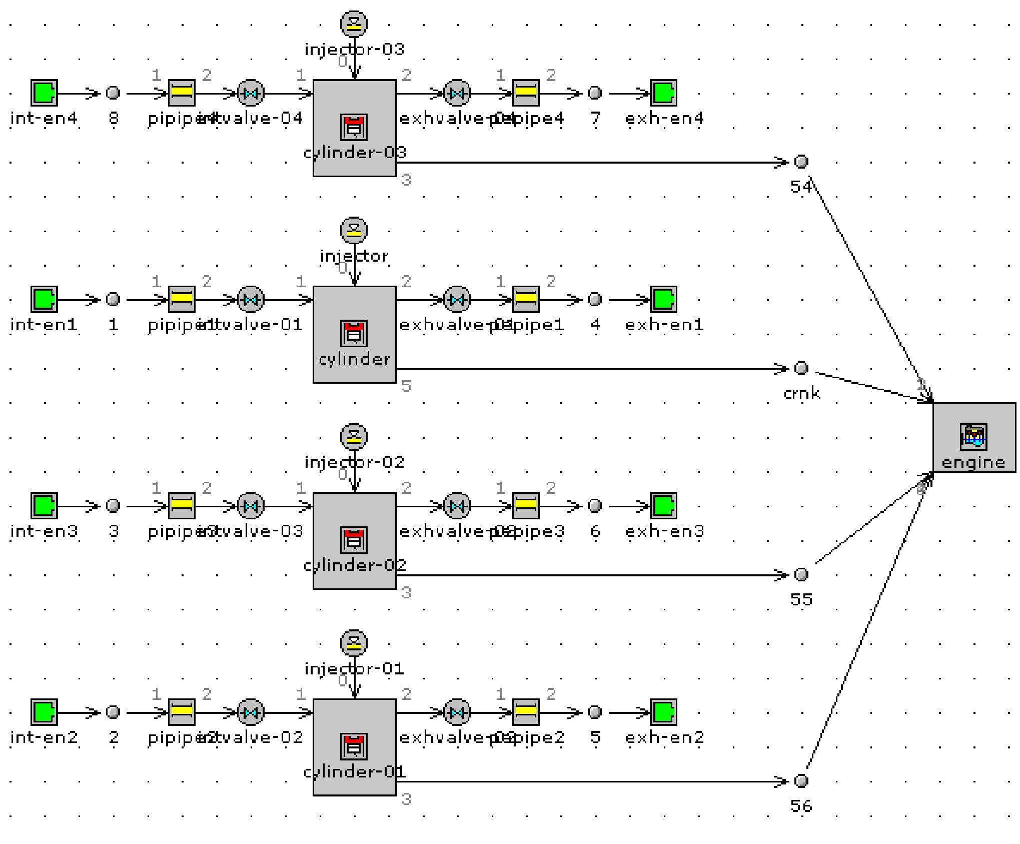

Figure 3.2: The model of 4 cylinder diesel engine through GT-power software

This model is consist of 4 cylinder. The model is having intake, intake manifold, intake valve, combustion chamber, injestor, exhaust valve, exhaust manifold and exhaust. All the dimension of the engine such as bore diameter, length stroke, intake air diameter, exhaust diameter, fuel injected mass and so on is setting as a constant. The different between these two engines is the friction occurs between piston and cylinder liner. So, both engine frictions are setting differently.

3.3.1 Intake environment setting

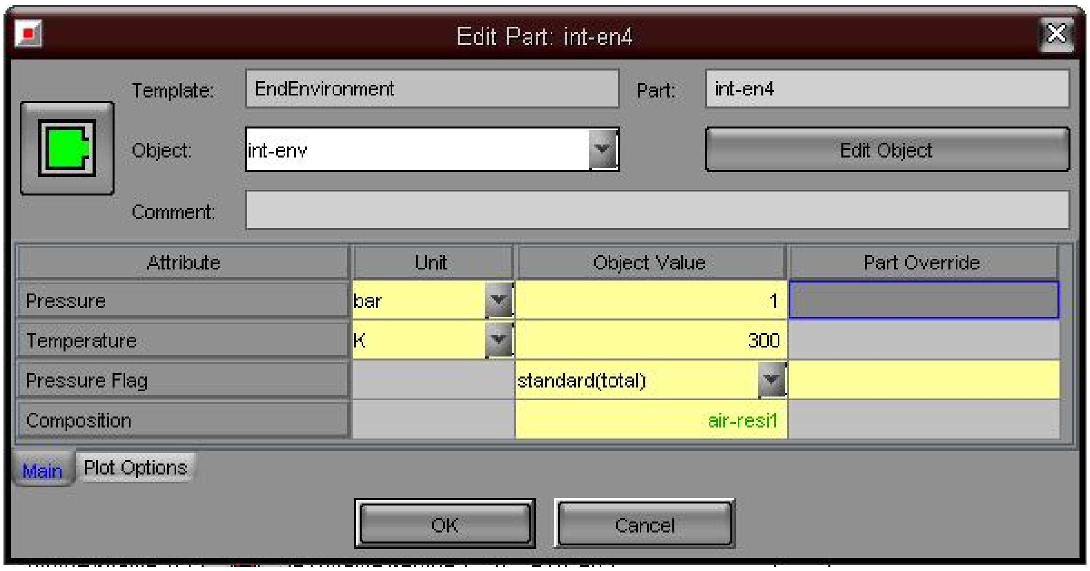

Figure 3.3: Intake environment setting

At the intake, the pressure is setting as 1 bar and the temperature is 300 Kelvin based on the standard environment.

3.3.2 Intake manifold setting

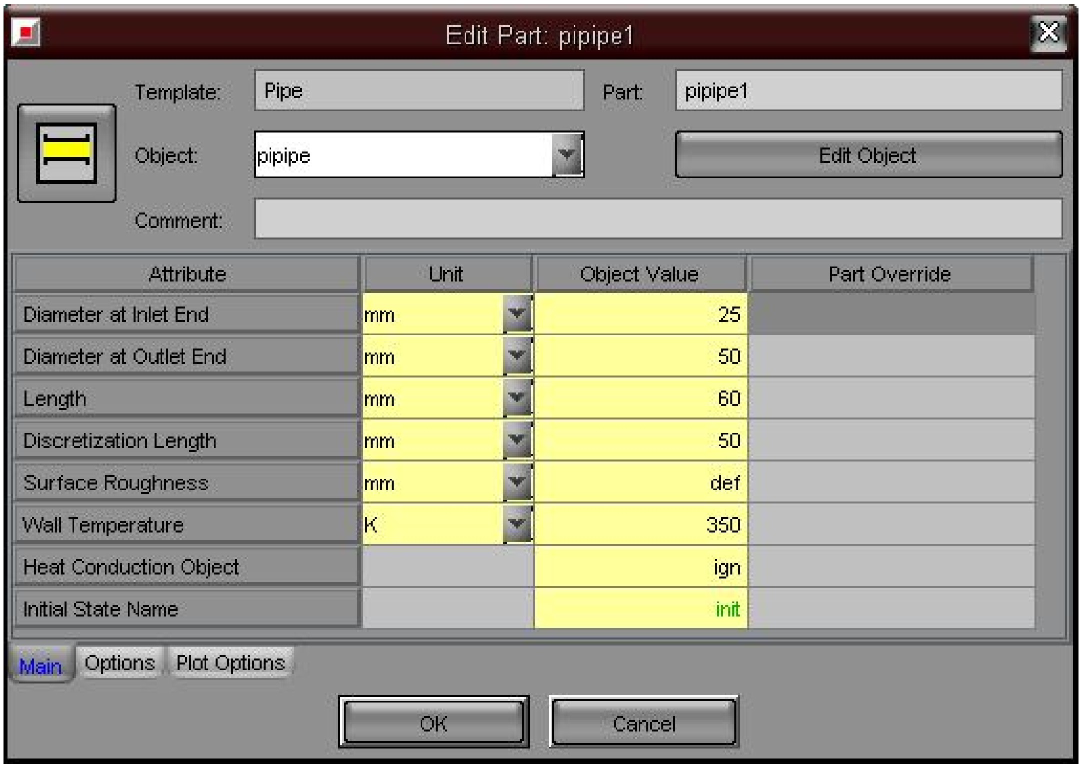

Figure 3.4: Intake manifold setting

The intake and outlet diameter for manifold is setting. The inlet diameter is 25mm and the outlet diameter is 50mm. the length of the intake manifold is 60mm.

3.3.3 Intake valve setting

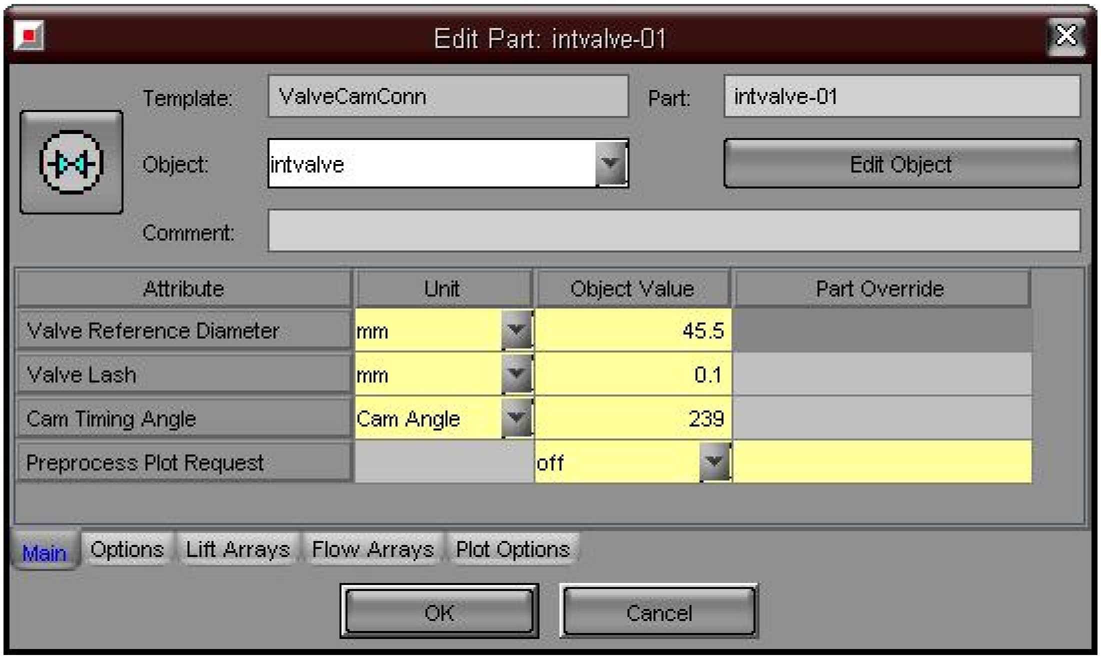

Figure 3.5: Intake valve setting

The intake valve diameter is setting at the intake valve.

3.3.4 Cylinder geometry

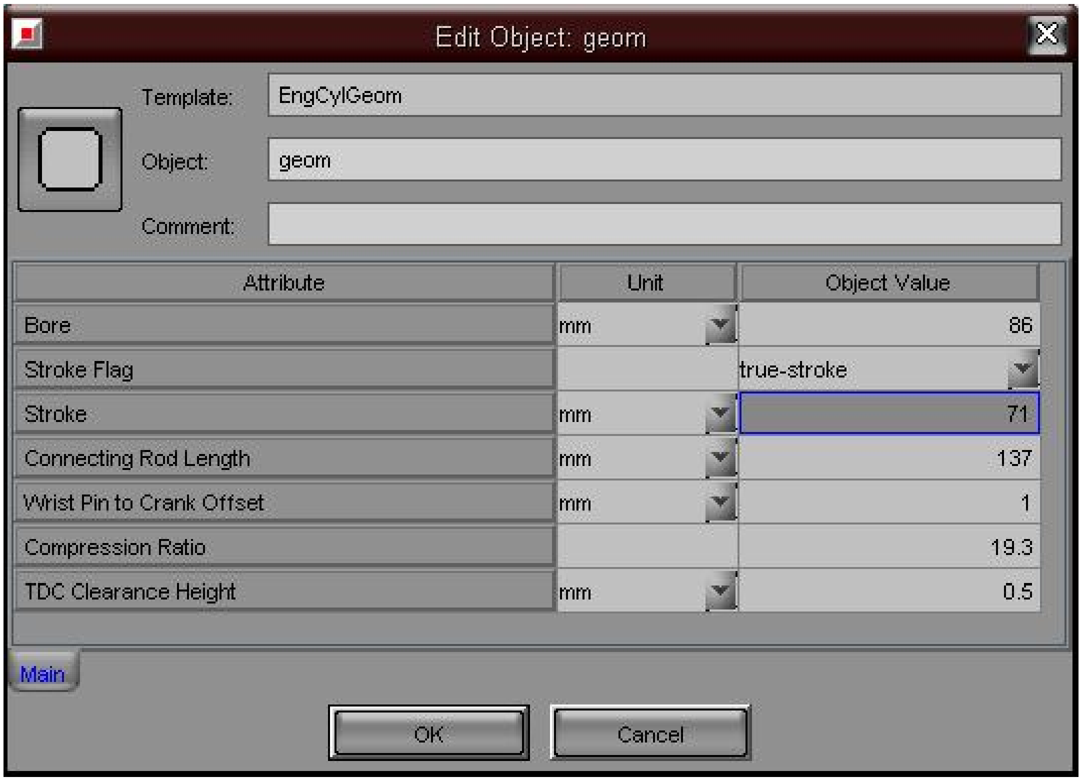

Figure 3.6: Cylinder geometry

Refer to the design. The bore for the cylinder is setting as 86 mm, and the cylinder liner is 71 mm.

3.3.5 Exhaust valve setting

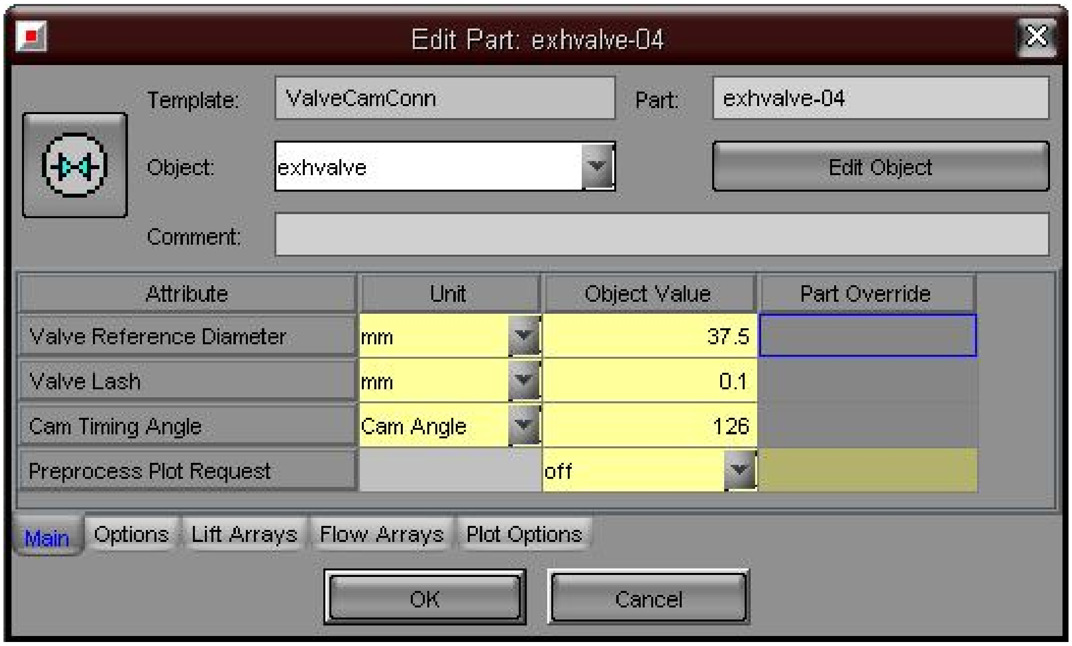

Figure 3.7: Exhaust valve setting

The exhaust valve diameter is setting at the exhaust valve.

3.3.6 Exhaust manifold setting

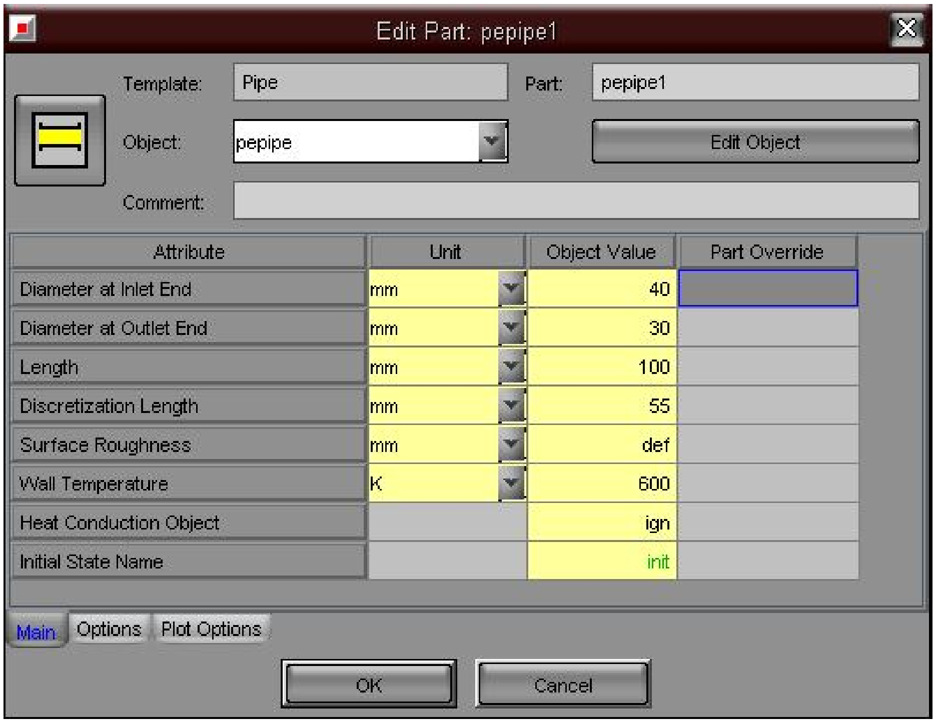

Figure 3.8: Exhaust manifold setting

The exhaust is having inlet diameter equal to 40mm and the outlet diameter equal to 30 mm.

3.3.7 Friction setting

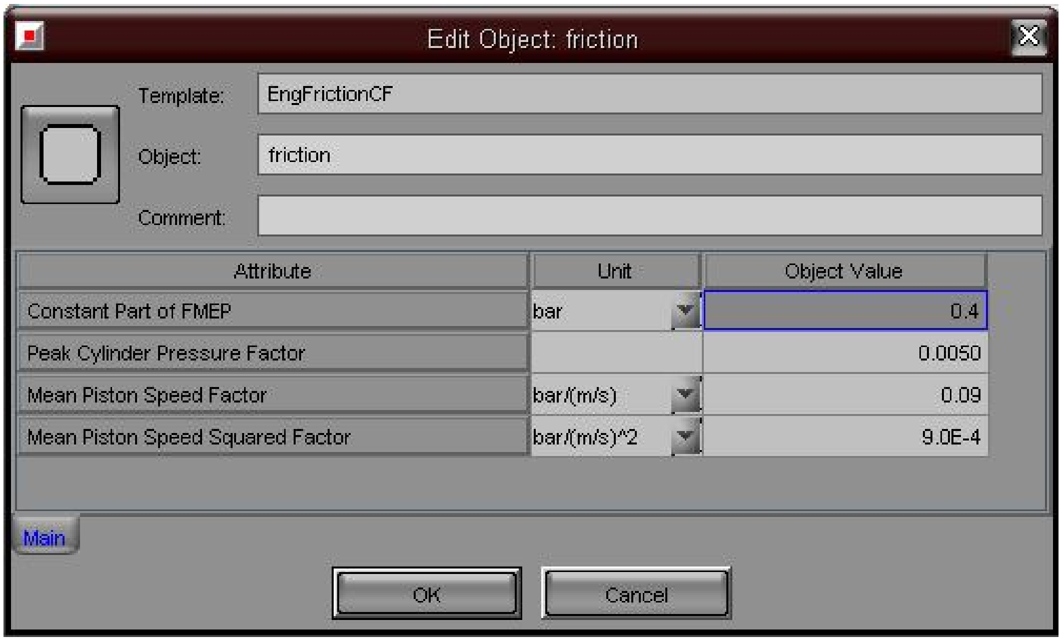

Figure 3.9: Friction in conventional engine

The friction of conventional diesel engine having cylinder bore equal to 86 mm and stroke length equal to 71 mm. George A. Livanos, Nikolaos P. Kyrtatos "*Friction model of a marine diesel engine piston assembly*"

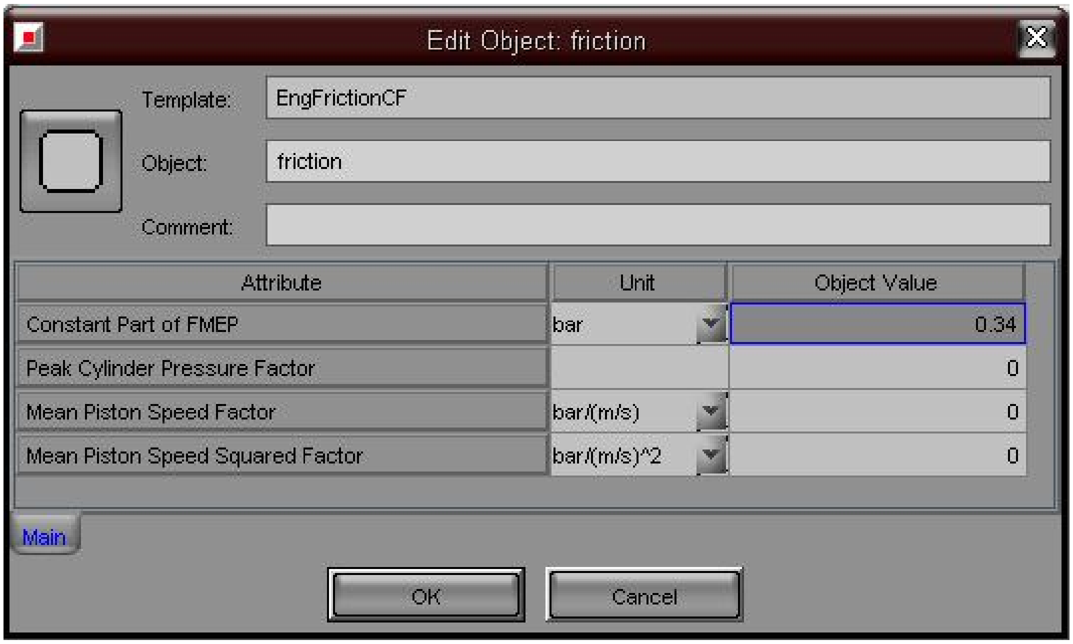

Figure 3.10: Friction in linear engine

The friction of linear engine having cylinder bore equal to 86 mm and stroke length equal to 71 mm. This value is refer to thesis written by Sorin Petreanu entitle "*Conceptual Analysis of a Four-Stroke Linear Engine*", page 84. He says that the FMEP for linear engine having 86mm bore and 71mm stroke length is equal to 0.034MPa.

The data is taken based on several engine speeds (rpm). The data is plotting on the graph for further study.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

This chapter discusses about the three items which are designing, simulation and also the analysis. For the first item, the design is obtained from a few concept designs and by considering the dimensions and the materials.

The selected design was analyzed by using the GT-power software for the performance analysis and the result was the comparison of brake power, brake torque and brake specific fuel consumption between linear and conventional engine. After that, it was followed by the analyzed result. The result and discussion is written in this chapter.

4.2 Engine part

4.2.1 Cylinder block design

The main part in a linear engine is the cylinder block. This engine is consisting of four cylinders, arranged in apposed position. All the dimension of cylinder block is same, having cylinder bore equal to 86mm and stroke equal to 71mm.

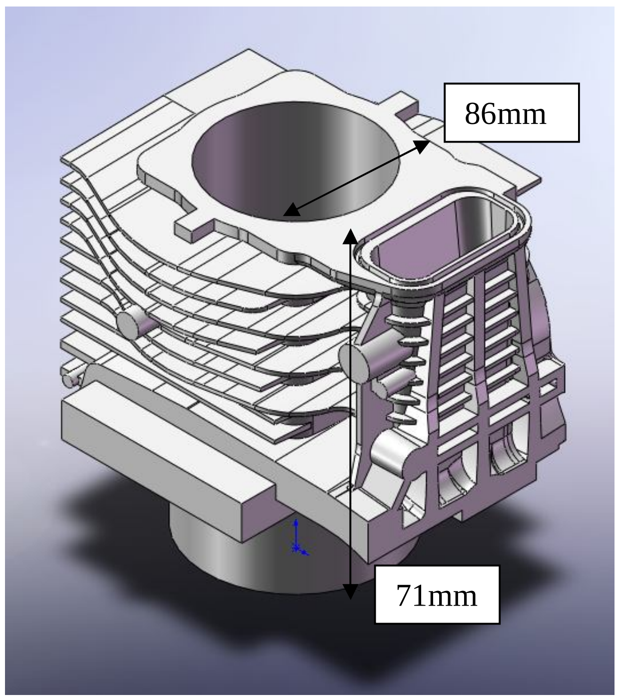

Figure 4.1: Cylinder block

4.2.2 Cylinder head design

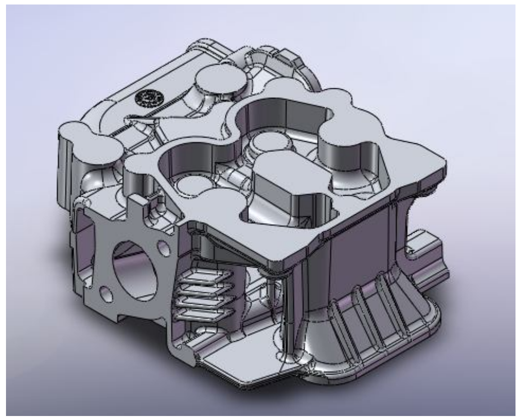

Figure 4.2: Cylinder head

4.2.3 Piston design

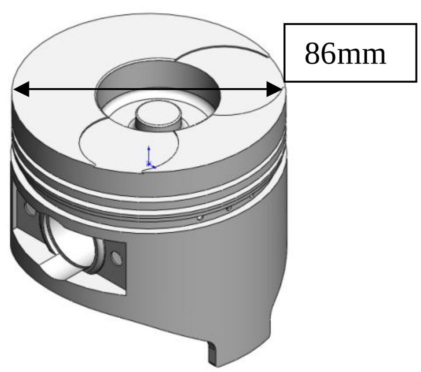

Figure 4.3: Piston

4.2.4 Connecting rod design

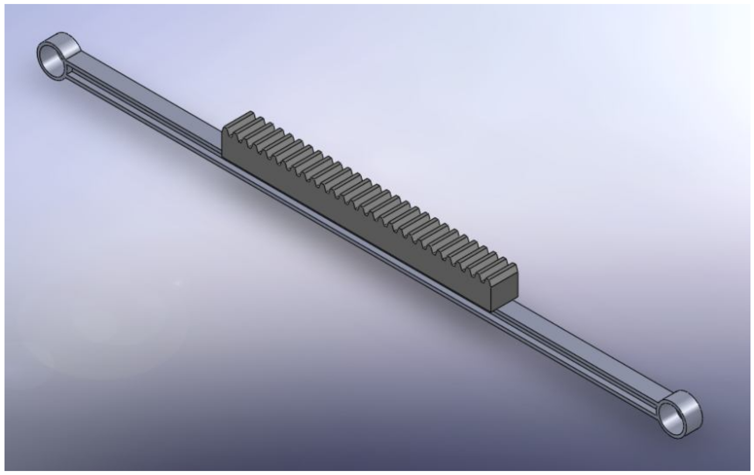

Figure 4.4: Linear engine connecting rod

The length of connecting road is 574.24mm. Note that this connecting rod is different with conventional connecting rod. The rack is installed at the connecting rod to make it can relate to another connecting rod as the design desire.

4.2.5 Gear Design

Figure 4.5: Gear

The gear is having diameter 52.96mm. Gear is the important part of the linear engine, especially for four stroke linear engine. This is because the gear functionality is related to the stroke in linear engine.

4.3 Linear engine design

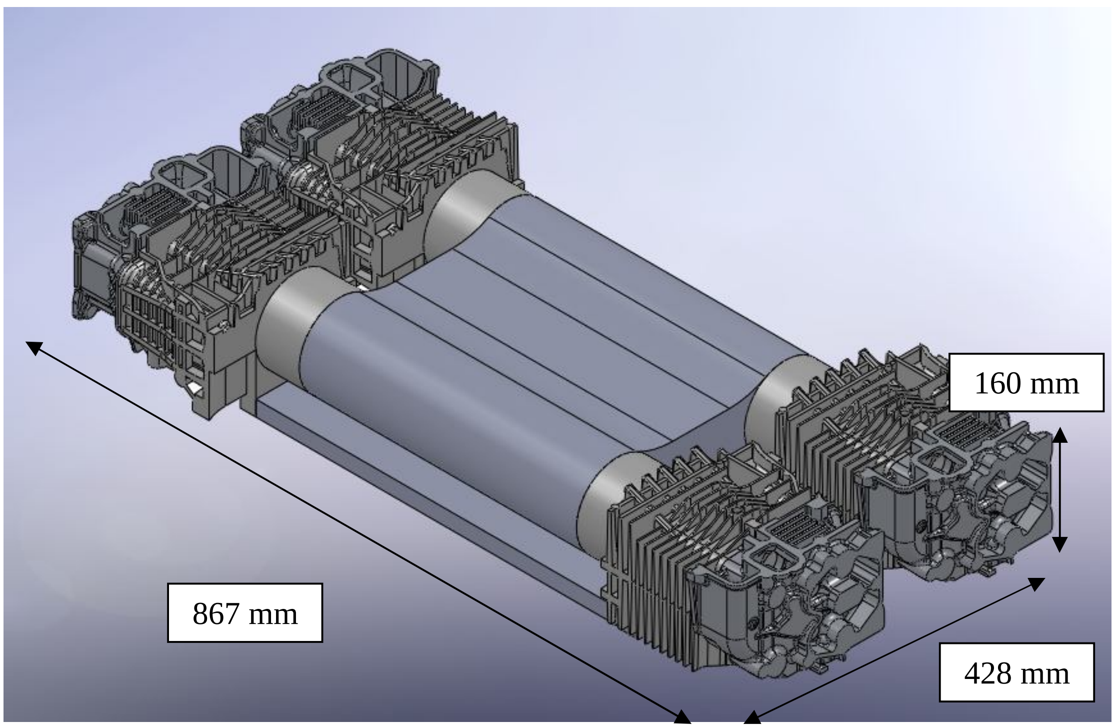

Figure 4.6: 3D view of linear engine design

The dimensions of the engine are:

Length : 867mm
Width : 428mm
High : 160mm

The engine is having reduction in total high which is to 0.16 meter but the length is increased to 0.867 meter. This situation gives several advantages and disadvantages.

Advantages

1. Linear engine is having low center of gravity, which can make the engine is more stable.
2. If this engine is applied to the vehicle, front of a vehicle can be made lower (improves the Cd)
3. Engine is much lighter and decreased torsional vibrations in the engine because of the crankshaft elimination.

Disadvantage

1. Increasing in total length make the engine need wider room space to place this engine.

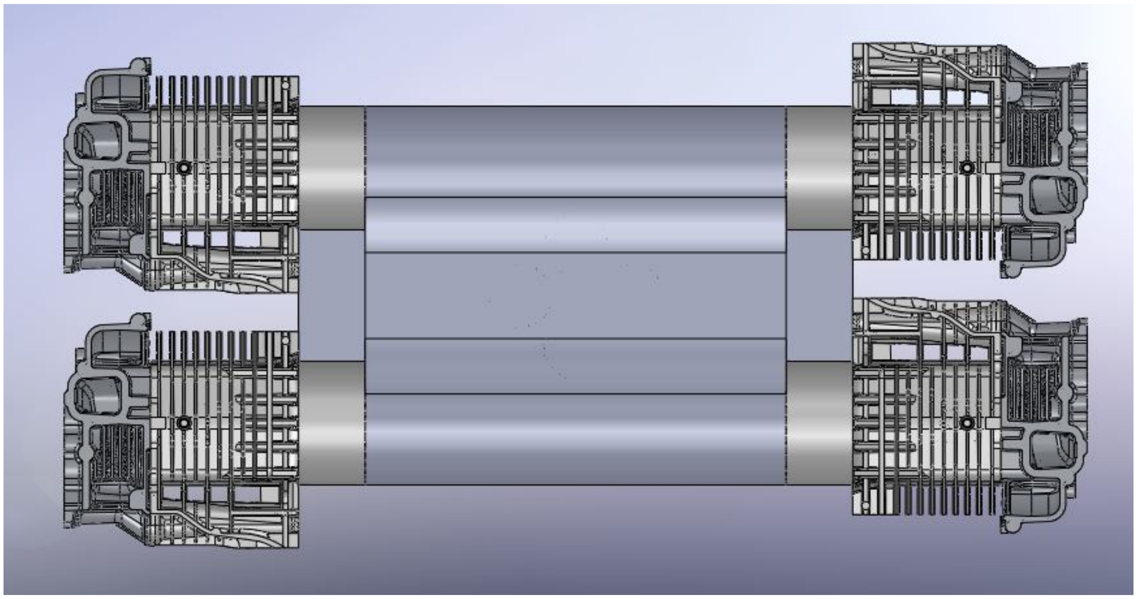

Figure 4.7: Top view of linear engine design

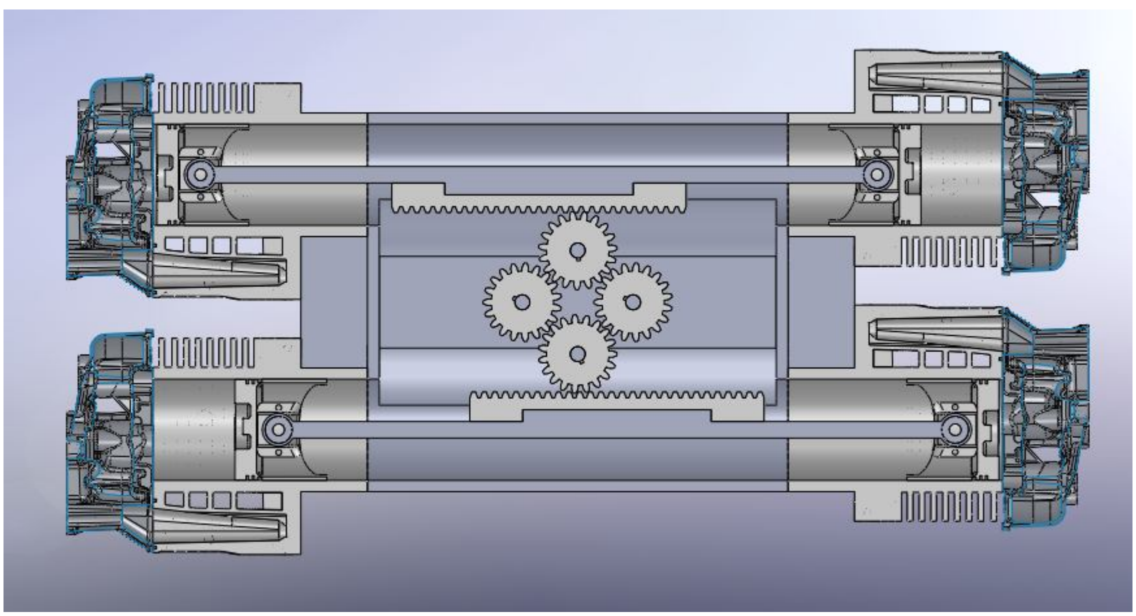

Figure 4.8: Cross sectional view of linear engine design

The engine is consist of four cylinders, each cylinder have a piston which is connected to the piston at the opposed cylinder by connecting rod. The rack is installed on the connecting rod and mate with the gear. The mechanical configuration is important because in linear engine, compression takes place in one cylinder while expansion takes place in the other apposed cylinder and vice versa. The stroke in linear engine is depending to each other to make it function. The proper explanation will be explained later.

4.4 Description of the Four-Stroke Linear Engine

This mechanical arrangement proposed is the Four-Stroke Linear Engine (FSLE). This arrangement promises to reduce or to eliminate the disadvantages experienced by the spark ignition version of the Two-Stroke Linear Engine (TSLE) arrangement. During the operation of the TSLE, noticeable vibrations were observed but they were not of primary concern for the preliminary investigation of the engine operation. Due to its mechanical arrangement, the FSLE has potential to diminish the vibration aspects met in free piston engine operation. The FSLE has a very similar configuration to the TSLE, and basically it represents a combination of two TSLE’s. The FSLE consists of two pairs of opposed-pistons connected by a rigid shaft that oscillates back and forth within the combustion cylinders (chambers). The shaft that links the pistons is coupled with a linear alternator able to absorb the energy generated by the engine. The proposed arrangement introduces a mechanical complication due to the existence of the linkage between the parallel pair of pistons. Nevertheless, this inconvenience can be overcome by means of a proper design for the reciprocating shaft. The FSLE will be able to reduce the vibration offering a better balance than TSLE version. Based on FSLE configuration, a "H" mechanical arrangement can be obtained by coupling two FSLE. Obviously there can be envisioned different mechanical arrangements of FSLE. The unconstrained motion of the reciprocating device, and therefore the variable compression ratio, makes the engine suitable for operation with

Homogeneous Charge Compression Ignition (HCCI), in which a premixed air-fuel charge is ignited by heating due to the compression.

The engine consists of four cylinders symmetrically arranged, in two pairs of opposite cylinders. The reciprocating device consists of four pistons rigidly connected by an H-shaped connecting rod. The cylinders are equipped with intake and exhaust valves. The linear alternator attached to the reciprocating assembly is responsible for converting the mechanical energy developed by the engine to electrical energy, which can then be used by external devices. It should be noted that the mechanical load on the engine (as a function of the displacement of the reciprocating assembly) can be tailored actively or passively to any function of displacement.

For a better understanding of the operation of the four-stroke linear engine, Table 4.1 illustrates the engine cycle phasing.

Table 4.1: Stroke in linear engine

	CYLINDER 1	CYLINDER 2	CYLINDER 3	CYLINDER 4
Stroke 1	Combustion + Expansion	Compression + Combustion	Intake	Exhaust
Stroke 2	Exhaust	Combustion + Expansion	Compression + Combustion	Intake
Stroke 3	Intake	Exhaust	Combustion + Expansion	Compression + Combustion
Stroke 4	Compression + Combustion	Intake	Exhaust	Combustion + Expansion

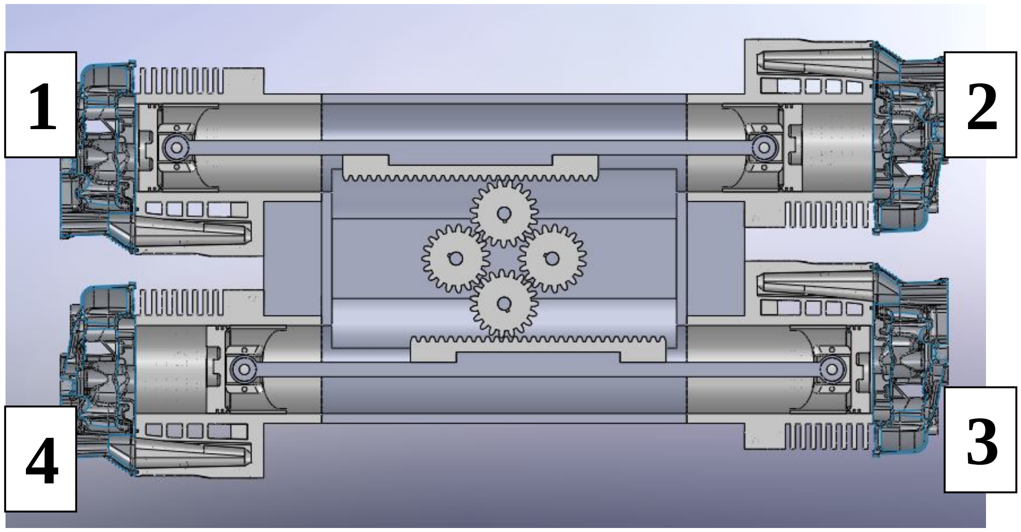

Figure 4.9: Cylinder numbering

Assume that each cylinder have the number as figure 4.9,

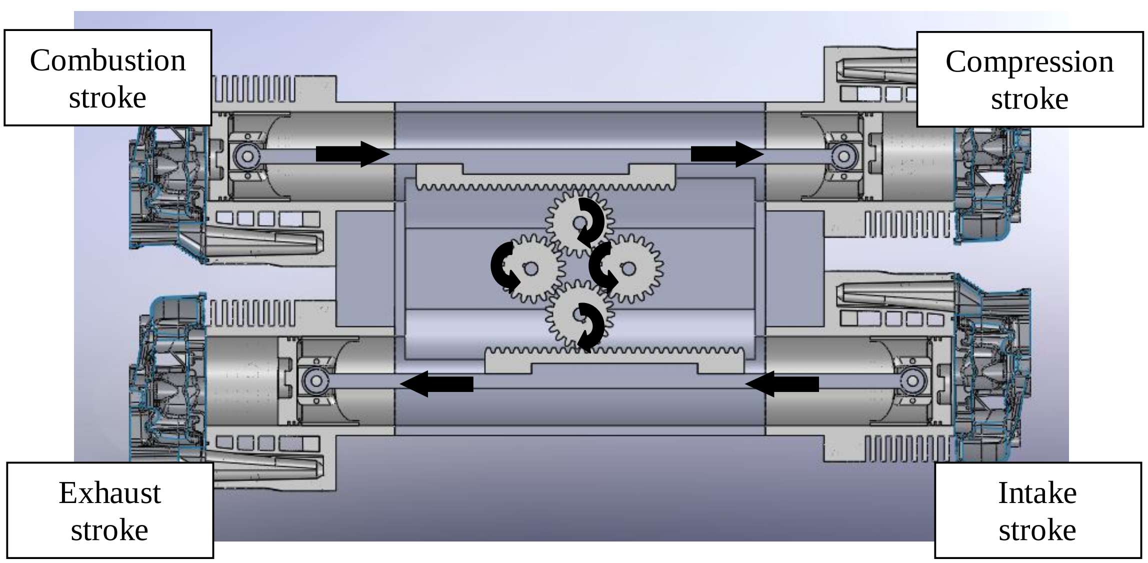

Figure 4.10: First stroke

For the first stroke, the combustion occurs at the cylinder 1; make the piston at cylinder 1 move to the right hand side. This will make the compression stroke occur at cylinder 2. As the mechanical configuration, the movement of the connecting rod will move in different direction. This will make intake stroke occur at cylinder 3 and exhaust stroke occur at cylinder 4.

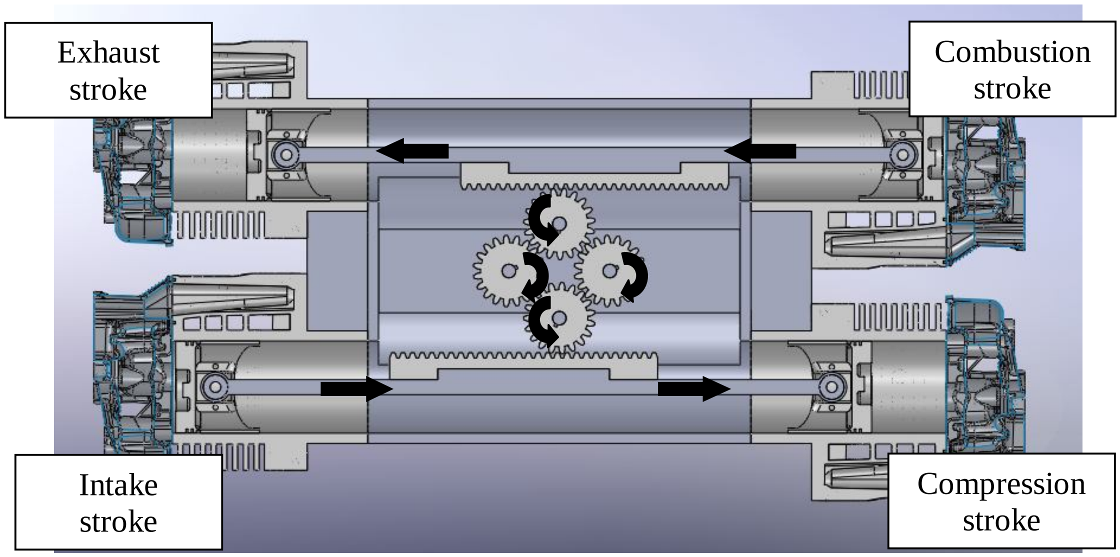

Figure 4.11: Second stroke

For the second stroke, the combustion now occurs at the cylinder 2; make the piston at cylinder 2 move to the left hand side. This will make the exhaust stroke occur at cylinder 1. As the mechanical configuration, the movement of the connecting rod will move in different direction. This will make compression stroke occur at cylinder 3 and intake stroke occur at cylinder 4.

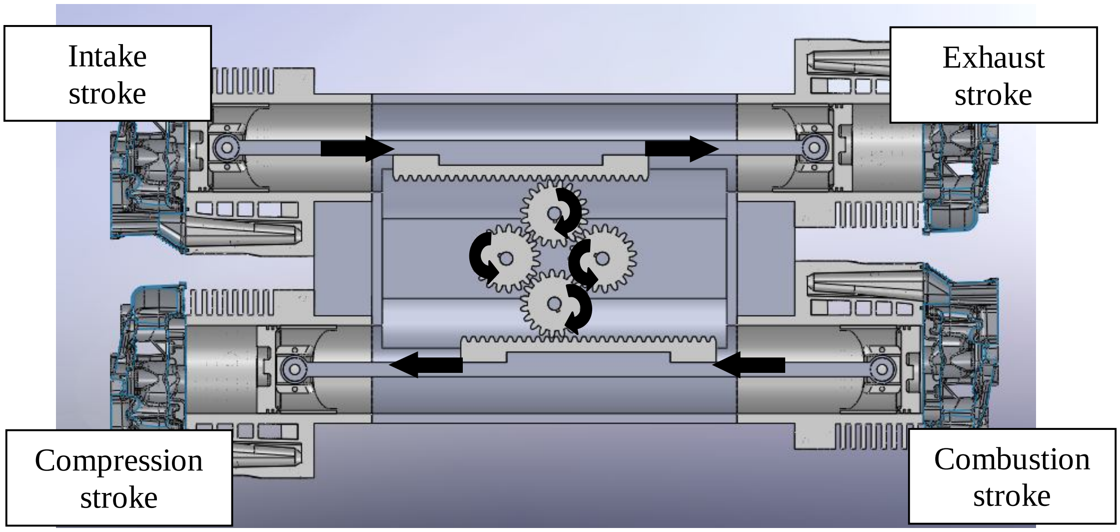

Figure 4.12: Third stroke

For the third stroke, the combustion now occurs at the cylinder 3; make the piston at cylinder 3 move to the left hand side. This will make the exhaust stroke occur at cylinder 2. As the mechanical configuration, the movement of the connecting rod will move in different direction. This will make compression stroke occur at cylinder 4 and intake stroke occur at cylinder 1.

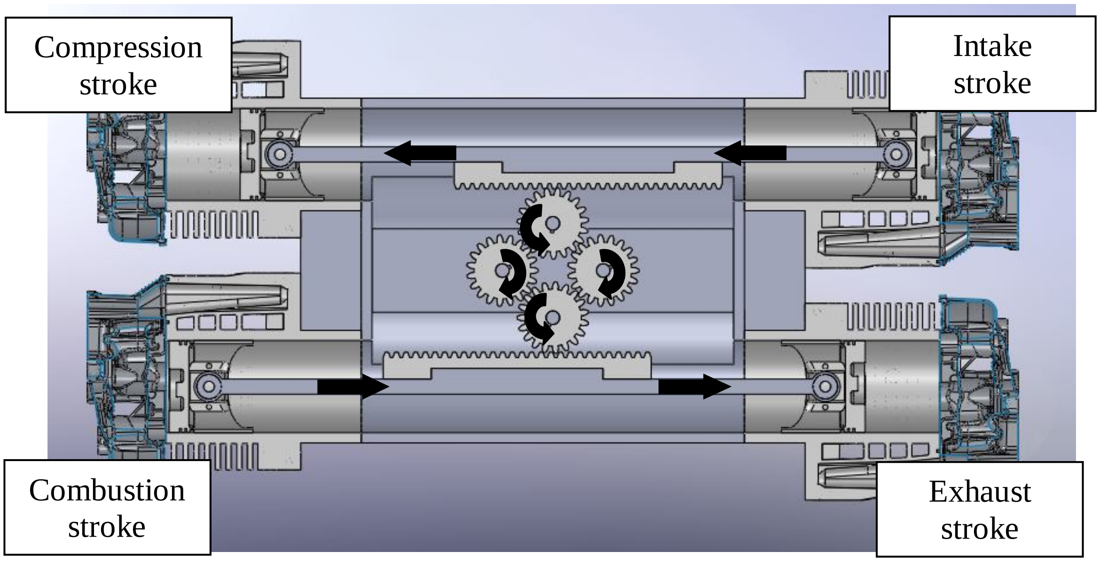

Figure 4.13: Fourth stroke

For the fourth stroke, the combustion now occurs at the cylinder 4; make the piston at cylinder 4 move to the right hand side. This will make the exhaust stroke occur at cylinder 3. As the mechanical configuration, the movement of the connecting rod will move in different direction. This will make compression stroke occur at cylinder 1 and intake stroke occur at cylinder 2.

4.5 Intake and Exhaust System

The four-stroke arrangement requires intake and exhaust valves for the gas exchange processes. Since there is no rotational motion and therefore no camshaft, the engine design requires a different solution for the valves operation. The solution adopted for this engine is that the cylinders employ intake and exhaust electromagnetic valves to ensure the gas exchange process, and the valves being operated by the engine control unit (ECU). In Table 4-2 it is presented the valve timing for the FSLE.

Table 4.2: Valve timing for linear engine

	CYLINDER 1		CYLINDER 2		CYLINDER 3		CYLINDER 4	
	INT.	EXH.	INT.	EXH.	INT.	EXH.	INT.	EXH.
STROKE 1	C	C	C	C	O	C	C	O
STROKE 2	C	O	C	C	C	C	O	C
STROKE 3	O	C	C	O	C	C	C	C
STROKE 4	C	C	O	C	C	O	C	C

Where,

INT = Intake valve

EXT = Exhaust valve

O = Open

C = Closed

4.6 Cooling System

The engine is water-cooled in order to avoid the high temperature gradients developed during the combustion process. This solution was chosen because it represents the most convenient one, water being the most convenient heat sink. The cooling water is required for the cylinder jacket and the cylinder heads to control the temperature. The cooling water can be delivered from a cooling tower, for the case of stationary applications, or from a radiator for mobile applications.

4.7 Lubrication

The frictional forces are much lower than those in the crankshaft IC engines, and the only frictional aspect that needs to be considered appears between the piston ring(s), the skirts and the cylinder. Therefore the lubrication requirements will be minimal since there are no large scale hydrodynamic bearings.

4.8 Starting

Previous designs for free-piston engines have proposed using the linear alternator as a starting device. For this operating regime the linear alternator is used to motor the engine. However, at these low values of the speed there is insufficient in-cylinder pressure to generate the spontaneous ignition, and therefore the cylinders will be equipped with glow plugs. The power required to motor the engine, and for all the auxiliaries involved in this operation may be supplied by an external source, such as an auxiliary battery, to be charged by the linear alternator during normal operation.

4.9 Result

After run the simulation, the result for brake power, brake torque and brake specific fuel consumption is being analyze. The result as shown in the table

Table 4.3: Analysis result

RPM		1200	1800	2400	3000	3600
Brake Power [kW]	Conventional Engine	1.5	4.2	8	10.9	15.3
	Linear Engine	2.6	6.2	11.1	15.2	21.1
Brake Torque [N-m]	Conventional Engine	12.1	22.1	31.9	34.5	40.6
	Linear Engine	21.1	32.8	44.2	48.3	55.9
BSFC [g/kW-h]	Conventional Engine	4732.9	2587.4	1794.5	1658.7	1412.7
	Linear Engine	2720	1744.8	1295.3	1185.8	1024.9

4.9.1 Brake torque

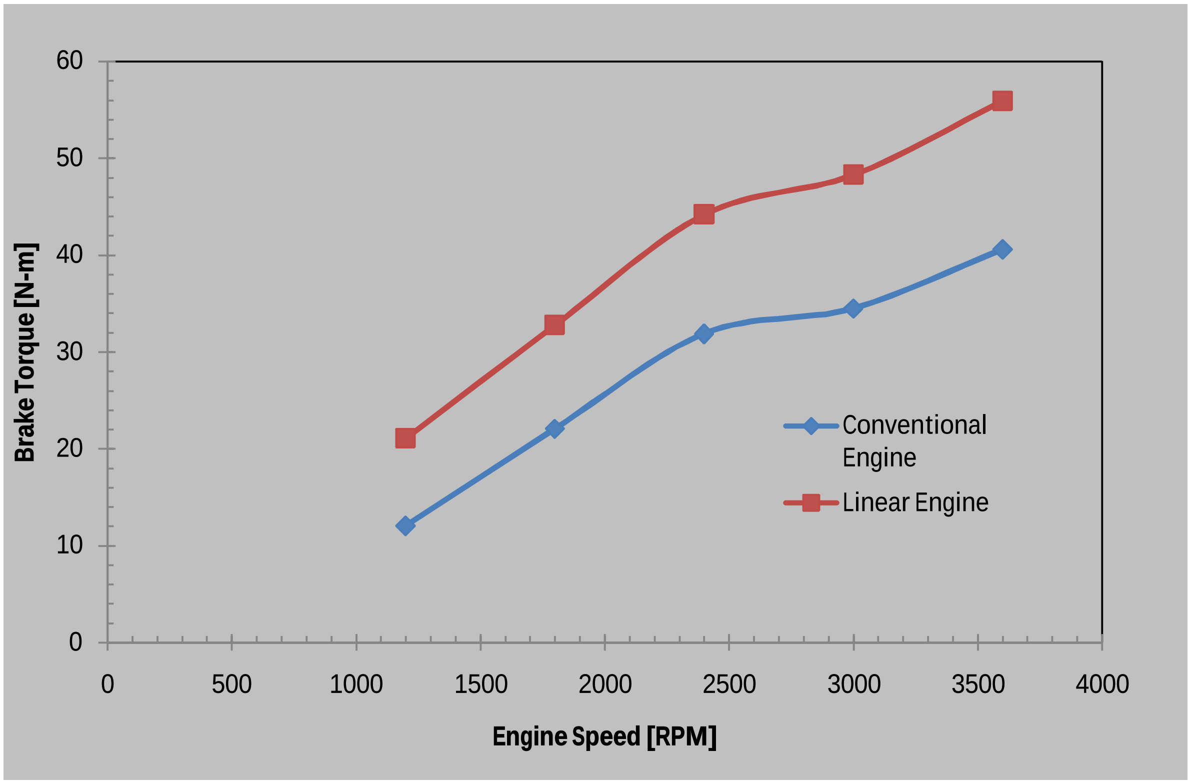

Figure 4.14: Brake torque vs engine speed graph

The graph shows that the linear engine is having higher brake torque than conventional engine at all the engine speed. Note that torque is a measure of an engine's ability to do work. Engine torque is normally measured with a dynamometer. Based on the equation of brake torque,

T = F x b,

Where,

T= torque

F= force

b= distance from rotor to load cell

As the piston movement in the cylinder, the friction is created between piston and the cylinder liner. High friction can reduce the force produced by the engine. Based on the formula of brake torque, when the force is decreased, the engine torque will also decrease. It is directly proportional. This is what actually happened in conventional engine using crankshaft. The different phenomenon occurs for the linear engine. Because of the elimination of the crankshaft, there is no side force happen on the piston. In the easy word, the piston doesn’t move in the radial direction which can created high friction between piston and cylinder liner. The less friction in linear engine can reduce the forced losses to against the friction. Based on the formula, the brake torque will increased when the friction is increased. This is the reason why the linear engine is said to have high brake power than conventional engine.

4.9.2 Brake power

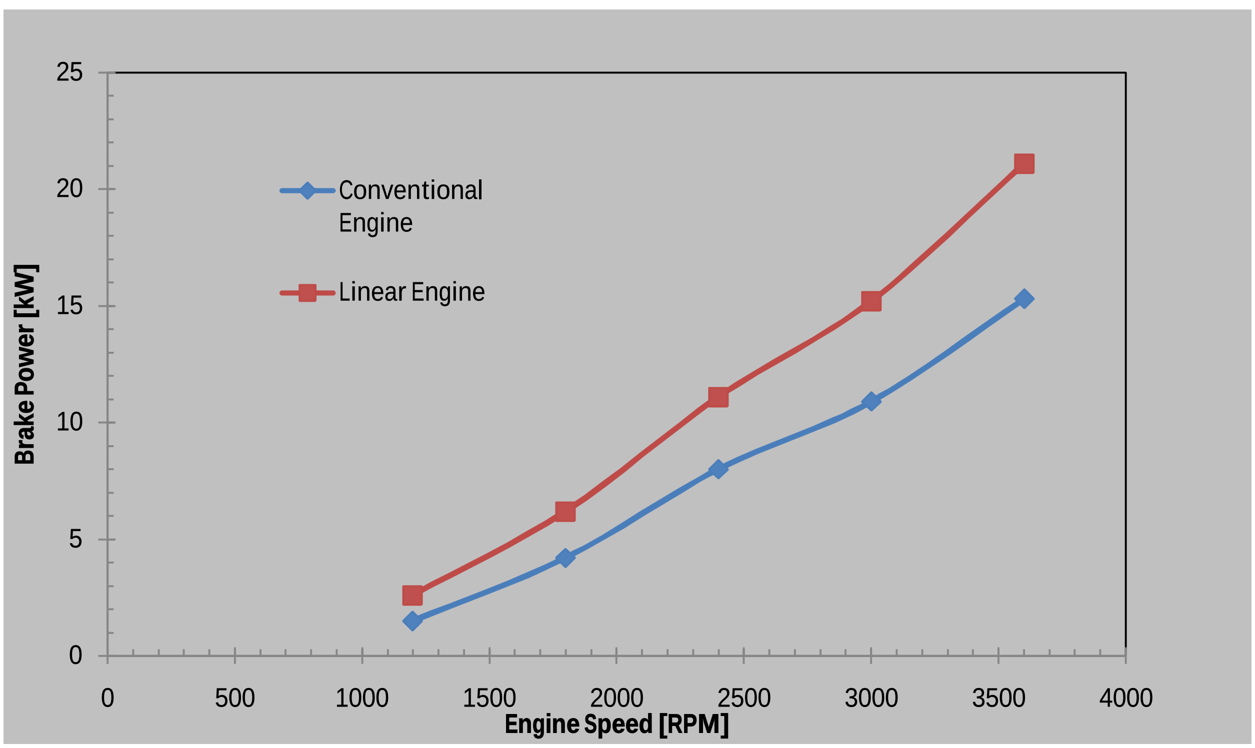

Figure 4.15: Brake power vs engine speed graph

The graph show linear engine having higher brake power than conventional engine at each engine speed. Brake power is the rate at which work is done. The power P delivered by the engine and absorbed by the dynamometer is the product of torque and angular speed. Based on the equation of brake torque,

$P = 2\pi NT$

Where,

P = brake power

N= engine speed

T = brake torque

From the formula above, we can see that the brake power is directly proportional to the brake torque. In the linear engine, because of high brake torque due to the less friction, make this engine also having high brake power. This is the reasons why linear engine having higher brake power than conventional engine.

4.9.3 Brake specific fuel consumption

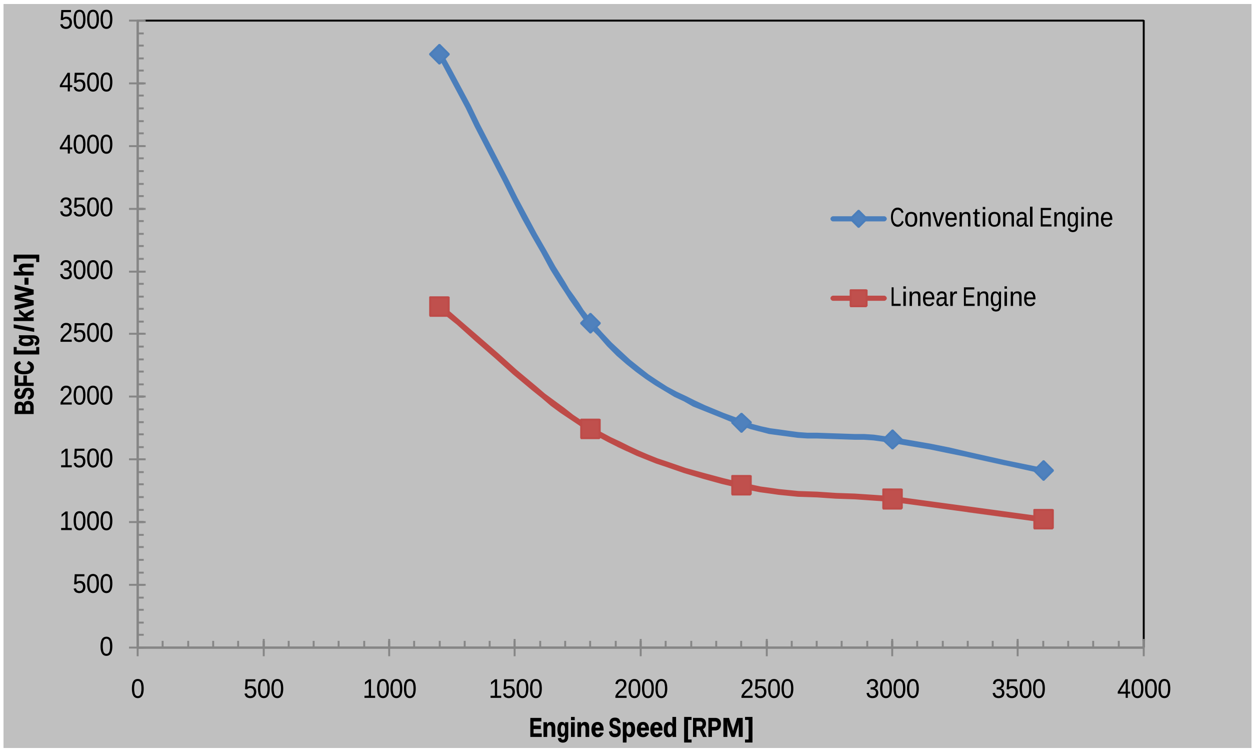

Figure 4.16: Brake specific fuel consumption vs engine speed graph

The graph show the conventional engine need more fuel than linear engine at each engine speed. As have been discussing before, the high force is needed to against the friction in conventional engine, that's why a lot of fuel is needed. Different with the linear engine, less friction between piston and cylinder liner make the engine is more fuel economic. Moreover, because of the elimination of crankshaft in linear engine, this will make the engine is much lighter than conventional engine. This is another reason why linear engine is said to be fuel economic engine.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Generally, the objective of this project is to design and analyze the performance of linear engine. Since the elimination of the crankshaft mechanism in free piston engine, it can reduce frictional, manufacturing costs, and maintenance costs. The result show that the brake power and brake torque of the linear engine is higher than conventional engine. This gives the high engine efficiency due to the less friction linear engine. The linear engine also said to be more fuel economic than conventional engine.

5.2 Recommendation

These are recommendations for this project to be pursued in future research:

a) A closed loop controller of the linear engine should be designed to control fuel injection according to the load applied to the linear engine
b) After optimization, emissions measurements should be performed on the linear engine

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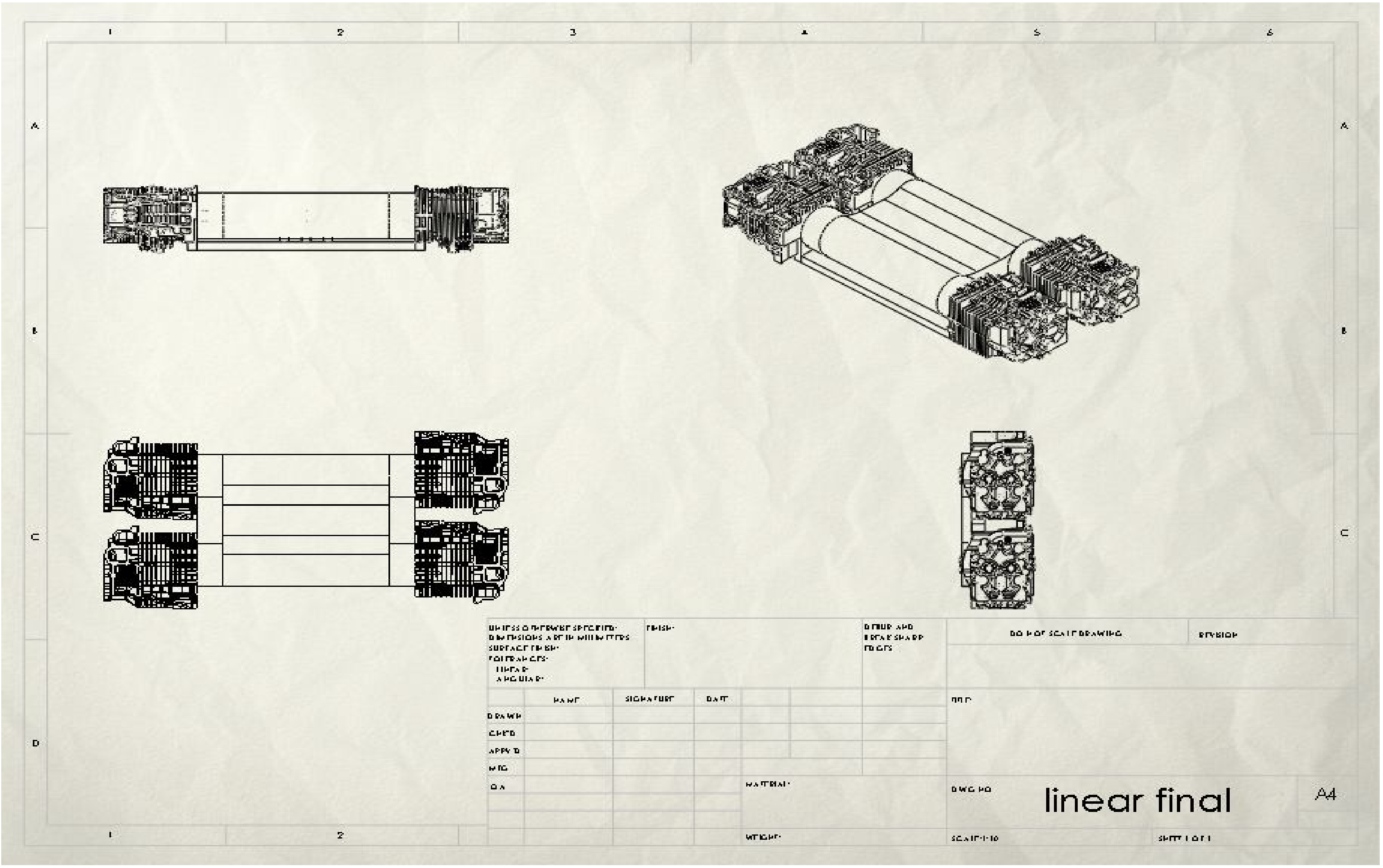
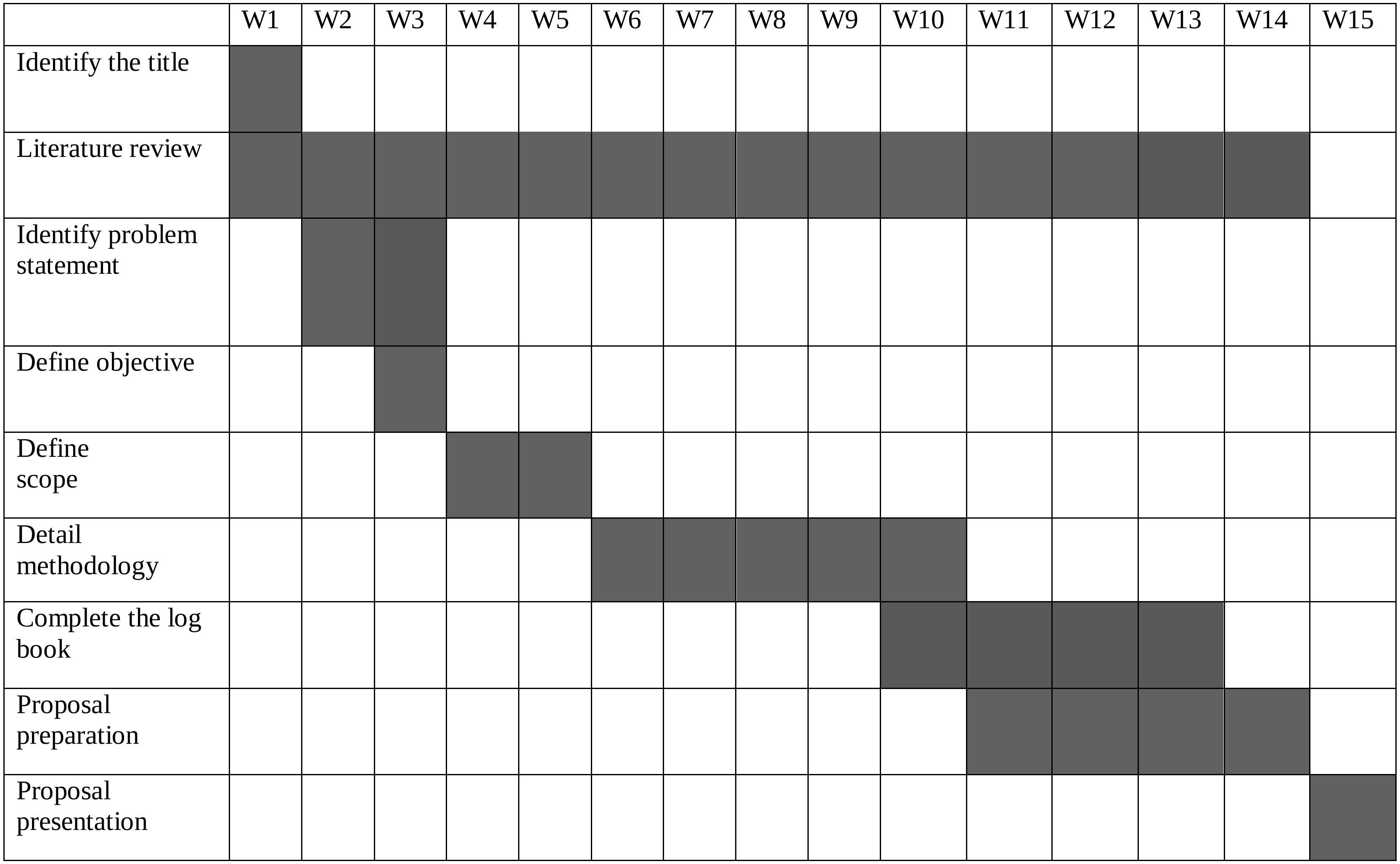
Appendix A (Solidwork Drawing)



Appendix B (Gantt Chart for FYP 1)



(Gantt Chart for FYP 2)

	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14
Literature review														
Design Linear Engine														
Analyze model														
Making conclusion														
Report preparation														
Final presentation														