DESIGN OF REVETEC ENGINE CAM WITH CYCLOIDAL MOTION PROFILE

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KHAIRUL ANUAR BIN A RAHMAN

Report submitted in fulfillment of the requirements
for the awards of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
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JUNE 2012

APPROVAL DOCUMENT

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

We certify that the project entitled Design Of Revetec Engine Cam With Cycloidal Motion Profile is written by Khairul Anuar Bin A Rahman. We have examined the final copy of this our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfilment the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

Examiner Signature

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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ABSTRACT

Efficiency of conventional engines reduced due to heat and friction losses. Some of the input energy is lost in exhaust gases and water cooling and the mechanical losses due to friction. All conventional engines are using crankshafts to convert the piston reciprocating motion to a rotating motion in the drive line, but crankshafts are responsible of side thrust force, vibrations and also they are not efficient in transferring the power to the drive line. Crank-less and free piston engines were a good example to overcome the crank shaft problems, but these new kinds of engines are facing a control and starting problems. Revetec engine is a new engine arrangement used to increase engine's efficiency by replacing the crankshaft and the connecting rod used in conventional engines by cams to control the piston movement. In revetec engine, it consists of two counter rotating three-lobed cams gearing together. So, both cams contribute of forward motion. Two bearings moving along the profile of both cams (four bearings for all) and stay in contact with the cams at all times. The two cams rotate and raise the piston with a scissor-like action to the bearings. It meaning, in every cycles of the revetec engine there are three power stokes compared to one power stroke in the conventional engines. Based on revetec engine performing, Cam profile contributes great effect in combustion characteristics, so it is very important to find the suitable cam profile to achieve the maximum cylinder pressure. In this project a computational work. Based on comparison result of the project between conventional engine and revetec engine. The result obtained from this study has shown that by using a cam profile, with which Cycloidal motion was applied to the piston, the cylinder pressure can be increased up to 23.91 percent.

ABSTRAK

Kecekapan enjin konvensional berkurangan kerana kehilangan haba dan geseran. Sebahagian daripada tenaga yang hilang dalam gas ekzos dan penyejukan air dan kerugian mekanikal yang disebabkan oleh geseran. Semua enjin konvensional menggunakan aci engkol untuk menukar pergerakan omboh salingan kepada gerakan berputar di talian drive, tetapi aci engkol bertanggungjawab memberi daya teras sampingan, getaran dan juga mereka tidak cekap dalam memindahkan kuasa kepada garis pemacu. Enjin omboh engkol-kurang dan bebas adalah satu contoh yang baik untuk mengatasi masalah aci engkol, tetapi jenis enjin baru ini menghadapi kawalan dan masalah sewaktu bermula. Enjin revetec adalah susunan enjin baru yang digunakan untuk meningkatkan kecekapan enjin dengan menggantikan aci engkol dan rod penyambung yang digunakan dalam enjin konvensional oleh sesondol untuk mengawal pergerakan omboh. Dalam enjin revetec, ia terdiri daripada dua sesondol kaunter tiga lobed berputar penggearan bersama. Jadi, kedua-dua sesondol menyumbang gerakan ke hadapan. Dua galas bergerak di sepanjang profil kedua-dua sesondol (empat galas untuk semua) dan tinggal di bersentuhan dengan sesondol pada setiap masa. Dua sesondol berputar dan meningkatkan omboh dengan tindakan gunting seperti galas. Ia makna, dalam setiap kitaran enjin revetec ini terdapat tiga kuasa stoke berbanding dengan satu kuasa lejang dalam enjin konvensional. Berdasarkan enjin revetec, profil cam menyumbang kesan yang besar dalam ciri-ciri pembakaran, jadi ia amat penting untuk mencari 'cam profile' yang sesuai untuk mencapai tekanan silinder maksimum. Berdasarkan hasil perbandingan projek antara enjin konvensional dan enjin revetec. Dalam projek ini kerja pengiraan. Keputusan yang diperolehi daripada kajian ini menunjukkan bahawa dengan menggunakan cam profile, dengan mana gerakan Cycloidal telah meningkatkan tekanan silinder kepada lebih 23.91 peratus.

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LIST OF SYMBOLS

A	Piston Cross-Section Area
V	Cylinder volume
V_{Π}	Maximum volume
V_{O}	Minimum volume
P	Pressure
P	Cylinder Pressure
Q	Heat Addition
$\boldsymbol{\gamma}$	Specific Heat Ratio
x	Fraction Of Heat Released
ΘS	Start Of Heat Release
ΘB	The Time Scale For Heat Release
n	Value Used To Fit Experimental Data
s	Piston Stroke, M
r	Compression Ratio
X	Piston Displacement ,M

LIST OF ABBREVIATIONS

BDC	Bottom Dead Center
TDC	Top Dead Center
BTDC	Bottom Top Dead Center
TBDC	Top Bottom Dead Center
FYP	Final Year Project
W1	Week 1
CCE	Controlled Combustion Engine
SAE	Society of Automotive Engineering
ASME	America Society of Mechanical Engineering
ATDC	Acceleration Top Dead Center

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Revetec engine is a new engine arrangement, were cams are used instead of crankshaft to convert the reciprocating piston motion to rotating motion. Crankshafts are inefficient devices for efficiently transferring power from the pistons to the driveline, with losses that can approach 36%. At the top of the piston stroke, where gas pressure is highest, force transfer efficiency is at its lowest, though it rises as the piston descends. Peak efficiency happens about 40% through the piston stroke, and then drops at an exponential.

In addition, the piston does not travel a path that is strictly parallel to the bore, so an angular force equal to the pressure on the top of the piston is transferred to the cylinder wall. This increases friction, wear, and fuel consumption. So, revetec engine is solution for this problem. By replacing the crankshaft and the connecting rod that used in conventional engines, the engine efficiency will increase by controlled combustion engine of the piston movement.

1.2 PROBLEM STATEMENT

Crankshafts are the main cause for many problems in the internal combustion engine, like vibration, noise and cylinder wear. These poor efficiencies of the crankshafts have leaded the engineers to invent other alternative to replace the crankshafts functions (Mikalsen, 2007). When using cams instead of crankshafts, the cam profile makes a great effect in combustion characteristics, so it is very important to find the suitable cam profile to achieve the maximum cylinder pressure. In this project, a comparison for one type of cam profiles, which gives a specific motion for the piston, mainly Cycloidal motion**,** to calculate the cylinder pressure during compression and combustion strokes. In this project an investigation of cam with cycloidal motion profile will be done to find the effect of the cam profile on the cylinder pressure. Revetec engine is a new custom engine.

1.3 OBJECTIVE

To investigate the effect of cam profile on the cylinder pressure

1.4 SCOPES

In this final year project there are three main point for the scope.

i. Modelling the cam profile using MATLAB.
ii. Simulating of cylinder pressure during the compression and exhaust strokes.
iii. Comparing these results with conventional engines.

1.5 FLOW CHART OF THE FINAL YEAR PROJECT

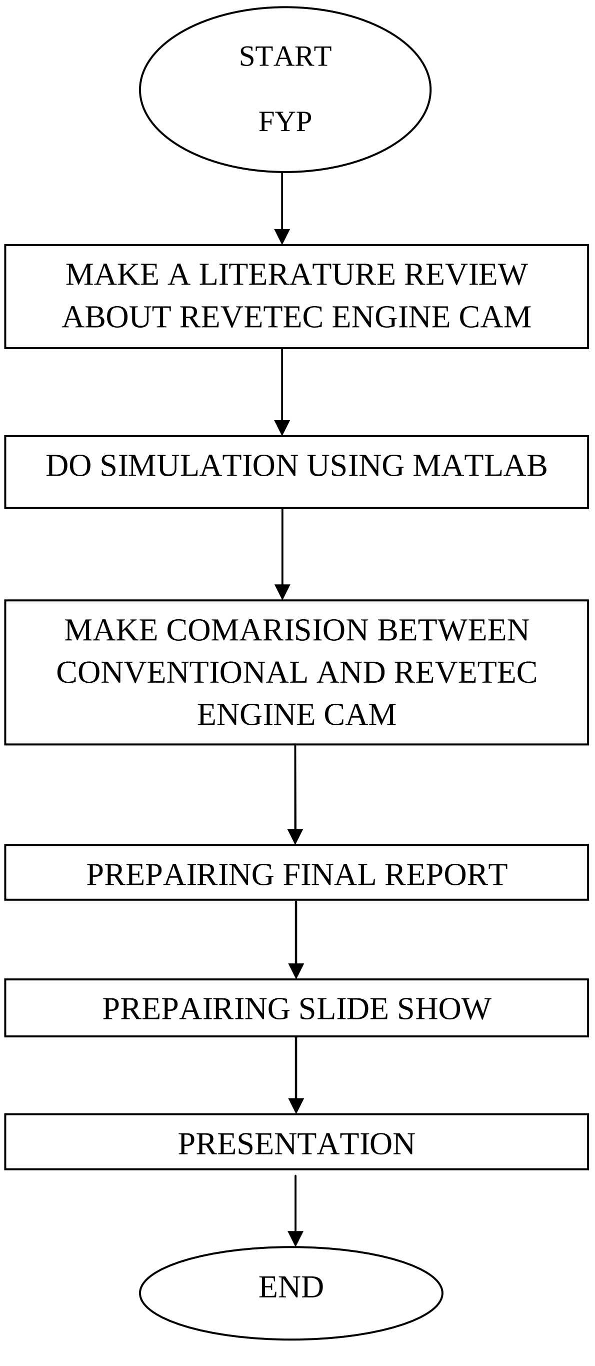
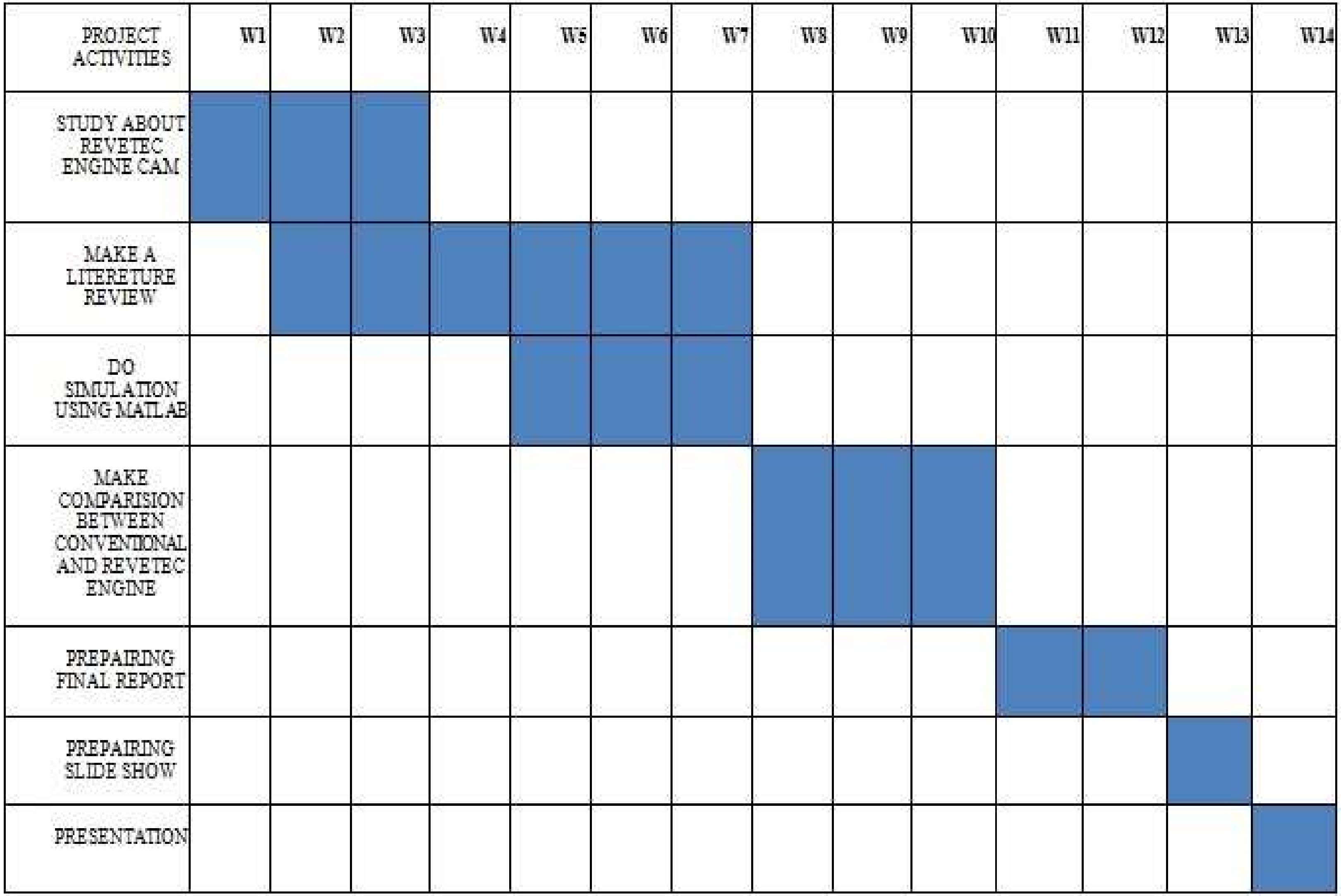


Figure 1.1: Flow chart of final year project

1.6 GANTT CHART



CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Currently, majority of the vehicle on the road used conventional engine. Revetec engine technology is still new in the automotive industry. Many people do not know the advantages of using revetec engine, when compared with conventional engines. It occurs due to lack of information on revetec engine. Therefore, research on revetec engine must be published to be seen by the public. So, people are more interested in studying or using technology of revetec engine.

With this study, the rate of wastage of fuel consumption can be reduced. This is because the revetec engine efficiency is better when compared with conventional engines. The main problem in the internal combustion engine to a conventional engine is the crankshaft. When the engine is running, a problem that often occurs like vibration, friction wears of the cylinder, and noise. Lack of efficiency of the engine requires the engineer to cope with a redesigned internal engine parts that can overcome the problem.

In 1996, Bradley Howell Smith, an Australian engineer conducting research and in 2006 he created a new display engine called Controlled Combustion Engine (CCE). This engine mechanism convert the reciprocating motion of the internal combustion engines pistons, to rotating motion in the drive line, by using two counter three-lobed cam geared together, two bearing run along the profile of both cam and stay in contact with the cam at all times known as Revetec engine (Bradley, 2006).

Revetec engine is a new engine design. Revetec engine, replace the crankshaft with the camshaft. In revetec engine, it consists of two counter rotating three-lobed cams gearing together. So, both cams contribute of forward motion. Two bearings moving along the profile of both cams (four bearings for all) and stay in contact with the cams at all times. The two cams rotate and raise the piston with a scissor-like action to the bearings.

It meaning, in every cycles of the revetec engine there are three power stokes compared to one power stroke in the conventional engines. In each stroke of the engine revetec, only 120 degrees cam rotates to complete a stroke, while the 360 degrees cam rotates required to complete a stroke by a conventional engine. That is why, cam profile contributes a major impact on engine performance and controlling the movement of the piston.

2.2 REVETEC ENGINE

The Revetec Engine design consists of two counter-rotating three lobed cams geared together, so both cams contribute to forward motion. Two bearings run along the profile of both cams with four bearings in all and stay in contact with the cams at all times. The bearings are mounted on the underside of the two inter-connected pistons, which maintain the desired bearing to three lobed clearances throughout the stroke. The two cams rotate and raise the piston with a scissor-like action to the bearings.

Once at the top of the stroke the air/fuel mixture is fired. The expanded gas then forces the bearings down the ramps of the cams spreading them apart ending the stroke. The effective cranking distance is determined by the length from the point of bearing contact to the centre of the output shaft. A conventional engine's turning distance is half of the piston stroke. The piston acceleration throughout the stroke is controlled by the cam grind which can be altered to suit a wide variety of fuels, torque requirements and rev range. The counter rotation is performed by a reverse gear set at a 1:3 ratio shaft providing two stroke piston to 360 degrees of output shaft rotation.

2.3 REVETEC ENGINE MODELLING

2.3.1 Revetec engine modelling for two stroke

With reference to Figure 2.1, there is shown two-stroke engine 1 comprising a single cylinder module having a single pair of cylinders made up of cylinders. Roller bearings are carried by shaft, which correspond to the roller bearings as generally indicated of figure 2.1

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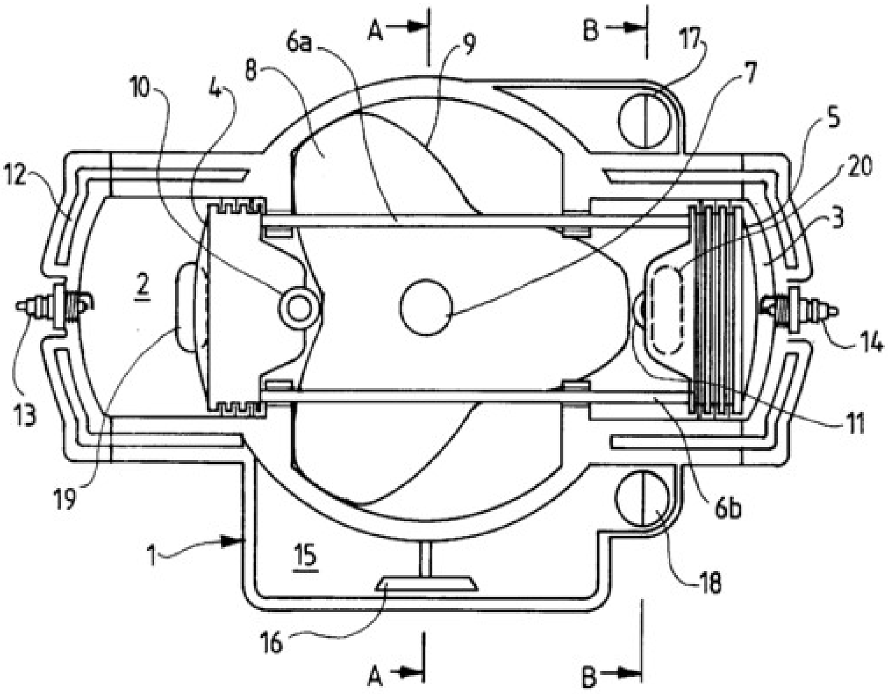

Figure 2.1: Cross-sectional view of a two-stroke engine comprising a single cylinder module with the cross-section being along the axis of the cylinders and transverse with respect to the engine shaft.

Source: Bradley (2006)

1- Comprising a single cylinder module, 2 and 3- cylinders. 4 and 5- pistons, 6a 6b- fours rod, 7- central shaft, 8 and 9- trilobate cams, 10 and 11- roller bearings, 12- water jacket, 13 and 14- spark plugs, 15- oil sump, 16- oil pump pickup, 17 and 18- balance shafts, 19 and 20- inlet ports of exhaust ports.

Turning to Figure 2.2, there is shown another two stroke engine having a single cylinder module. The engine is shown in partial cross-section. In effect, half of the engine block has been removed to reveal internal detail of the engine. The cross-section is in a plane coincident with the axis of the central shaft of the engine. The engine block has thus been split at its midline.

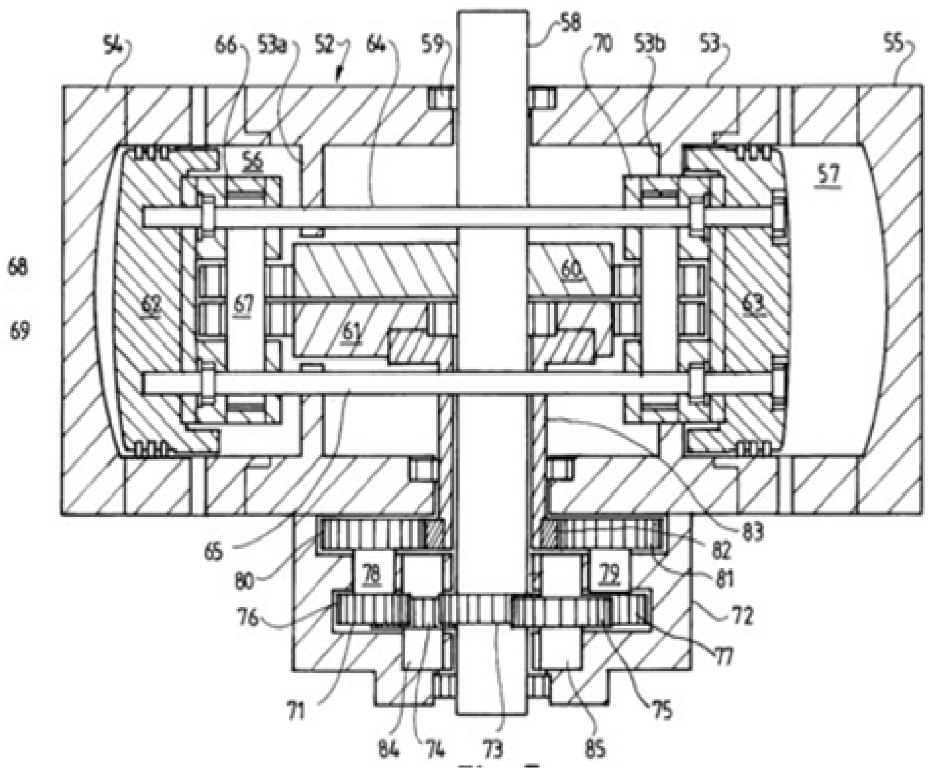

Figure 2.2: Cross-sectional view of another two-stroke engine comprising a single cylinder module with the cross-section being in the plane of the central shaft of the engine.

Source: Bradley (2006)

52- engine, 53- comprises block, 54 and 55- cylinder heads, 56 and 57- cylinders, 58- shaft, 59- roller bearings, 60- a first trilobate cam fixed, 61- counter rotating trilobate cam, 62- piston in cylinder 56, 63- piston in cylinder 57, 64 and 65- four connecting rods, 66- piston a bearing boss, 67- holds shaft, 68 and 69- roller bearings, 70- bearing boss, 71- gear train, 72- housing, 73- sun gear, 74 and 75- drive gears, 76 and 77- planetary gears, 78 and 79- shafts, 80 and 81- second set of planetary gears, 82- sun gear, 83-sleeve, 84 and 85- shafts.

An engine with offset cam contacting bearings is shown schematically in Figure 2.3. In this figure, which is a view along the central shaft of an engine, cam , counter rotating cam , and piston are shown. Piston includes bearing bosses and which carry roller bearings and, which bearings are shown in contact with a lobe, respectively, of the trilobate cams.

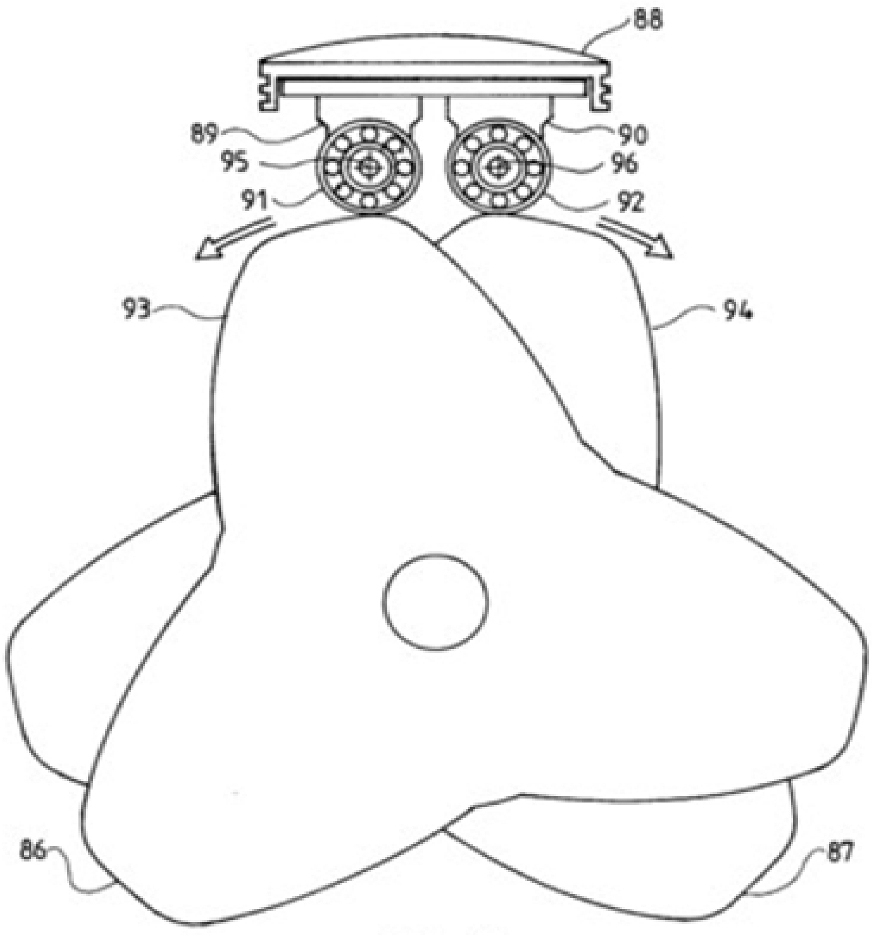

Figure 2.3: View of portion of an engine showing a piston in contact with counter rotating trilobate cams.

Source: Bradley (2006)

86- cam, 87- counter rotating cam, 88- piston, 89 and 90- bearing bosses, 91 and 92- roller bearings, 93 and 94- which bearings are shown in contact with a lobe, 95 and 96- axes

2.3.2 Type of revetec engine

Based on Figure 2.4, it shown one module can either comprise of two trilobate cams and either two, or four pistons in an "X" configuration.

Figure 2.4: Revetec engine for X-Series.

Source: Bradley (2006)

Refer to Figure 2.5 it show revetec engine for boxer series. In a boxer, the opposing pistons move away from each other and then towards each other. In this figure 2.5, they move in the same direction.

Figure 2.5: Revetec engine for Boxer- Series.

Source: Bradley (2006)

With reference to Figure 2.6, 120° might be described as the natural angle for a V type of engine cylinders fire every 120° of camshaft rotation. The 120° layout also produces an engine which is too wide for most automobile engine compartments like used in racing cars.

Figure 2.6: Revetec engine for 120DegV- Series.

Source: Bradley (2006)

With reference to Figure 2.7, the most efficient cylinder bank angle for a V type of is 60 degrees, minimizing size and vibration. While 60° V type of engines are not as well balanced as inline-6 and flat-6 engines.

Figure 2.7: Revetec engine for 60DegV- Series.

Source: Bradley (2006)

According to Figure 2.8, In general use it refers to any type of straight engine. Internal combustion engine with all cylinders aligned in one row, with no offset.

Figure 2.8: Revetec engine for Inline- Series.

Source: Bradley (2006)

2.3.3 Advantage and disadvantage

Advantage of controlled combustion engine (CCE)

i. Approximately one quarter the size and weight of a conventional engine combined with improved output substantially increases power/weight and torque/weight ratio.
ii. Fewer moving and total components. As a result of fewer components, more easily manufactured than conventional engines.
iii. Identical cylinder head assembly to conventional engines. Most existing head technology can be either adapted or utilised.
iv. Eliminated irregularly reciprocating components such as connecting rods.
v. Output shaft can be run in either direction if multi lobed cams with symmetrical lobes are employed.
vi. All rotational forces are counteracted via the counter rotating cam eliminates the need for a heavy flywheel.
vii. Torque and power output can be varied using a fixed capacity and piston stroke.

viii. The CCE can be designed to operate at greatly reduced operating speeds while delivering high torque output.
ix. Substantial reduction in stroke reduces heat loss through cylinder wall.
x. Extended piston dwell is possible because engine design allows a lower than normal compression ratio to be used reducing power loss from compression cycle.
xi. Maximum mechanical advantage can be applied to output shaft at only 10 degrees ATDC utilising high cylinder pressure early in the stroke, compared to around 60 degrees ATDC for conventional engines.
xii. Lower emissions can be achieved due to increased control over combustion.
xiii. Extremely low idle speed due to increase in mechanical efficiency at the top of the stroke.
xiv. Little or no bore contact/piston side thrust, which reduces wear on cylinder bore.
xv. Can have different port timing on compression stroke than power stroke allowing better control two-stroke.
xvi. Lower centre of gravity.
xvii. Due to controlled piston acceleration rates the CCE reduces engine vibration.

Disadvantage of controlled combustion engine (CCE)

i. Vibration: it occur when engine in overheating
ii. Emissions: at higher performance the release of HC is reduce, but higher of NOx is increase
iii. Overheating: for higher performance engine the ability to overheat is higher.

2.4 TYPE OF CAM

2.4.1 Definition of cam

Cam is defined as a machine element having a curved outline or a curved groove. By oscillation or rotation motion, it gives a predetermined specified motion to another element called the follower.

The cam has a very important function in the many operation of classes machines, especially those of the automatic type, such as printing presses, shoe machinery, textile machinery, gear-cutting machines, and screw machines. In any class of machinery in which automatic control and accurate timing are paramount, the cam is an indispensable part of mechanism. The possible applications of cams are unlimited, and their shapes occur in great variety.

A cam mechanism usually consists of two moving elements, the cam and the follower, mounted on a fixed frame. Cam devices are versatile, and almost any arbitrarily-specified motion can be obtained. In some instances, they offer the simplest and most compact way to transform motions. (Harold,2004)

2.4.2 Classification of cam mechanisms

It can classify cam mechanisms by the modes of input/output motion, the configuration and arrangement of the follower, and the shape of the cam. The cams design also classify by the different types of motion events of the follower and by means of a great variety of the motion characteristics of the cam profile.

2.4.2.1 Modes of input/ output motion

i. Rotating cam-translating follower: The follower system will follow the surface of the cam rotating (Figure 2.9a,b,c,d,e)
ii. Rotating follower: The follower arm swings or oscillates in a circular arc with respect to the follower pivot. (Figure 2.9f)
iii. Translating cam-translating follower: The follower arm swings or oscillates in a circular arc with respect to push valve. (Figure 2.10)
iv. Stationary cam-rotating follower: The follower system revolves with respect to the center line of the vertical shaft.

2.4.2.2 Follower configuration

i. Knife-edge follower: The sharp edge follower that contact to the cam. (Figure 2.9a)

ii. Roller follower: The follower roller with bearing that contact to the cam. (Figure 2.9b,e,f)

iii. Flat-faced follower: Flat surface of the follower that tangential to the cam. (Figure 2.9c)

iv. Spherical-faced follower: Hemisphere follower that contact to the cam. (Figure 2.9d)

According to Figure 2.9, it show a variety of follower that contact with cam profile.

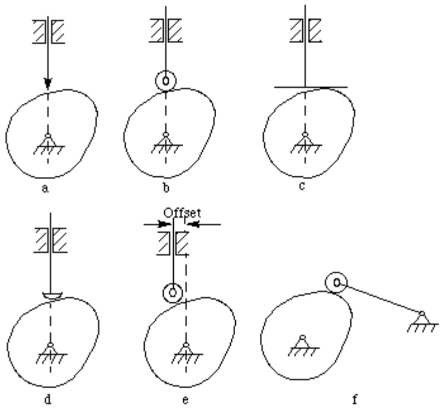

Figure 2.9: Classification of cam mechanisms.

Source: Harold (2004)

Based on Figure 2.10, it show translating cam translating follower. Where follower arm swings or oscillates in a circular arc with respect to push valve.

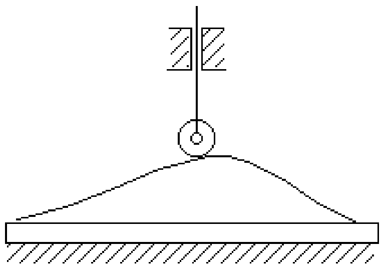

Figure 2.10: Translating cam - translating follower.

Source: Harold (2004)

2.4.2.3 Follower arrangement

i. In-line follower: The center line of the follower passes through the center line of the camshaft.
ii. Offset follower: The center line of the follower does not pass through the center line of the cam shaft. The amount of offset is the distance between these two center lines. The offset causes a reduction of the side thrust present in the roller follower.

2.4.2.4 Cam shape

Plate cam or disk cam is the follower moves in a plane perpendicular to the axis of rotation of the camshaft. A translating or a swing arm follower must be constrained to maintain contact with the cam profile. Grooved cam or closed cam: This is a plate cam with the follower riding in a groove in the face of the cam. (Figure2.11)

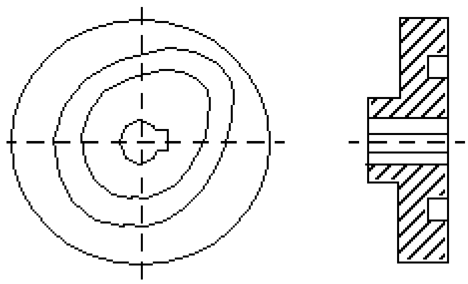

Figure 2.11: Grooved cam.

Source: Harold (2004)

Cylindrical cam or barrel cam is the roller follower operates in a groove cut on the periphery of a cylinder. The follower may translate or oscillate. If the cylindrical surface is replaced by a conical on a conical cam results. (Figure 2.12a) End cam has a rotating portion of a cylinder. The follower translates or oscillates, whereas the cam usually rotates. The end cam is rarely used because of the cost and the difficulty in cutting its contour. (Figure 2.12b)

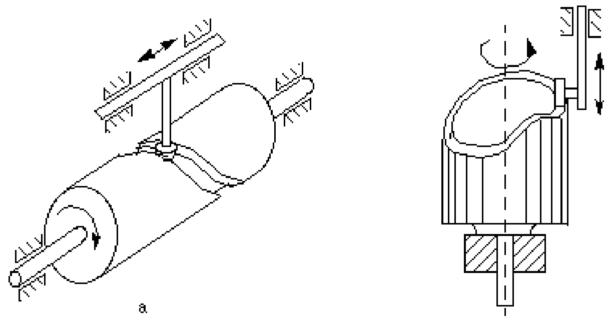

Figure 2.12: Cylindrical cam and end cam.

Source: Harold (2004)

2.5.2.5 Constraints on the follower

i. Gravity constraint: The weight of the follower system is sufficient to maintain contact.
ii. Spring constraint: The spring must be properly designed to maintain contact.
iii. Positive mechanical constraint: A groove maintains positive action. Based on Figure 2.11 and Figure 2.12a)

For the cam in Figure 2.13, the follower has two rollers, separated by a fixed distance, which act as the constraint; the mating cam in such an arrangement is often called a constant-diameter cam.

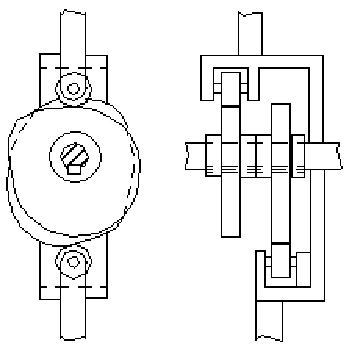

Figure 2.13: Constant diameter cam.

Source: Harold (2004)

A mechanical constraint cam also is introduced by employing a dual or conjugate cam in arrangement similar to what shown in Figure 2.14. Each cam has its own roller, but the rollers are mounted on the same reciprocating or oscillating follower.

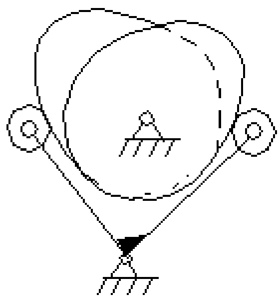

Figure 2.14: Dual cam.

Source: Harold (2004)

2.4.2.6 Examples in sim design

Rotating cam, translating follower

Turn the cam, the follower will move. The weight of the follower keeps them in contact. This is called a gravity constraint cam. It is shown in Figure 2.15.

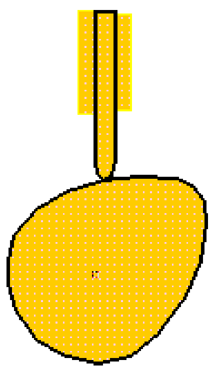

Figure 2.15: SimDesign translating cam.

Source: Robert (2002)

Rotating cam/rotating follower

Notice that a roller is used at the end of the follower. In addition, a spring is used to maintain the contact of the cam and the roller. It is shown in Figure 2.16.

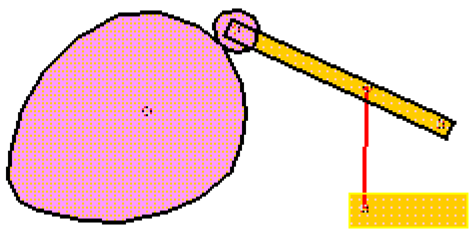

Figure 2.16: SimDesign oscillating cam.

Source: Robert (2002)

2.2.2 Cam nomenclature

Figure 2.17 show illustrates some of cam nomenclature. Cam nomenclature is base circle added with pitch curve and cam profile.

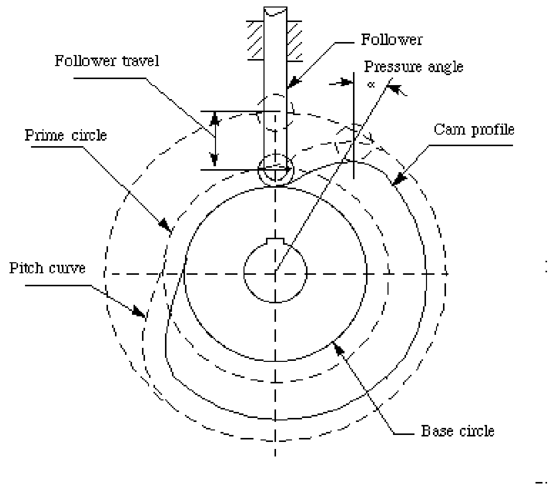

Figure 2.17: Cam nomenclature.

Source: Harold (2004)

i. **Trace point**: A theoretical point on the follower, corresponding to the point of a fictitious knife-edge follower. It is used to generate the pitch curve. In the case of a roller follower, the trace point is at the center of the roller.

ii. **Pitch curve**: The path generated by the trace point at the follower is rotated about a stationary cam.

iii. **Working curve**: The working surface of a cam in contact with the follower. For the knife-edge follower of the plate cam, the pitch curve and the working curves coincide. In a close or grooved cam there is an inner profile and an outer working curve.

iv. **Pitch circle**: A circle from the cam center through the pitch point. The pitch circle radius is used to calculate a cam of minimum size for a given pressure angle.

v. **Prime circle** (**reference circle**): The smallest circle from the cam center through the pitch curve.

vi. **Base circle**: The smallest circle from the cam center through the cam profile curve.

vii. **Stroke** or **throw**: The greatest distance or angle through which the follower moves or rotates.

viii. **Follower displacement**: The position of the follower from a specific zero or rest position (usually its the position when the follower contacts with the base circle of the cam) in relation to time or the rotary angle of the cam.

ix. **Pressure angle**: The angle at any point between the normal to the pitch curve and the instantaneous direction of the follower motion. This angle is important in cam design because it represents the steepness of the cam profile.

2.3 DERIVATION

2.3.1 Cycloidal motion calculation

The following equations give the piston displacement, when using Cycloidal motion (Myszka, 2005):

Displacement equation for cycloidal motion

$$X = s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) \tag{2.1}$$

Cylinder volume for different equation

$$V = A \times X + V_o \tag{2.2}$$

Displacement equation between maximum and minimum volume

$$V_\pi - V_o = A \times s \tag{2.3}$$

Compress ratio

$$r = \frac{V_\pi}{V_o} \tag{2.4}$$

From equation (2.4)

$$V_\pi = V_o \times r \tag{2.5}$$

Substitute equation (2.5) into equation (2.4)

$$V_o \times r - V_o = A \times s \tag{2.6}$$

$$V_o(r-1) = A \times s \tag{2.7}$$

Area of cylinder cross-section

$$\mathrm{A} = \frac{\mathrm{V_o(r-1)}}{\mathrm{s}} \tag{2.8}$$

Substitute equation (2.1) and (2.8) into equation (2.2)

$$V = \frac{V_o(r-1)}{s} \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + V_o \tag{2.9}$$

$$V = V_o(r-1) \times \left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + V_o \tag{2.10}$$

$$\frac{V}{V_\pi} = \frac{V_o(r-1)}{V_\pi} \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + \frac{V_o}{V_\pi} \quad (2.11)$$

$$\tilde{V} = \frac{1(r-1)}{r} \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + \frac{1}{r} \quad (2.12)$$

Differentiation

$$\tilde{V} = \frac{(r-1) \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + 1}{r} \quad (2.13)$$

$$\frac{d\tilde{V}}{d\theta} = \frac{(r-1)}{r\beta} \times \left(1 - cos\left(\frac{2\pi\theta}{\beta}\right)\right) \quad (2.14)$$

2.3.2 Cylinder pressure calculation

Fraction of heat released (x)

$$\frac{d\check{P}}{d\theta} = -\gamma \frac{\check{P}}{\tilde{V}} \frac{d\tilde{V}}{d\theta} + (\gamma - 1) \frac{\tilde{Q}}{\tilde{V}} \frac{dx}{d\theta} \quad (2.1)$$

Source: Ferguson (1986)

The fraction of heat release x

$$x = 1 - exp\left[1 - \left(\frac{\theta - \theta_s}{\theta_b}\right)^n\right] \quad (2.2)$$

$$\frac{dx}{d\theta} = n(1 - x)\left(\frac{\theta - \theta_s}{\theta_b}\right)^n / \theta_b \quad (2.3)$$

2.3.3 Derivation of the equation for conventional engine

$$V = A \times X + V_o \quad (2.1)$$

Subs equation $\frac{s}{2}(1 - \cos 3\,\theta)$ into equation (2.1)

$$V = A \times \frac{s}{2}(1 - \cos 3\,\theta) + V_o \tag{2.2}$$

The displacement volume:

$$V_\pi - V_o = A \times s \tag{2.3}$$

The compression ratio:

$$r = \frac{V_\pi}{V_o} \rightarrow V_\pi = V_o \times r \tag{2.4}$$

Substituting Equation (2.4) into Equation (2.3):

$$V_o(r - 1) = A \times s \tag{2.5}$$

By using Eq. (2.2)

$$V = V_o \frac{(r-1)}{2}(1 - \cos 3\,\theta) + V_o \tag{2.6}$$

To normalize the equation:

$$\tilde{V} = \frac{V_o}{V_\pi} = \frac{V_o}{V_\pi}\frac{(r-1)}{2}(1 - \cos 3\,\theta) + \frac{V_o}{V_\pi} \tag{2.7}$$

$$\tilde{V} = \left[1 + \frac{(r-1)}{2}(1 - \cos 3\,\theta)\right]/r \tag{2.8}$$

And its derivative:

$$\frac{d\tilde{V}}{d\theta} = 3\,\frac{r-1}{2r}\sin 3\,\theta \tag{2.9}$$

To ensure a fair comparison between Revetec engine and conventional engines, the same bore (b), stroke (h = 2r), piston mass (m) and initial pressure (P1) are kept the same for both types of engines. Also the angular speed (ω) in the case of Revetec engine is reduces to 50 rad/ s, because in Revetec engine the compression and power strokes just take 120^o instead of 360^o in conventional engines. It is shown in Figure 2.18.

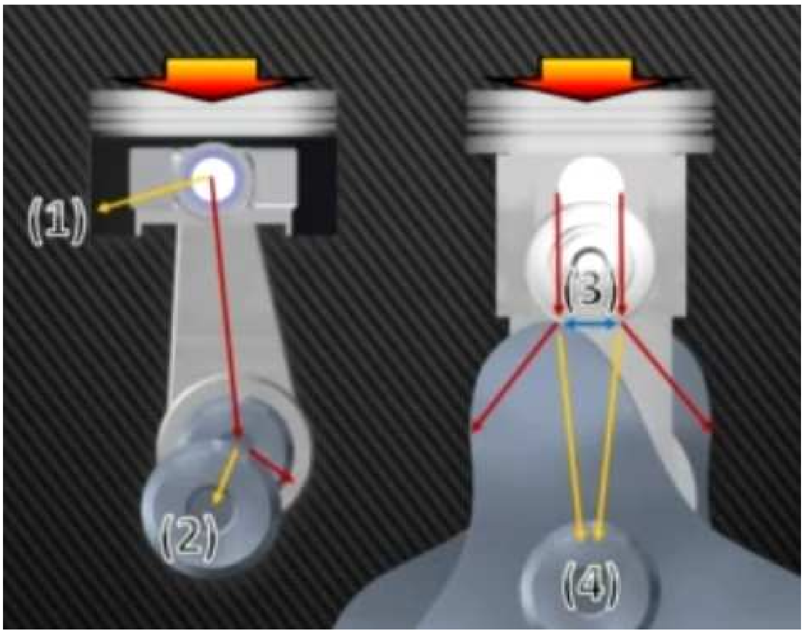

Figure 2.18: Figure of crankshaft and cam shaft.

Source: Bradley (2006)

2.6 SUMMARY

According to figures obtained on Revetec engine, there are many advantages of using this engine type, such as increased efficiency, improve performance, reduce fuel consumption, and so forth. After doing research, all the advantages of using revetec engines will be proved.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, a description about how the project been done and the method used to achieve the project objectives. This chapter also will show the overview of the project and the flow from the beginning until the end of the project. The flow chart show the of the Final Year project started with Final Year project One (FYP1) until Final Year project Two (FYP2). Then follow by preparing project proposal that includes problem statements, project objectives, scope of study, expected outcome and report arrangement. Then continue by literature review. After that, the next step is the methodology.

The methodology shows the design of the project study, start with searching information, find the related equation, derive the equation, do simulation using MATLAB software consist of function, program and graph, make a comparison between revetec engine and conventional engine. Then, the next steps are the preliminary results and discussions of the project. After that, the next step is the conclusions and recommendations.

Overall, the Final Year Project One (FYP 1) is supposed start from chapter one that is introduction until chapter 3 which is methodology. For this Final Year Project Two is start from chapter three until chapter five which is just preliminary result and discussion. Then will continue in Final Year Project Two (FYP 2) with full chapter 4 (result and discussion) and chapter 5 (conclusion and recommendation).

3.2 DESCRIPTION OF PROJECT

The next step is design the methodology start with searching information, find the related equation, derive the equation, do simulation using MATLAB software consist of function, program and graph. This test is for checking better performing between revetec engine and conventional engine. Then, complete the report proposal and slide presentation for Final Year Project 1. Next, go to final task for Final Year Project 1 which is a project presentation.

For Final Year Project 2, it starts with doing programming using MATLAB for pressure. The output data was collected at the function and program. Then, analyze the data in form of graph with the detail explanations. After that, compare the analyze data with the project objective. If the data is satisfied, the project proceeds with the final report. But if the data not satisfied, repeat the program again to get the exact data.

The full report writing is dividing to five chapters and including all the process and activity to complete the project from the beginning. Lastly, make a presentation about the project to the examiner and summit the complete report to finish the Final Year Project 2 task.

3.3 FLOW CHART OF MATLAB PROGRAMMING

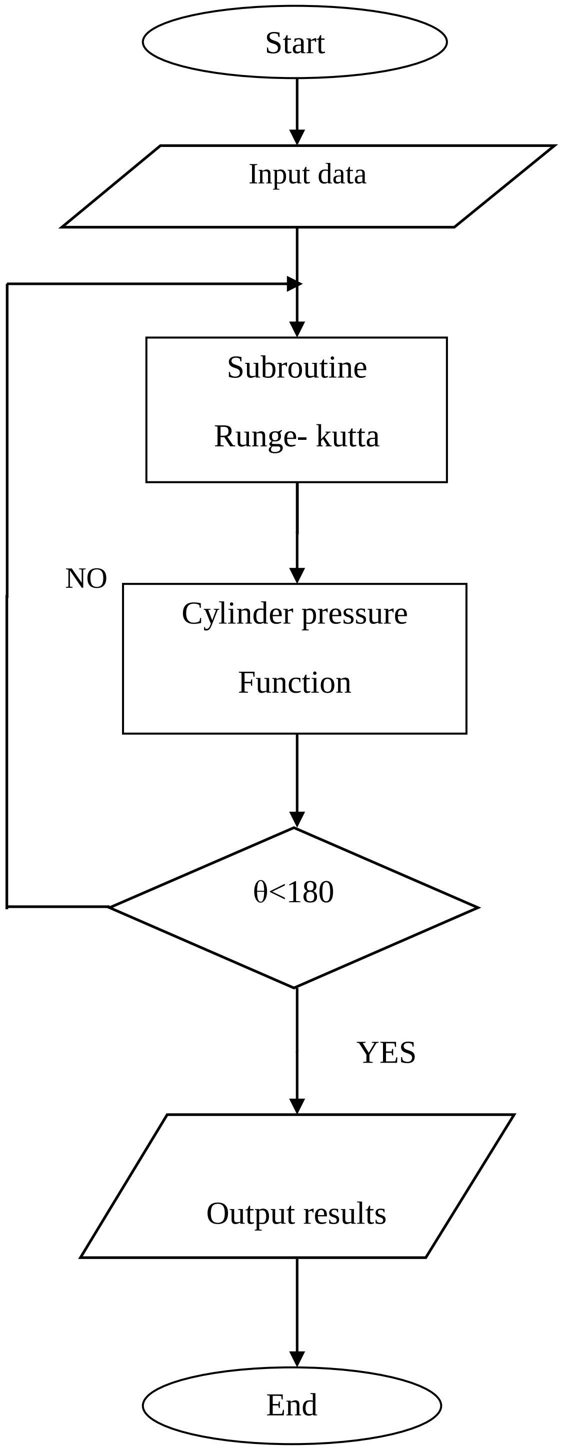

Figure 3.1: Program flow chart

3.4 PROCEDURE IN DOING SIMULATION USING MATLAB PROGRAMMING

3.4.1 Derivation of the equation for conventional engine

$$V = A \times X + V_o \qquad (3.1)$$

Subs equation $\frac{s}{2}(1 - \cos 3\,\theta)$ into equation (3.1)

$$V = A \times \frac{s}{2}(1 - \cos 3\,\theta) + V_o \qquad (3.2)$$

The displacement volume:

$$V_\pi - V_o = A \times s \qquad (3.3)$$

The compression ratio:

$$r = \frac{V_\pi}{V_o} \rightarrow V_\pi = V_o \times r \qquad (3.4)$$

Substituting Equation (3.4) into Equation (3.3):

$$V_o(r - 1) = A \times s \qquad (3.5)$$

By using Eq. (3.2)

$$V = V_o \frac{(r-1)}{2}(1 - \cos 3\,\theta) + V_o \qquad (3.6)$$

To normalize the equation:

$$\tilde{V} = \frac{V_o}{V_\pi} = \frac{V_o}{V_\pi}\frac{(r-1)}{2}(1 - \cos 3\,\theta) + \frac{V_o}{V_\pi} \qquad (3.7)$$

$$\tilde{V} = \left[1 + \frac{(r-1)}{2}(1 - \cos 3\,\theta)\right]/r \tag{3.8}$$

And its derivative:

$$\frac{d\tilde{V}}{d\theta} = 3\,\frac{r-1}{2r}\sin 3\,\theta \tag{3.9}$$

3.4.2 Derivation of cycloidal motion calculation for revetec engine

The following equations give the piston displacement, when using Cycloidal motion (Myszka, 2005):

Displacement equation for cycloidal motion

$$X = s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) \tag{3.1}$$

Cylinder volume for different equation

$$V = A \times X + V_o \tag{3.2}$$

Displacement equation between maximum and minimum volume

$$V_\pi - V_o = A \times s \tag{3.3}$$

Compress ratio

$$r = \frac{V_\pi}{V_o} \tag{3.4}$$

From equation (3.4)

$$V_\pi = V_o \times r \tag{3.5}$$

Substitute equation (3.5) into equation (3.4)

$$V_o \times r - V_o = A \times s \tag{3.6}$$

$$V_o(r-1) = A \times s \tag{3.7}$$

Area of cylinder cross-section

$$\mathrm{A} = \frac{\mathrm{V_o(r-1)}}{\mathrm{s}} \tag{3.8}$$

Substitute equation (3.1) and (3.8) into equation (3.2)

$$V = \frac{V_o(r-1)}{s} \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + V_o \tag{3.9}$$

$$V = V_o(r-1) \times \left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + V_o \tag{3.10}$$

$$\frac{V}{V_\pi} = \frac{V_o(r-1)}{V_\pi} \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + \frac{V_o}{V_\pi} \tag{3.11}$$

$$\tilde{V} = \frac{1(r-1)}{r} \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + \frac{1}{r} \tag{3.12}$$

Differentiation

$$\tilde{V} = \frac{(r-1) \times s\left(\frac{\theta}{\beta} - \frac{1}{2\pi} sin\left(\frac{2\pi\theta}{\beta}\right)\right) + 1}{r} \tag{3.13}$$

$$\frac{d\tilde{V}}{d\theta} = \frac{(r-1)}{r\beta} \times \left(1 - cos\left(\frac{2\pi\theta}{\beta}\right)\right) \tag{3.14}$$

3.4.3 Cylinder pressure calculation

Fraction of heat released (x)

$$\frac{d\check{P}}{d\theta} = -\gamma \frac{\check{P}}{\tilde{V}} \frac{d\tilde{V}}{d\theta} + (\gamma - 1) \frac{\tilde{Q}}{\tilde{V}} \frac{dx}{d\theta} \tag{3.1}$$

Source: Ferguson (1986)

The fraction of heat release x

$$x = 1 - exp\left[1 - \left(\frac{\theta - \theta_s}{\theta_b}\right)^n\right] \tag{3.2}$$

$$\frac{dx}{d\theta} = n(1 - x)\left(\frac{\theta - \theta_s}{\theta_b}\right)^n / \theta_b \tag{3.3}$$

3.5 SUMMARY

In summary to this chapter, it shows the method used to obtain a source of information for final year project. Resources for the project last year came from the journal, the supervisor of the project, research and the previous book. After that, the means to complete this final year project presented in this chapter. Describes the beginning of the question, then do a simulation using MATLAB programming and then make comparison between the conventional engine and revetec engine. Results from this project will show a best performance of the engine.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

In this chapter, it describes the results obtained through tests conducted on the conventional engine and engine revetec. Discussion and comparison was made to know the results. After getting both data for conventional and revetec engine, the comparison between the conventional engine and engine revetec can be done. Data and graphs obtained from the MATLAB programming will show the best performance of the engine.

4.2 RESULTS

4.2.1 Pressure for conventional engine

$r = 10$, $\gamma = 1.3$, $\theta_s = -40^o$, $\theta_b = 40^o$, $n = 4$

According to Table 4.1, it show the table for conventional engine pressure during compression and power stroke. The data get from simulation using MATLAB.

Table 4.1: Table conventional engine pressure during compression and power stroke

Crank angle (θ)	Pressure (kpa)	Crank angle (θ)	Pressure (kpa)
1	1241.056	10	1250.052
5	1242.827	15	1262.959

Table 4.1: Continue

Crank angle (θ)	Pressure (kpa)	Crank angle (θ)	Pressure (kpa)
20	1281.757	183	25268.53
25	1306.758	184	25184.30
30	1338.381	185	25055.10
35	1377.173	186	24882.13
40	1423.818	187	24667.01
45	1479.172	188	24411.73
50	1544.281	189	24118.65
55	1620.432	190	23790.41
60	1709.192	195	21727.50
65	1812.479	200	19250.80
70	1932.636	205	16704.17
75	2072.539	210	14315.03
80	2235.723	215	12196.26
85	2426.549	220	10380.97
90	2650.423	225	8857.191
95	2914.062	230	7592.389
100	3225.843	235	6547.830
105	3596.237	240	5686.043
110	4038.339	245	4973.920
115	4568.504	250	4383.589
120	5207.047	255	3892.199
125	5978.919	260	3481.288
130	6914.131	265	3136.049
135	8047.436	270	2844.639
140	9416.376	275	2597.589
145	11056.09	280	2387.314
150	12989.52	285	2207.717
155	15210.76	290	2053.887
160	17658.24	295	1921.849
165	20182.44	300	1808.374
170	22523.55	305	1710.833
171	22939.75	310	1627.079
172	23331.53	315	1555.352
173	23695.81	320	1494.215
174	24029.61	325	1442.491
175	24330.04	330	1399.219
176	24594.42	335	1363.626
177	24820.26	340	1335.090
178	25005.37	345	1313.129
179	25147.89	350	1297.376
180	25246.33	355	1287.574
181	25299.59	360	1283.564
182	25307.06	361	1283.449

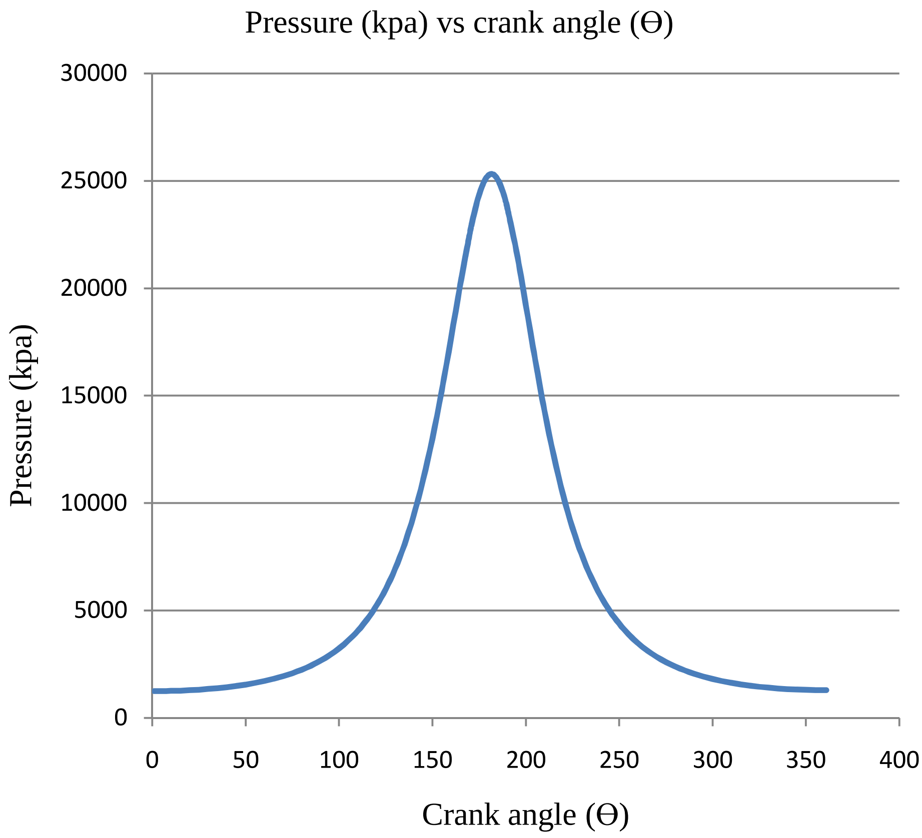

Figure 4.1: Conventional engine pressure graph during compression and power stroke

Figure 4.1 shown, the pressure against crank angle for conventional engine. Based on graph, it show pressure increase and decrease by changing of crank angle. Graph below continuous happen while engine is run until it stop. At bottom dead center (BDC) or minimum peak for one degree the pressure is 1241.056 kpa. Then, the pressure will increase by increasing degree of crank angle until pressure achieving maximum pressure or maximum peak or top dead center (TDC). In between two stage, start from BDC to the TDC it was named as BTDC or ignition. The pressure at TDC is a maximum pressure. At this stage, the high pressure reach up to 25307.06 kpa at 182 degree of crank angle. After it achieves 183 degree, the pressure gradually drop until it back to the lower pressure. But, the pressure must be higher than 1241.056 kpa. It is because the pressure in the combustion chamber do not fully released through exhaust manifold. In between two stage, start from TDC to the BDC it was named as TBDC or exhaust valve opens.

4.2.2 Pressure for revetec engine

$r = 10$, $\gamma = 1.3$, $\theta_s = -40^o$, $\theta_b = 40^o$, $n = 4$, $Q = 60$

According to Table 4.2, it show the table for revetec engine pressure during compression and power stroke. The data get from simulation using MATLAB.

Table 4.2: Table of revetec engine pressure during compression and power stroke

Crank angle (θ)	Pressure (kpa)	Crank angle (θ)	Pressure (kpa)
1	1241.056	165	28167.75
5	1241.175	170	29789.89
10	1242.427	171	30053.38
15	1246.295	172	30294.56
20	1254.340	173	30512.69
25	1268.213	174	30707.08
30	1289.672	175	30877.10
35	1320.642	176	31022.20
40	1363.275	177	31141.88
45	1420.049	178	31235.66
50	1493.883	179	31303.05
55	1588.284	180	31343.13
60	1707.527	181	31357.41
65	1856.855	182	31356.04
70	2042.741	183	31321.83
75	2273.159	184	31260.56
80	2557.900	185	31172.91
85	2908.895	186	31059.32
90	3340.514	187	30920.24
95	3869.791	188	30756.14
100	4516.477	189	30567.57
105	5302.814	190	30355.13
110	6252.831	195	28960.50
115	7391.007	200	27093.13
120	8740.070	205	24881.81
125	10317.80	210	22462.06
130	12132.81	215	19971.07
135	14179.52	220	17516.01
140	16432.80	225	15187.18
145	18843.35	230	13045.60
150	21334.87	235	11126.67
155	23804.50	240	9444.038
160	26127.67	245	7994.836

Table 4.2: Continue

Crank angle (θ)	Pressure (kpa)	Crank angle (θ)	Pressure (kpa)
250	6764.882	310	1553.223
255	5733.295	315	1470.467
260	4876.145	320	1406.345
265	4169.076	325	1357.683
270	3589.011	330	1321.808
275	3115.091	335	1296.420
280	2729.107	340	1279.488
285	2415.550	345	1269.165
290	2161.456	350	1263.739
295	1956.129	355	1261.592
300	1790.828	360	1261.185
305	1658.448	361	1261.183

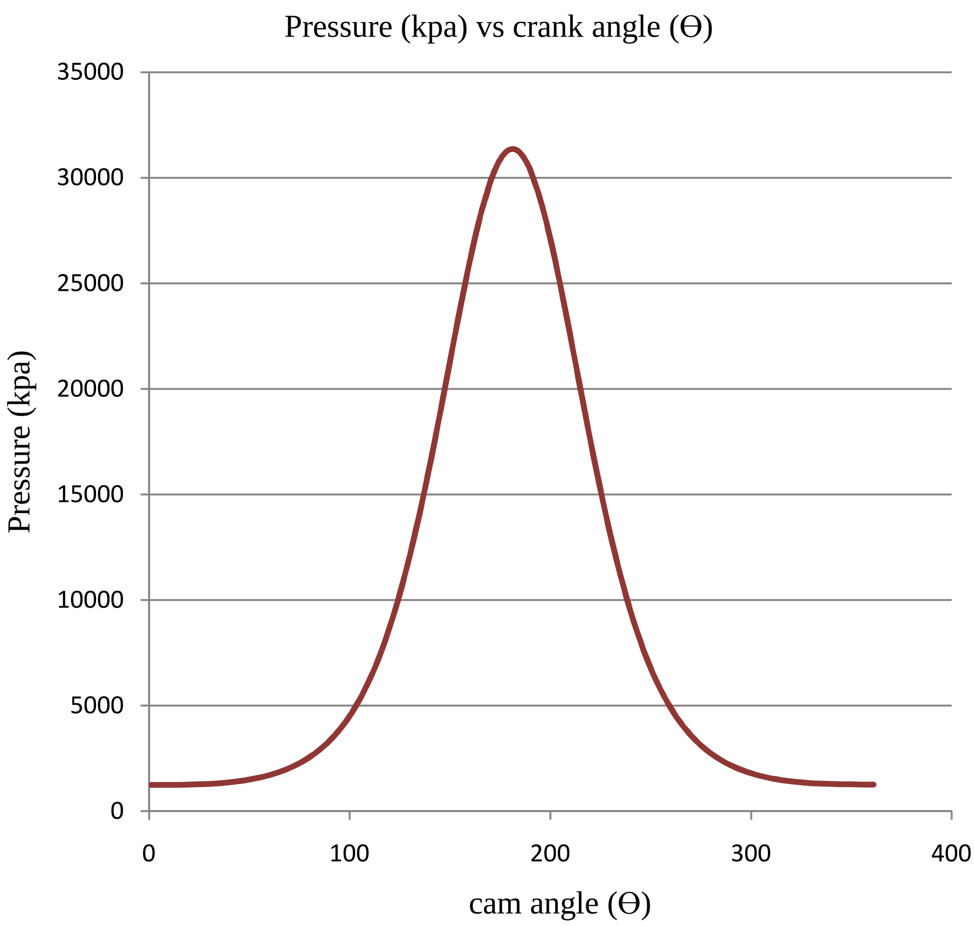

Figure 4.2: Revetec engine pressure graph during compression and power stroke

Figure 4.2 shown, the pressure against cam angle for revetec engine. Based on graph, it show pressure increase and decrease by changing of cam angle. Graph below will continuously happen while engine is running until the engine stop running. At bottom dead center (BDC) or minimum peak for one degree the pressure is 1241.056 kpa. Then, the pressure will increase by increasing degree of crank angle until pressure achieving maximum pressure or maximum peak or top dead center (TDC). In between two stage, start from BDC to the TDC it was named as BTDC or ignition. The pressure at TDC is a maximum pressure. where the pressure at this state reach 31357.41 kpa at 181 degree of crank angle. After it achieves 182 degree, the pressure gradually drop until it back to the lower pressure. But, the pressure must be higher than 1241.056 kpa. It is because the pressure in the combustion chamber do not fully release through exhaust manifold. In between two stage, start from TDC to the BDC it was named as TBDC or exhaust valve opens.

4.2.3 Comparison pressure between conventional engine and revetec engine

$r = 10$, $\gamma = 1.3$, $\theta_s = -40^o$, $\theta_b = 40^o$, $n = 4$, $Q = 60$

According to Table 4.3, it show the comparison table between conventional engine and revetec engine pressure during compression and power stroke. The data get from simulation using MATLAB.

Table 4.3: Comparison table between conventional engine and revetec engine pressure during compression and power stroke

Crank / cam Angle (θ)	**Conventional engine pressure (kpa)**	**Revetec engine pressure (kpa)**
1	1241.056	1241.056
10	1250.052	1242.427
20	1281.757	1254.340
30	1338.381	1289.672
40	1423.818	1363.275
50	1544.281	1493.883
60	1709.192	1707.527
70	1932.636	2042.741

Table 4.3: Continue

Crank / cam Angle (θ)	**Conventional engine pressure (kpa)**	**Revetec engine pressure (kpa)**
80	2235.723	2557.900
90	2650.423	3340.514
100	3225.843	4516.477
110	4038.339	6252.831
120	5207.047	8740.070
130	6914.131	12132.81
140	9416.376	16432.80
150	12989.52	21334.87
160	17658.24	26127.67
170	22523.55	29789.89
180	25246.33	31343.13
181	25299.59	31357.41
182	25307.06	31356.04
190	23790.41	30355.13
200	19250.80	27093.13
210	14315.03	24881.81
220	10380.97	17516.01
230	7592.389	13045.60
240	5686.043	9444.038
250	4383.589	6764.882
260	3481.288	4876.145
270	2844.639	3589.011
280	2387.314	2729.107
290	2053.887	2161.456
300	1808.374	1790.828
310	1627.079	1553.223
320	1494.215	1406.345
330	1399.219	1321.808
340	1335.090	1279.488
350	1297.376	1263.739
360	1283.564	1261.185
361	1283.449	1261.183

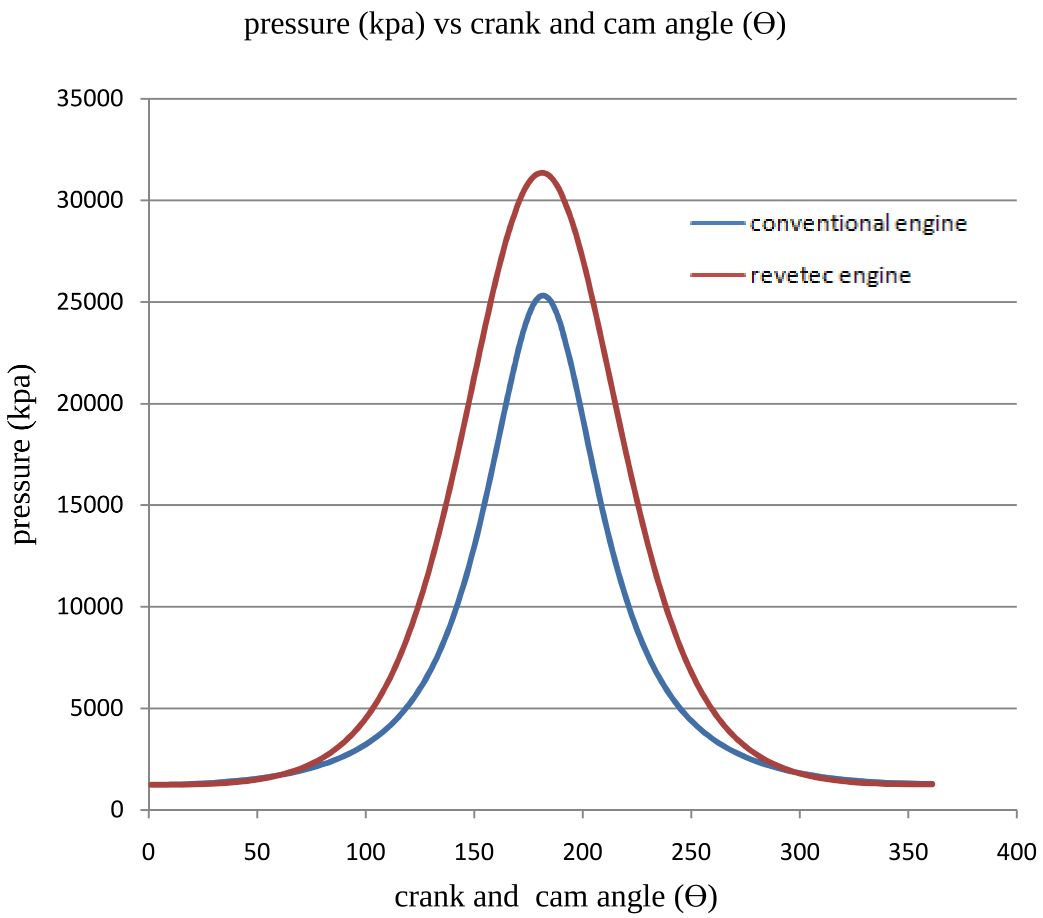

Figure 4.3: Comparison graph between conventional engine and revetec engine pressure during compression and power stroke

Figure 4.3 shown the pressure against change of angle for both engine, conventional engine and revetec engine. Based on graph, it show pressure increase and decrease by changing the angle. This shape of graph is named by harmonic motion graph. Both of engine do the same combustion process starting with intake, compression, combustion and lastly exhaust. At four stage of internal combustion engine, the position of piston also different. At bottom dead center (BDC) or minimum peak for both engine. The pressure for one degree is 1241.056 kpa. Then, the pressure will increase by increasing degree of crank angle until pressure achieving maximum pressure or maximum peak or top dead center (TDC). At TDC, the significant pressures for both of engine are shown. For conventional engine at TDC, the pressure is 25307.06 kpa at 182 and for revetec engine at TDC, the pressure is 31357.41 kpa at 181.

The different of pressure happen started at ignition point until it achieves maximum pressure. With exchange of angle for both engine at TDC, the pressure gradually drop until it back to BDC. This type of exchange is call as exhaust opens or TBDC. But, the pressure at BDC must be higher than 180 psi. At BDC after TDC, the significant pressure for both the engine is shown. For conventional engine at BDC after TDC, the pressure is 1283.449 kpa and for revetec engine at BDC after TDC, the pressure is 1261.183 kpa. This pressure difference occurs at 361 degree. The reason why the pressure does not return to the original pressure or 1241.056 kpa because the pressure in the combustion chamber does not fully released through exhaust manifold.

Calculation

The percentage of increasing revetec engine performing

Maximum pressure for conventional engine = 25307.06 kpa

Maximum pressure for Revetec engine = 31357.41 kpa

Pressure different = 31357.41 kpa - 25307.06 kpa

= 6050.35 kpa

Percentage = $\frac{6050.35 \text{ kpa}}{25307.06 \text{ kpa}} \times 100$

= 23.91 %

In conventional combustion engine to engine, there are many factors that affect engine performance. One-third percent of the internal combustion engine power switch to power the engine. Then, two-thirds percent of the internal combustion engine is converted to energy that is lost like exhaust heat, heat transfer, cooling systems, pumping losses, combustion, mechanical and parasitic.

According to other researchers, nearly 30 percent of the mechanical loss for the conventional engine comes from the transfer of torque. One of the factors that cause mechanical losses is crankshaft. By replacing the crankshaft to the camshaft, engine pressure increase up to 23.91 percent. The increase of pressure for revetec engine becauseof the torque leverage increase geometrically near peak pressure. The design of revetec engine will deflect some of the wasted normal force in conventional engine.

Based on Figure 2.18, first is wasted side thrust to the cylinders bore for engine using crankshaft. Second, represent wasted down force on the main bearing for crankshaft. For cam shaft, third represent deflected side thrust into useable torque. Blue colour at point 3 of revetec design is a useable torque due to the increase deflected site thrust. Four show reducing wasted down force. Other reasons why conventional engine lower performance compare to revetec engine because of fiction happen at point one and point two. First is friction happen between piston bore and connecting rod. Second is friction happen between main bearing and connecting rod.

Revetec engine can simulate as push and pull rod engine characteristic as well as infinite connecting rod ratio. Another future is that the design can utilize asymmetrical piston movement and creating different high position at the ignition point. Asymmetrical piston movement can increase mechanical leverage between points of ignition and top dead center by reducing pumping losses.

CHAPTER 5

CONCLUSION AND RECOMENDATIONS

5.1 CONCLUSION

As a conclusion, the introduction of Revetec engine is a new discovery to the engine technology. By replacing the crankshaft to the cam shaft, the performing of engine will increase up to 23.91 percent comparing with conventional engine This happen because some of mechanical loss by the crankshaft for conventional engine will reduce by replace cam shaft for revetec engine.

Based on MATLAB programming, for the same angle for both the conventional engine and engine revetec. starting from a negative hundred and eighty to one hundred and eighty or equal to three hundred sixty degree or equivalent to a revolution. Pressure for the conventional engine and engine revetec is the same at bottom dead center (BDC), which is 180 psi. At top dead center (TDC), the engines began to show a significant difference to the engine where the pressure is 31357.41 kpa revetec and while the conventional engine pressure is 25307.06 kpa. Based on the results, 23.91 percent is much higher an increase in efficiency.

According to other researchers, technology of revetec has provided many benefits like world fuel efficiency, leading to better thermal efficiency, higher mechanical transfer, higher torque at low RPM, operate on a mixture of stronger, leaner cold start and running, emission reduction, leaner mixture can reduce NOx, style of driving efficiency, drive ability improvements, permanent increase in the piston, the combustion is more efficient, less wasteful down force, less friction and wear, the pistons do not specify torque, special tools for multiple applications, a very compact in the design, a higher power to weight ratio, engine assembly easy.

5.2 RECOMENDATIONS FOR THE FUTURE RESEARCH

To get better results, the project must include a prototype or real revetec engine. Therefore, tests such as dynamometer test, speed test, RPM test, emission test and other tests relate with engine can be done to obtain reliable results. Next, there are many types of cam profile curve like cycloidal, trapezoidal and sine curve. Based on three cam profiles, there is a need to design a better cam profile for revetec engine performance and to improve the internal combustion engine. Then, the results of the study must be published to the public more frequently. Perhaps, more interested parties to conduct a study on the revetec engine in the future. So people know the advantages of using the engine revetec.

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APPENDICES

MATLAB Program Coding For Conventional Engine

```
function [ FCN ] = mas( t,xn)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here

r =10;
thetas =-40;
thetab =40;
en =4;
gamma =1.3;

vol= (1+((r-1)/2)*(1-cos(t.*pi/180)))/r;
dvol=((r-1)/2*sin(t*pi/180)*pi/180)/r;

xx=1-exp(-((t-thetas)/thetab)^en);
dxx=(1-xx)*en*(((t-thetas)/thetab)^(en-1))/thetab;
if t>thetas
FCN = -gamma.*xn.*dvol./vol+(gamma-1).*40.*dxx./vol;
else

FCN = -gamma.*xn.*dvol./vol;

end
```

MATLAB Function Coding For Conventional Engine

```
b=180;
N a=-180;
=b-a;
h = (b-a)/N;        %the step size
t(1) = a;
xn(1) = b;      %the initial value
for i = 1:N
   k1 = h*mas(t(i), xn(i));
   k2 = h*mas(t(i)+h/2, xn(i)+(k1)/2);
   k3 = h*mas(t(i)+h/2, xn(i)+(k2)/2);
   k4 = h*mas(t(i)+h, xn(i)+k3);
   xn(i+1) = xn(i) + (k1 + 2*k2 + 2*k3 + k4)/6;
   t(i+1) = a + i*h;

end



%this line of code below is optional if visualization is
not needed


plot(t, xn)
```

Graph Program Coding and Function Coding for Conventional Engine

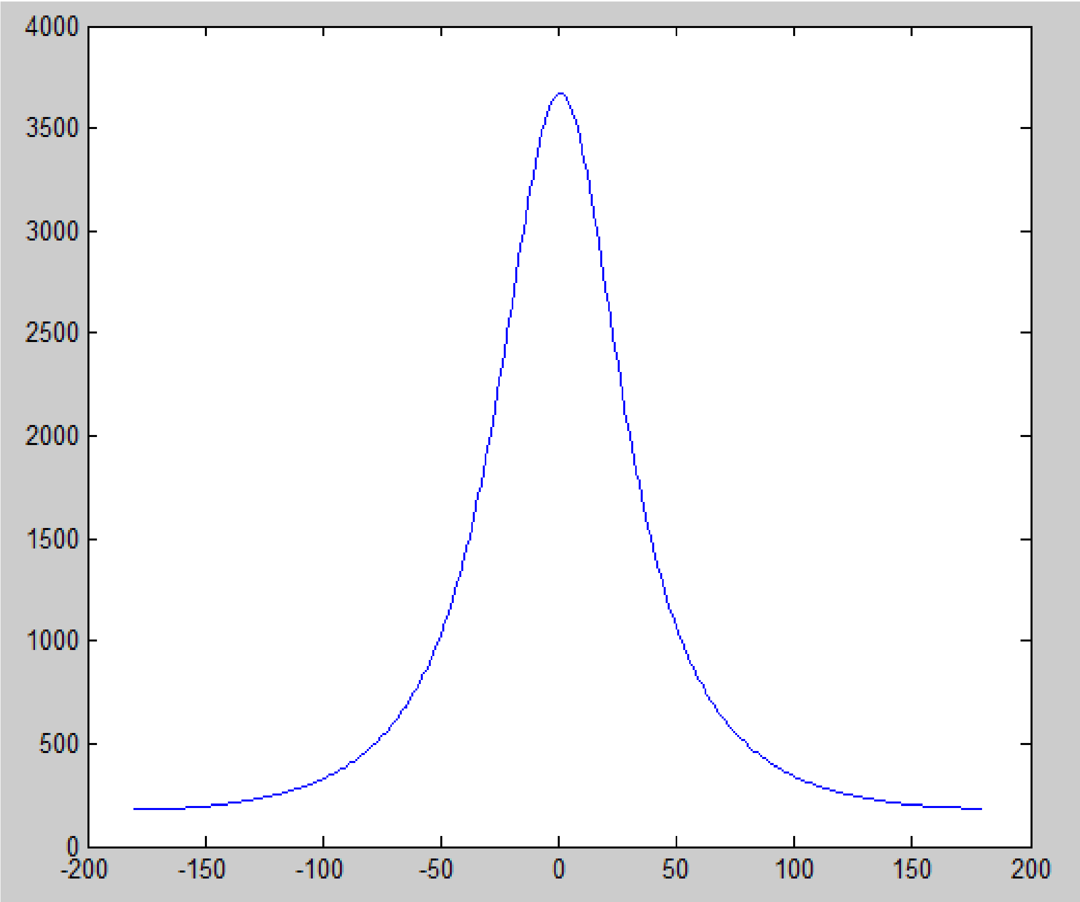


Figure 3.2: Graph for conventional engine

MATLAB Program Coding for Revetec Engine

```
function [ FCN ] = baiki( t,xn)
%UNTITLED2 Summary of this function goes here
%   Detailed explanation goes here

gamma =1.3;
thetas =-40;
r =10;
betta =60;
thetab =40;
en =4;
vol= (1+((r-1).*((t./(betta*pi/180))-
((1/2*pi)*(sin(2*t.*pi/180))))))/r;
dvol=(((r-1)/(r.*(betta*pi/180))).*(1-(cos(2*t.*pi/180))));

xx=1-exp(-((t-thetas)./thetab).^en);
dxx=(1-xx).*en.*((t-thetas)./thetab).^(en-1)./thetab;
if t>thetas
FCN = -gamma.*xn.*dvol./vol+(gamma-1).*40.*dxx./vol;
else

FCN = -gamma.*xn.*dvol./vol;

end
```

MATLAB Function Coding for Revetec Engine

```
a=-180;
b=180;
N=b-a;
h = (b-a)/N;        %the step size
t(1) = a;
xn(1) = b;      %the initial value
fid = fopen('muna5.dat', 'w');
for i = 1:N
   k1 = h*baiki(t(i), xn(i));
   k2 = h*baiki(t(i)+h/2, xn(i)+(k1)/2);
   k3 = h*baiki(t(i)+h/2, xn(i)+(k2)/2);
   k4 = h*baiki(t(i)+h, xn(i)+k3);
   xn(i+1) = xn(i) + (k1 + 2*k2 + 2*k3 + k4)/6;
   t(i+1) = a + i*h;
   fwrite(fid, xn(i), 'single');
end



%this line of code below is optional if visualization is
not needed


fclose(fid);
plot(t, xn)
```

Graph Program Coding and Function Coding for Revetec Engine

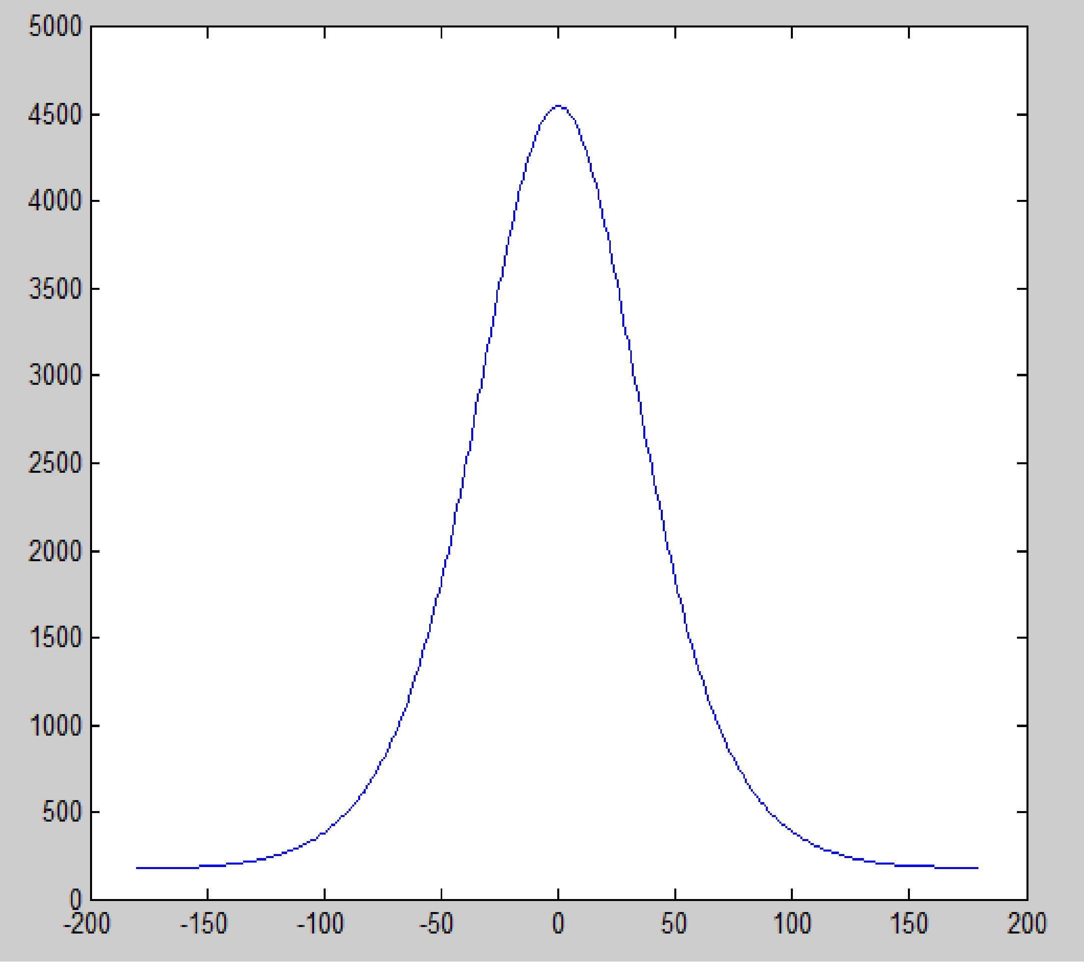


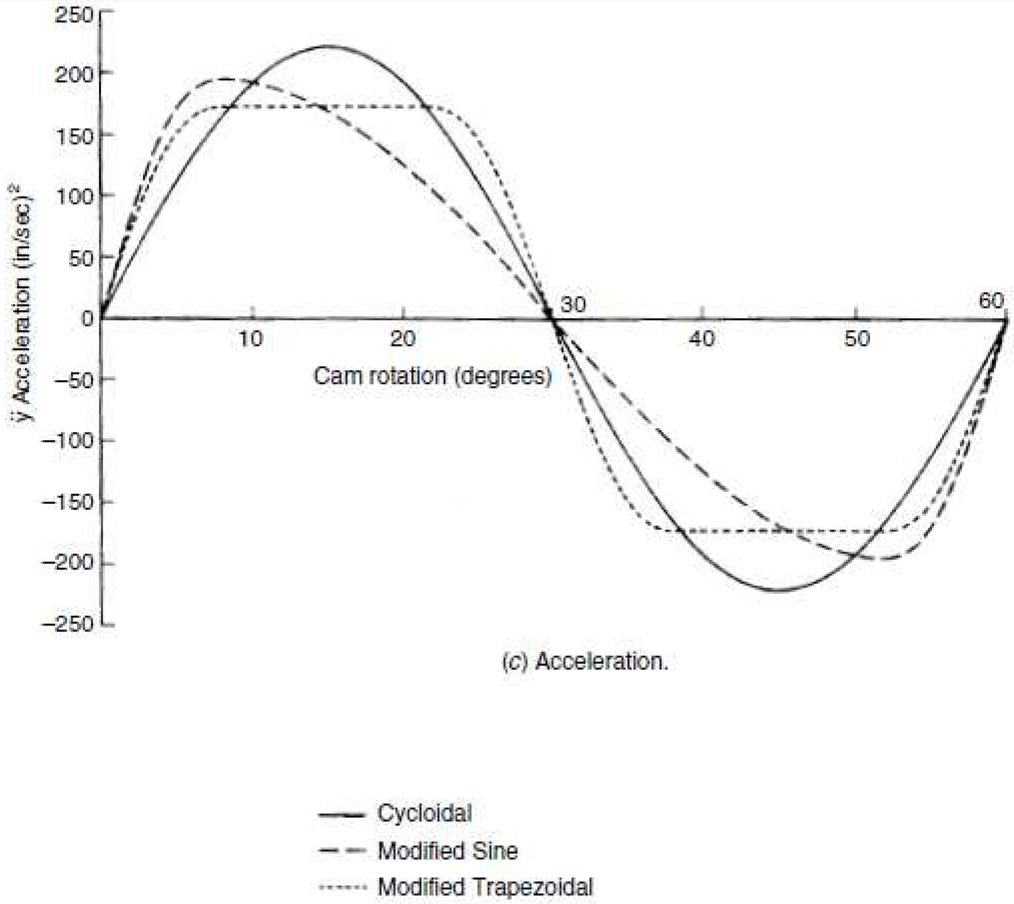
Figure 3.3: Graph for revetec engine

TABLE 2.1 Characteristic Equations of Basic Curves

Curves		Displacement y, in.	Velocity $\dot{y}$, ips	Acceleration $\ddot{y}$, in./sec^2
Constant velocity		$\frac{h\theta}{\beta}$	$\frac{\omega h}{\beta}$	0
Simple harmonic motion (SHM)		$\frac{h}{2}\left(1-\cos\frac{\pi\theta}{\beta}\right)$	$\frac{h\pi\omega}{2\beta}\sin\frac{\pi\theta}{\beta}$	$\frac{h}{2}\left(\frac{\pi\omega}{\beta}\right)^2\cos\frac{\pi\theta}{\beta}$
Double harmonic		$\frac{h}{2}\left[\left(1-\cos\frac{\pi\theta}{\beta}\right)-\frac{1}{4}\left(1-\cos\frac{2\pi\theta}{\beta}\right)\right]$	$\frac{h\pi\omega}{2\beta}\left(\sin\frac{\pi\theta}{\beta}-\frac{1}{2}\sin\frac{2\pi\theta}{\beta}\right)$	$\frac{h}{2}\left(\frac{\pi\omega}{\beta}\right)^2\left(\cos\frac{\pi\theta}{\beta}-\cos\frac{2\pi\theta}{\beta}\right)$
Cycloidal		$\frac{h}{\pi}\left(\frac{\pi\theta}{\beta}-\frac{1}{2}\sin\frac{2\pi\theta}{\beta}\right)$	$\frac{h\omega}{\beta}\left(1-\cos\frac{2\pi\theta}{\beta}\right)$	$\frac{2h\pi\omega^2}{\beta^2}\sin\frac{2\pi\theta}{\beta}$
Parabolic or constant acceleration	$\frac{\theta}{\beta}\leq 0.5$	$2h\left(\frac{\theta}{\beta}\right)^2$	$\frac{4h\omega\theta}{\beta^2}$	$4h\frac{\omega^2}{\beta^2}$
	$\frac{\theta}{\beta}\geq 0.5$	$h\left[1-2\left(1-\frac{\theta}{\beta}\right)^2\right]$	$\frac{4h\omega}{\beta}\left(1-\frac{\theta}{\beta}\right)$	$-4h\frac{\omega^2}{\beta^2}$
Cubic no. 1	$\frac{\theta}{\beta}\leq 0.5$	$4h\left(\frac{\theta}{\beta}\right)^3$	$\frac{12h\omega}{\beta}\left(\frac{\theta}{\beta}\right)^2$	$\frac{24h\omega^2}{\beta^2}\left(\frac{\theta}{\beta}\right)$
	$\frac{\theta}{\beta}\geq 0.5$	$h\left[1-4\left(1-\frac{\theta}{\beta}\right)^3\right]$	$\frac{12h\omega}{\beta}\left(1-\frac{\theta}{\beta}\right)^2$	$-\frac{24h\omega^2}{\beta^2}\left(1-\frac{\theta}{\beta}\right)$
Cubic no. 2		$h\left(\frac{\theta}{\beta}\right)^2\left(3-2\frac{\theta}{\beta}\right)$	$\frac{6h\omega\theta}{\beta^2}\left(1-\frac{\theta}{\beta}\right)$	$\frac{6h\omega^2}{\beta^2}\left(1-2\frac{\theta}{\beta}\right)$

where h = maximum rise of follower, in.
β = cam angle of rotation to give rise h, radians.
ω = cam angular velocity, rad/sec.
θ = cam angle rotation for follower displacement y, radians.

Graph For Some Of Cam Curve



(c) Acceleration.