DESIGN OF SINGLE CYLINDER VARIABLE COMPRESSION RATIO 4-STROKE ENGINE

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Thesis submitted in fulfillment of the requirements
For the award of the degree of
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We certify that the project entitled "Design *of single cylinder variable compression ratio 4-stroke engine"* is written by *Firdaus Haikal bin Ramli*. We have examined the final copy of this project and in 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 of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive Engineering.

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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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Dedicated to my parents

Respected father, Mr. Ramli bin Yahya

Loving mother, Mrs. Azizah binti Biron

My brothers and sisters

My precious friends

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ABSTRACT

This thesis is about designing a new method to increase engines efficiency. The method used in this study is variable compression ratio (VCR) engines, where the compression ratio of the engine can be changed according to driving conditions. A mechanism of VCR is designed and simulated. The motion analysis is used to analyze the VCR mechanism and engines component behaviour under different compression ratio. Solidworks simulation software is used to perform the motion analysis. The data of stress distribution, deformation of engines component and factor of safety (FOS) from the simulation are used to determine whether the components are safe to operate at compression ratio higher than the original. Yamaha FZ150i engine has been chosen as the baseline engine design. The engine are disassembled and modelled in solidworks in order to perform the simulation. The engine is simulated at 2000 rpm and the compression ratio are varies between 8:1 and 18:1. The result from of the simulation indicates that the compression ratio can safely be increased up to 12:1 with the original engines component specifications. If higher compression ratio wanted to be used, the specification of the engines component (piston and connecting rod) needed to be changed .However, since the Factor of safety (FOS) value of the components is critical at certain compression ratio, the fatigue and thermal analysis is purposed to be carried out in order to obtain more accurate result.

ABSTRAK

Tesis ini berkaitan proses mencipta kaedah untuk meningkatkan kecekapan enjin. Kaedah yang digunakan dalam kajian ini ialah enjin variable compression ratio (VCR), di mana nisbah mampatan enjin boleh berubah mengikut keadaan memandu. Mekanisme VCR direka dan simulasi. Analisis gerakan digunakan untuk menganalisis keadaan mekanisme VCR dan komponen enjin di bawah nisbah mampatan yang berbeza atau tekanan silinder yang berbeza. Perisian Solidworks simulation digunakan untuk melaksanakan analisis gerakan. Data taburan tekanan, perubahan bentuk enjin dan komponen faktor keselamatan (FOS) daripada simulasi digunakan untuk menentukan sama ada komponen adalah selamat untuk beroperasi pada nisbah mampatan yang lebih tinggi daripada yang asal. Enjin Yamaha FZ150i telah dipilih sebagai reka bentuk asas model enjin. Enjin dibuka dan di model mengunakan Solidworks untuk menjalankan simulasi. Simulasi enjin dijalankan pada 2000 rpm dan nisbah mampatan berbeza antara 8:1 dan 18:1. Hasil dari simulasi menunjukkan bahawa nisbah mampatan selamat boleh meningkat sehingga 12:1 dengan spesifikasi komponen enjin asal. Jika mampatan yang lebih tinggi nisbah mahu digunakan, spesifikasi komponen enjin (omboh dan rod penyambung) perlu ditukar. Walau bagaimanapun, oleh kerana nilai FOS komponen adalah kritikal pada nisbah mampatan tertentu, analisis lesu dan analisis termal disarankan untuk mendapatkan keputusan yang lebih tepat.

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LIST OF ABBREVIATIONS

VCR	Variable compression ratio
CR	Compression ratio
IC	Internal combustion
EC	External combustion
NOx	Nitrous oxide
CO	Carbon monoxide
CO2	Carbon dioxide
LPG	Liquefy petroleum gas
SI	Spark ignition
CI	Compression ignition
MPI	Multi-point injection
BDC	Bottom dead centre
TDC	Top dead centre
CA	Crank angle
Sfc	Specific fuel consumption
DFI	Direct fuel injection
VVA	Variable valve actuation
SVC	SAAB variable compression
FOS	Factor of safety
UTS	Ultimate tensile strength

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter gives a short description of the project background including the approaches taken to achieve the objective of study. This chapter then introduces objectives, scopes, problem statement and the importance of this study on the design of a variable compression ratio (VCR) engine.

1.2 Project Background

The prime mover in the world today is the Internal Combustion (IC) engine. The development and improvement of the internal combustion engines since Nicolaus August Otto and Rudolf Diesel has continued until today and will continue long into the future. The environmental impact of the IC engine, due to its large numbers, is unacceptable. The advanced engine control and exhaust after treatment of the conventional IC engines have decreased the regulated emissions of Nitrous Oxide (NOx), CO, Hydrocarbon (HC), and particulates, to very low levels. However, the main greenhouse gas, Carbon Dioxide (CO_2), from IC engines is and will continue to be a problem in the future. The global heating of the world is directly connected to the increasing in CO_2 emissions emitted to the atmosphere by human activities. In order to decrease CO_2 emission from IC engines running on fossil fuel, the fuel consumption must be reduces, hence, we need more fuel efficient IC engines.

The needs to reduce automotive fuel consumption and CO_2 emissions is leading to the introduction of various new technologies like Hybrid technologies for the gasoline engine as its fights for market share with the diesel. Today, the variable compression ratio (VCR) engines have not reached the market, despites patents and experiments dating back over decades. A variable compression ratio (VCR) engine is able to operate at a different compression ratios depending on the performance needs. The VCR engine is optimized for the full range of driving conditions, such as acceleration, speed, and load. At low power levels, the VCR engine operates at high compression to capture fuel efficiency benefits, while at high power levels, it operates at low compression levels to prevent knock.

This project will focus on designing the mechanism of VCR and identify the challenge in designing it. There are several methods of VCR, we will compare and find out the best method to be used as the final design of our VCR mechanism. The design will then be tested and analyzed.

1.3 Problem Statement

The usage of fossil fuel in internal combustion (IC) engine has lead to the emission of hazardous green house gases that cause a significant damage to our world and the spiking prices of fossil fuel will become a burden to the people because it is used widely throughout the world. The IC engine used today has low efficiency, making the energy in every drop of fuel is not fully utilized

.

In order to increase engine efficiency, a high compression ratio must be used to increase the performance of gaseous fuel. VCR technologies enable the compression ratio to be change thus increasing the engines efficiency. The variable compression ratio (VCR) engine technology can be the solution to these problems. However, it is truly a challenge to design the simplest but effective mechanism of VCR as various factors and aspect of the engine must be considered.

1.4 Project Objective

The objectives of the project are to:

1. To design the mechanism of variable compression ratio (VCR) for single cylinder four-stroke engine.
2. To simulate the mechanism of variable compression ratio (VCR) for single cylinder four-stroke engine.

1.5 Scope Of Project

In order to achieve the objectives of this project, the scopes are list as below:

1. The design of the VCR mechanism is based on single cylinder four-stroke engine (150 cc)

2. Minimize the modification on existing engine component

3. The study try to identify the simplest technique of VCR engine which can be attain manually.

4. The design will be analyzed using motion analysis.

5. The VCR engine is design solely for the purpose laboratory testing (it will be used to study the effect of different CR on gaseous fuel)

1.6 Project Flow Chart

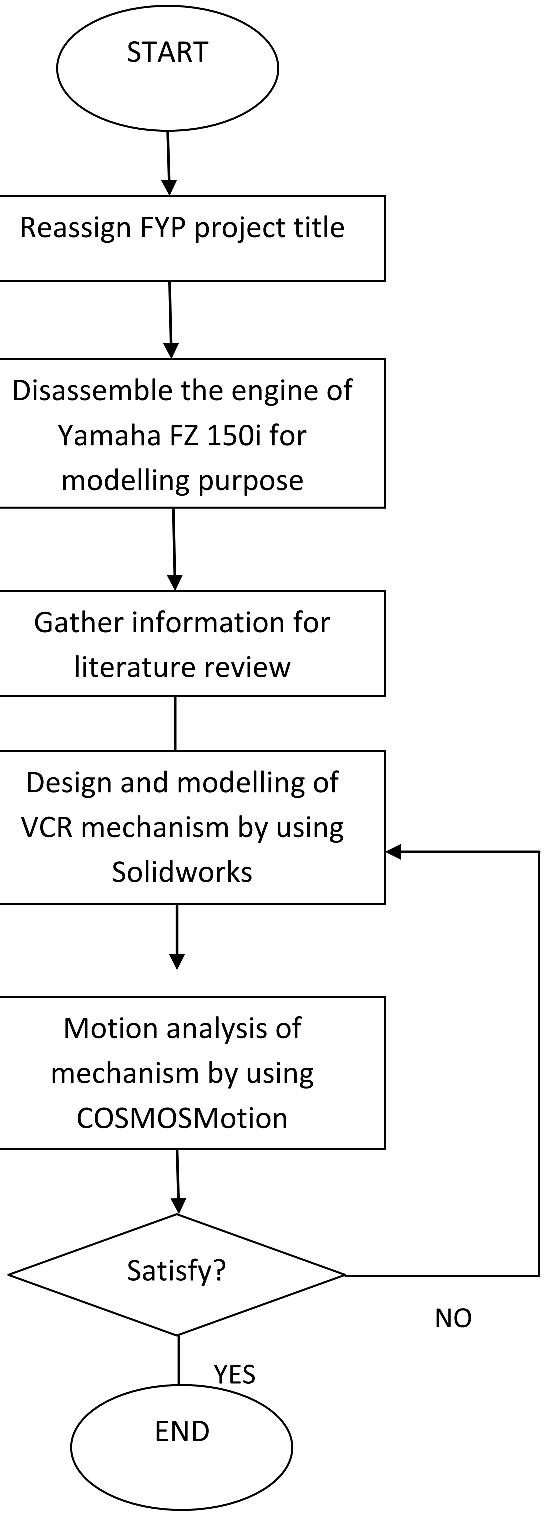

Figure 1.1: Project flow chart

1.7 SUMMARY

Chapter 1 has discussed generally about project, problems statement, objective and the scope of the project in order to achieve the objective as mention. This chapter is as a fundamental for this project and as a guidelines to complete the project study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Literature review is a body of text that aims to review the critical points of current knowledge and or scientific methodological approaches on the topic related to the study. In this chapter, literature will give information about the background knowledge in internal combustion engine field and other technologies that being used as references to generate idea to conduct this study.

2.2 Background of Internal Combustion (IC) Engine

An engine is a device which transforms the chemical energy of the fuel into thermal energy and uses this energy to produce mechanical work (Crouse and Anglin 2005). The engine is also called 'heat engine' because they normally convert thermal energy into mechanical work. When the fuel burns with the presence of air, a large amount of energy is release. The released energy was then converted to useful work by a heat engine with the help of a working fluid. The heat engines can be classified into two groups:

a) External Combustion Engine (EC engines)
b) Internal Combustion Engines (IC engines)

In EC engine, the combustion process will take place outside the cylinder. The heat energy released from the fuel was used to raise the high-pressure steam in a boiler from water. In this case, steam is a working fluid which enters the cylinder of a steam engine to perform mechanical work. The product of combustion of fuel do not enter the engine's cylinder, thus they do not form the working fluid.

The examples of EC engine are the steam turbine in a steam power plant, Sterling engines and a closed cycle gas turbine plant. Here, normally the air act as the working substance which completes the thermodynamics cycle and the product of the combustion process do not enter the turbine. The steam turbine is the most popular EC engine used for large electric power generation.

In IC engine, the combustion process of the fuel can either take place inside the engine's cylinder or the products of the combustion process enter the cylinder as a working fluid. In reciprocating engines having a cylinder and piston, the combustion process of fuel will take place inside the cylinder and this type of engine may be called intermittent internal combustion engines. In an open cycle gas turbine plant, the product of the combustion of fuel enters the gas turbine and work is obtained in the form of rotation of the turbine shaft. This type of turbine is an example of a continuous IC engine.

The intermittent IC engines are the most popular because of their use in the prime transportation in motor vehicles, and reciprocating engines are the typically used one. The reciprocating engine mechanism consists of piston which moves in a cylinder and forms a movable gas-tight seal. Through connecting rod and a crankshaft arrangement, the reciprocating motion of a piston is converted to rotary motion of a crankshaft.

The main advantage of IC engines over EC engines are:

a) Greater mechanical efficiency
b) Higher power output per unit weight because of the absence of auxiliary units like boiler, condenser and feed pump
c) Lower initial cost
d) Higher brake thermal efficiency because only small fraction of heat energy of the fuel is dissipated to the cooling system

The advantages of IC engine accrue from the fact that they work at an average temperature which is much below the maximum temperature of the working fluid in the cycle.

The disadvantages of the IC engines over EC engines are:

a) The IC engines cannot use solid fuel which is cheaper.
b) The IC engines are not self-starting whereas the EC engines have high starting torque
c) The intermittent IC engines have reciprocating parts, thus they are susceptible to vibration problems

2.2.1 Classification of IC Engines

There are different types of IC engines that can be classified on the following basis (Gupta, 2006):

Thermodynamics cycle

- Constant volume heat supplied or Otto cycle
- Constant pressure heat supplied or Diesel cycle
- Partly constant volume and partly constant pressure heat supplied or Dual cycle
- Joule or Brayton cycle

Working cycle

- Four-stroke cycle naturally aspirated, supercharge and turbocharged
- Two-stroke cycle naturally aspirated, supercharge and turbocharged

Types of fuel

- Light oil engines using kerosene or petrol.
- Heavy oil engines using diesel or mineral oils.
- Gas engines using gaseous fuels like natural gas, liquefied petroleum gas (LPG) and hydrogen.
- Bi-fuel engines. In these engines the gas is used as the basic fuel and the liquid fuel is used for starting the engine.

Method of ignition

- Spark ignition (SI) used in conventional petrol engines
- Compression ignition (CI) used in conventional diesel engines
- Pilot injection of fuel oil in gas engines

Method of fuel supply

- Fuel supply through carburettor. In petrol engine, the fuel is mixed with air in the carburettor and the charge enters into the cylinders during the suction stroke.
- Multi-point port injection (MPI), used in modern spark-ignition (SI) engine.
- Single point throttle body injection. This method is also applied to SI engine.
- Fuel injection at high pressure into the engine cylinder. Used in diesel engines or compression-ignition (CI) engine

Type of cooling

- Water cooled engine. The cylinder walls are cooled by circulating water in the jacket surrounding the cylinder
- Air cooled engines, the atmospheric air blows over the hot surfaces. Common vehicle with this type of cooling is motor cycles and scooters

Number of cylinder

- Single cylinder. This engine gives one power stroke per crank revolution (2-stroke) and two revolutions (4-stroke). The torque pulses are widely spaced, and engine vibration and smoothness are significant problems. Used in small engine application where engine size is more important.
- Multi-cylinder. This engines spread out the displacement volume amongst multiple cylinder. Increased frequency of power stroke produces smoother torque characteristic and the engines balance is better than single cylinder.

Basic engine design

- Reciprocating engine, subdivided by the arrangement of cylinders, for example, in-line engines, V-engines, opposed cylinder engines, opposed piston engines and radial engines
- Rotary engines (wankel engines)

2.2.2 Principle Operation of IC Engine

The action or event in the spark-ignition engine can be divided into four parts, or the piston strokes (Crouse and Anglin 2005). Those parts are intake, compression, power, and exhaust. Each stroke is the movement of the piston from Bottom Dead Centre (BDC) to Top Dead Centre (TDC) or from TDC to BDC. Is a four-stroke cycle engine, one complete cycle of event in the engine cylinder requires two complete revolution of the crankshaft.

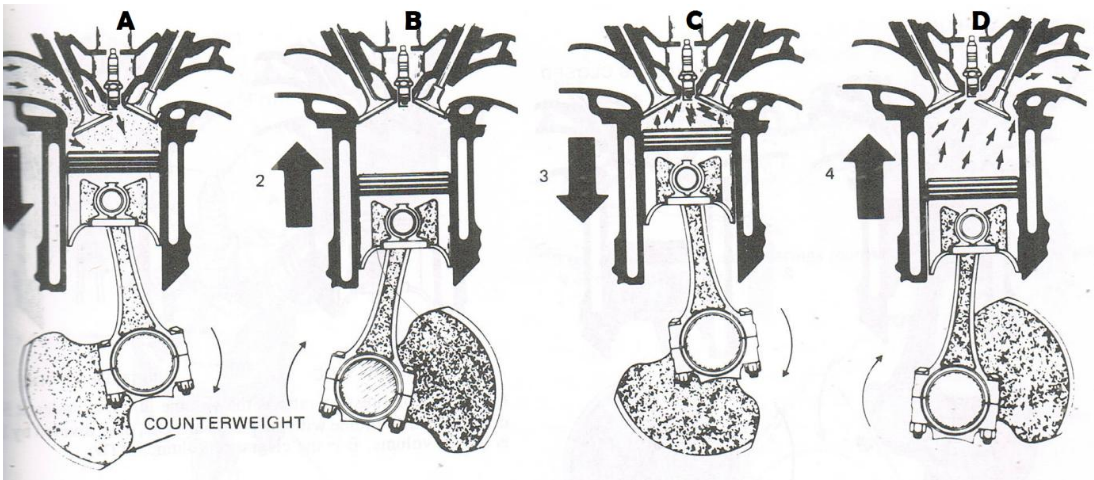

Figure 2.1: The strokes of engine

Source: Crouse and Anglin 2005.

a) *Intake Stroke*

During the intake stroke of a spark-ignition engine, the intake valve is open and the piston is moving downward. This movement will create a partial vacuum above the piston. Atmospheric pressure forces air-fuel mixture to flow through the intake port and into the cylinder. The fuel system supplies the mixture like carburettor or injector (Crouse and Anglin 2005). As the piston passes through the BDC, the intake valve closes. This seal off the upper end of the cylinder.

b) *Compression Stroke*

After the piston passes BDC, it starts moving up. Both valves are closed. The upwards moving piston compresses the air-fuel mixture into a smaller space between top of the piston and the cylinder head. This space is the combustion chamber. In typical spark-ignition engines, the mixture is compressed into one-eight or less of its original volume (Crouse and Anglin 2005).

The amount that the mixture is compressed is called the compression ratio (CR). This is the ratio between the original volume (before being compress) and the compressed volume in the combustion chamber. If the mixture is compressed to one-eight of its original volume, then the compression ratio is 8:1.

c) *Power/Expansion Stroke*

As the piston move nears TDC at the end of the compression stroke, an electric spark jumps the gap at the spark plug. The heat from the spark ignites the compressed the air-fuel mixture. It burns rapidly, producing a high temperature. This high temperature cause very high pressure which pushes down the top of the piston. The connecting rod carries the force to the crankshaft, which turns to move the drive wheels. Power is obtain during this stroke.

d) *Exhaust Stroke*

As the piston approaches BDC on the power stroke, the exhaust valve will open. After passing through BDC, the piston move up again and the burn gases escape through the open exhaust port. As the piston approached TDC, the intake valve will open. When the piston passes through TDC and starts moving down again, the exhaust valve will close and another intake stroke will begin. The whole cycle will repeat again continuously in all cylinder for as long as the engine running.

2.2.3 Four-Stroke and Two-Stroke Engines

In four-stroke cycle SI engine, the cycle of operation is completed in four-strokes of the piston or in two revolution of the crankshaft. Therefore crank angle

(CA) of 720° is required to complete the cycle (Gupta, 2006). The individual stroke of the cycle is:

- Intake or suction stroke
- Compression stroke
- Expansion or power stroke
- Exhaust stroke

Since each cylinder of a four-stroke engine completes all the operations in two engine revolution, for one complete cycle, there is only one power stroke while the crankshaft makes two revolutions (Gupta, 2006).

In two-stroke engine, all the processes are the same, but there are only two stroke involved. Those two strokes of the cycle are completed once during each revolution of the crankshaft. Since there is only one power stroke per revolution of the crankshaft, the power output of a two-stroke engine will be twice that of a four-stroke engine with the same displacement (Gupta, 2006).

Stroke 1:	Air fuel mixture is introduced into the cylinder and then compressed, combustion initiated at the end of the stroke
Stroke 2:	combustion products expand doing work and then exhausted

In these engines, the crankcase is sealed and the piston's outward motion is used to pressurize the air-fuel mixture in the crankcase, as shown in figure 2.2. Instead of having valves (intake and exhaust), they are replaced by the opening on the lower portion of the cylinder (Cengel and Boles, 2007).

Two-stroke engines are generally less efficient than their four-stroke counterparts because of the incomplete expulsion of the exhaust gases and there are some fresh air-fuel mixture escaping along with exhaust gases (Cengel and Boles, 2007). However, they are relatively simple and inexpensive. They also have high power-to-weight and power-to-volume ratios (Cengel and Boles, 2007). Those facts make them suitable for application requiring small size and weight such as motorcycle, chain saw and lawn mowers.

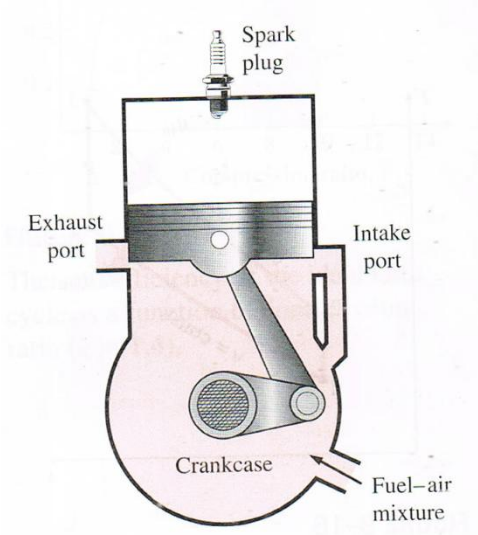

Figure 2.2: Two-stroke SI engine

Source: Cengel and Boles, 2007.

2.2.4 Comparison of Four-Stroke and Two-Stroke Engines

Table 2.1: Comparison of four-stroke and two-stroke engines

Four-stroke engine	Two–stroke engine
- one power stroke obtain in every two revolution of the crankshaft (the cycle is completed in two revolution of the crankshaft)	- one power stroke obtain per revolution of the crankshaft (the cycle complete in one revolution of the crankshaft)
- The movement of the shaft is non-uniform because only one power stroke obtain in two revolution of crankshaft, hence heavier fly is needed to rotate the shaft uniformly	- The turning movement of the shaft is more uniform, hence lighter flywheel can be used.
- The power produce for the same size of the engine is less and for the same power output, the engine is bigger in size	- The power produce for the same size of the engine is more and for the same power output, the engine is smaller in size
- It have valves and valve mechanism	- it has ports. Some engine are equipped with exhaust valve or reed valve
- higher initial cost because heavy weight and valve mechanism	- Lower initial cost because it is lighter and have no valve mechanism
- Thermal and volumetric efficiency is higher due to positive scavenging and higher time of induction	- Lower thermal and volumetric efficiency due to some fresh charge escape unburn during scavenging
- Used when high efficiency is priority as in automobile and power generation	- used where low cost, low weight and compactness is desirable.
- Less wear and tear due to water cooled system. Require less lubricant (placed in crankcase)	- More wear and tear due to air cooled system. Require more lubricant (mix in fuel)

Source: Gupta, 2006.

It can be said that the two-stroke cycle has twice many power stroke per crank revolution than the four-stroke cycle. However in two stroke engines, the power output per unit displaced volume is less than twice the power output of an equivalent four-stroke cycle engine at the same engine speed. This is because of the reduction in effective expansion stroke and some fresh charge escape during scavenging process.

2.3 Compression Ratio of Engine

The compression ratio (CR) is the measure of how much the air-fuel mixture is compressed during the compression stroke of the piston (Crouse and Anglin 2005). The formula used to determine CR is given by:

$$\boldsymbol{CR = \frac{V_{BDC}}{V_{TDC}}} \tag{2.1}$$

Where:

V_{BDC} is the volume above the piston at ‘Bottom dead centre’.
V_{TDC} is the volume above the piston at ‘Top dead centre’ (clearance volume)

We can see the relationship between the CR and the $V_{TDC,}$ where CR is inversely proportional with V_{TDC}. When the volume above the piston at ‘Top dead centre’ increase, CR will decrease and vice versa.

2.3.1 How the Compression Ratio Affect Performance of Engine

The compression ratio has a significant influence towards performance of an internal combustion engine. The power produce by an engine is one of the features that can be affected by CR.

In the combustion process, the more air-fuel mixture is compressed the greater the pressure in the cylinder before the air-fuel mixture is ignited. This leads to more combustion pressure at ignition and increased push on the piston. When a CR of an engine is higher, the pressure and temperature of the air-fuel mixture in the cylinder at the point of ignition will increase and the amount of residual gas in the mixture decreases, therefore the ignition lag reduces. Ignition lag is the period between spark initiation ant flame developments (Gupta, 2006). As the ignition lag decreases, the rate of pressure rise and the maximum pressure achieved in the cylinder increases and enable the burning gas expand to a greater volume. This exerts more force on the piston for a longer part of the power stroke. Each power stroke then produces more power (Crouse and Anglin 2005).

Engine efficiency can also be influenced by CR. As shown of figure 2.3, the thermal efficiency of SI engine is increasing along with CR. As CR increases the pressure, temperature and the overall density of the air-fuel mixture (charge) will increase (Gupta, 2006). If the CR used is too high autoignition or engine knocking is tend to happen (Cengel and Boles, 2007). The impact of knock will depend on its duration and intensity. If the knock duration is short it is unlikely to cause damage, but a heavy and constant knock can easily lead to severe damage to engine (Gupta, 2006). Engine knock acts to limit the compression ratio, thus limiting the engine efficiency (Wong and Stewart, 1998) To avoid knocking, the effective CR of the engine during high load must be reduce and high CR during part loads is use to maintain high engine efficiency (Wong and Stewart, 1998). The usage of special blends gasoline (gasoline mixed with tetraethyl lead) which have an antiknock characteristic can also reduce the knocking tendency (Cengel and Boles, 2007).

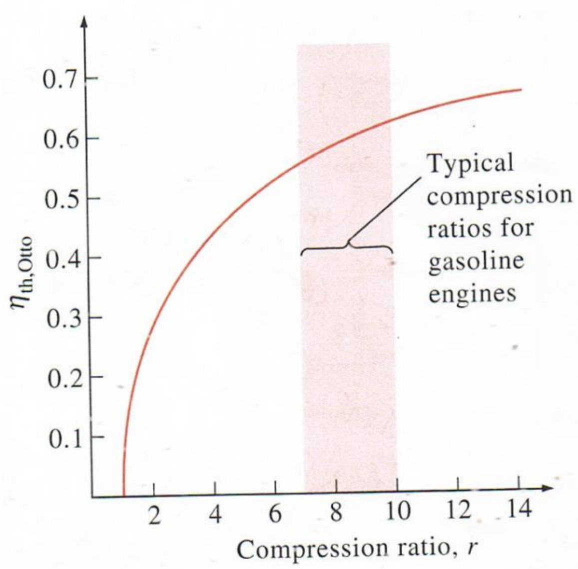

Figure 2.3: A plot of thermal efficiency versus CR

Source: Cengel and Boles, 2007.

2.3.2 Formulating the Compression Ratio

In diagnosing and rebuilding of engine, knowing the compression ratio (CR) can be very helpful. There are several factors can combine to affect CR of an engine, for example the carbon build-up in the cylinder head and on top of the piston, the thickness of head gasket or differences in the manufacture (design) of replaced parts over the originals. From equation 2.1, the CR can be calculated by measuring the V_{BDC} and V_{TDC}. These volumes are indicated by the blue coloured region as shown in Figure 2.4.

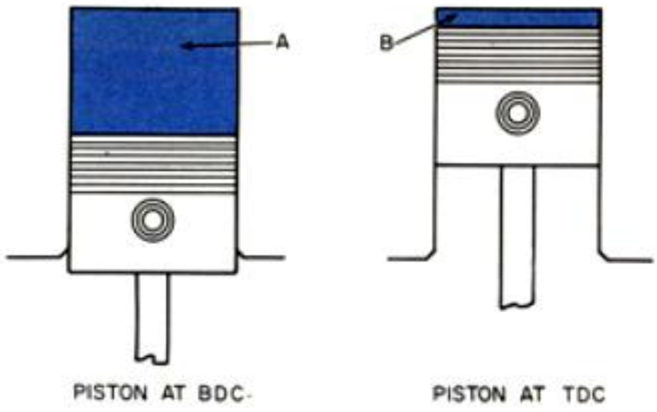

Figure 2.4: The V_{BDC} and V_{TDC}

Source: Anderson, 2000

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Although a simple mathematical formula is use to calculate CR, it require measurement that must be done precisely. Event a slight change in these measurements can have a significant effect on CR. The V_{TDC} is comprised of several parameters. Those parameters are:

- Deck clearance:

  The distance from the top of the piston flat surface to the block deck, ignore any valve relief notches or domes. This distance multiplied by the area of the cylinder provides the volume (Anderson, 2000).
- Head gasket:

  The compressed thickness of the gasket and the diameter of the cylinder opening in the gasket. The area of gasket opening multiplied by the thickness results in the head gasket volume (Anderson, 2000).
- Head volume:

  The volume of the combustion chamber in the head with the valves installed (Anderson, 2000).
- Piston variations:

  Since not all pistons have perfectly flat surfaces, these variations need to be determined. Valve relief notches or depressions add to V_{TDC} and domes decrease it. Piston manufacturers can provide the necessary volume information for these variations of it must be measured manually.

After calculating all the above parameters, the sum of those parameters is the total V_{TDC}. To calculate V_{BDC}, the cylinder volume at BDC must first be calculated, then adding the V_{TDC} with the cylinder volume at BDC. The cylinder volume at BDC is obtained by multiplying the cylinder area by the distance from the block deck to the top of the flat piston surface without the deck clearance.

2.4 Variable Compression Ratio (VCR)

2.4.1 Definition of VCR

Variable compression ratio is the technology to adjust internal combustion engine cylinder compression ratios on the fly. The terms ‘variable’ alone shows that the value of the compression ratio (CR) of an engine can be change (increases or decreases) according to engine load or driving conditions. This is done to increase fuel efficiency while under varying loads. Higher loads require lower ratios to be more efficient and vice versa. For automotive use this needs to be done dynamically in response to the load and driving demands.

2.4.2 REASONS OF APPLICATION OF VCR

The needs to reduce automotive fuel consumption are one of the reasons that lead to the introduction of new technologies like the VCR for the gasoline engine. The VCR engine is optimized for the full range of driving conditions, such as acceleration, speed, and load. At low load, the VCR engine operates at high compression to capture fuel efficiency benefits, while at medium and high load, it operates at low compression levels. At medium and high loads, the VCR presents a noticeable advantage in comparisons with a fixed lower CR limit.

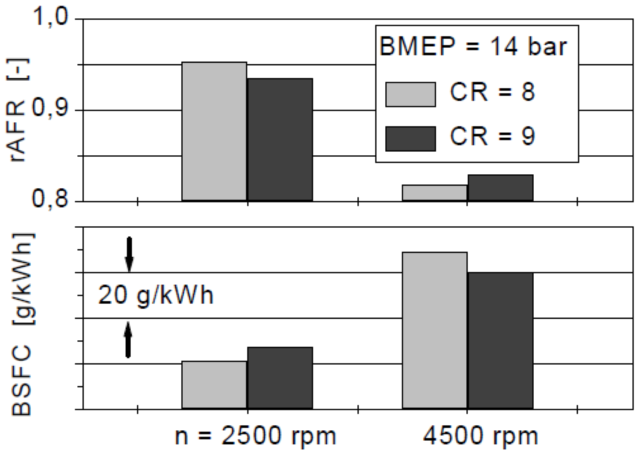


Figure 2.5: The influence of VCR on relative air-fuel ratio and specific fuel consumption

Source: Schwaderlapp et al, 2002.

The specific fuel consumption (sfc), is a measure of how efficiently the fuel supplied to the engine is used to produce power (Gupta, 2006). Therefore, a low value for sfc is desirable since for a given power level less fuel is consumed. At lower rpm (2500 rpm) the engine is submitted to high load, in order to decrease fuel consumption low CR must be used (8:1) and at higher rpm (4500 rpm) the engine is submitted to low load, thus the CR must be increased (9:1) to decreased fuel consumption as shown in figure 2.5. When combining with the other technology like direct fuel injection (DFI), variable valve actuation (VVA) and turbocharging, the VCR potential fuel reduction is 15% to 45%.

The environmental impact of the IC engine, due to its large numbers, is unacceptable. The advanced engine control and exhaust after treatment of the conventional IC engines have decreased the regulated emissions of NOx, CO, HC, and particulates, to very low levels. However, the main greenhouse gas, CO2, from IC engines is and will continue to be a problem in the future. The global heating of the world is directly connected to the increasing in CO2 emissions emitted to the atmosphere by human activities. In order to decrease CO2 emission from IC engines running on fossil fuel we need more fuel efficient IC engines, hence the use of VCR.

2.4.3 VCR ENGINE MECHANISM

There is numerous kind of method or design being developed and presented over the years which modify the compression ratio by manipulating V_{TDC}. Those methods are:

- Moving head/pivoting head.
- Variation of combustion chamber volume/head design.
- Changing piston geometry.
- Multi-link connecting rod (additional rod and levers).
- Force transmission by rack gear.
- Eccentric con rod bearing/con rod length.
- Eccentric crankshaft bearing.

In most cases, the deviation from ordinary production engine structure will have a significant commercial barrier in which the barrier will determine whether the technology will spread or not (Roberts, 2003). Following are the brief explanation on some of the VCR mechanism design:

Moving head/pivoting head

This method was widely known to be pioneered by SAAB's. The SAAB variable compression (SVC) engine is comprised of a cylinder head with integrated cylinders, which known as the monohead, and a lower portion consisting of the engine block, crankshaft and piston. The engines head is pivoted at point (1) as in figure 2.6. The compression ratio was varied by tilting the monohead to adjust the effective height of the piston crown/top at top dead centre. A hydraulic actuator is used at point (2) to tilt the monohead as shown in figure 2.6. The monohead can be tilted up to 4° angle (θ).This will alters the volume combustion chamber, V_{TDC} shown by shaded area in figure 2.6, thus changes the compression ratio which is varied between 8:1 and 14:1(Roberts, 2003).

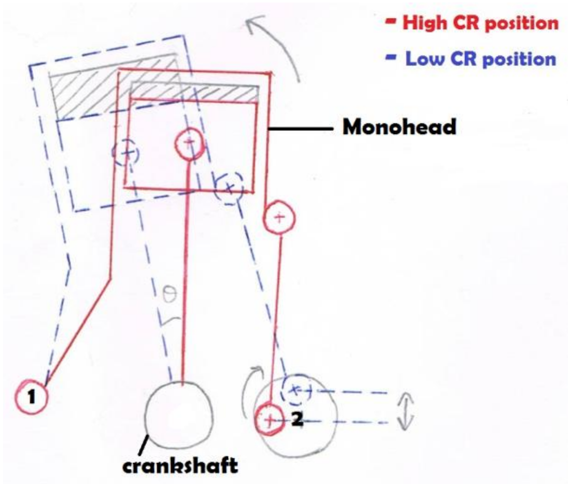


Figure 2.6: The mechanism of SVC engine

Variation of combustion chamber volume/head design

The Alvar-Cycle engine from Volvo is the VCR engine that uses this method as the means to manipulate the volume of combustion chamber to change CR. The Alvar-Cycle engine is consisting of additional smaller crankshaft and piston that mounted in the cylinder head (Wong and Stewart, 1998). The additional crankshaft is driven at half speed from the main crankshaft. A phase shifting mechanism between the crankshafts enables the variation of the CR. The range of CR for this method is 7:1 at 0° phase shift (low CR position) and 13:1 at 180° phase shift (high CR position) as shown in Figure 2.7 (Wong and Stewart, 1998). By changing the geometry of the combustion chamber, the turbulent flow of flame will be interrupted, therefore in designing the secondary chamber geometry this factor must be considered.

Figure 2.7: The Alvar-cycle VCR mechanism

Multi-link connecting rod (additional rod and levers)

This method is one of the most popular methods used in VCR engine design. This method utilizes an additional rod or levers that replace the conventional connecting rod with a multi-link design which the upper member connects with the piston while the lower parts connect with the crankshaft (Roberts, 2003). Figure 2.8 and 2.9, shows the connection of multi-link/levers (2) with the con rod (1).

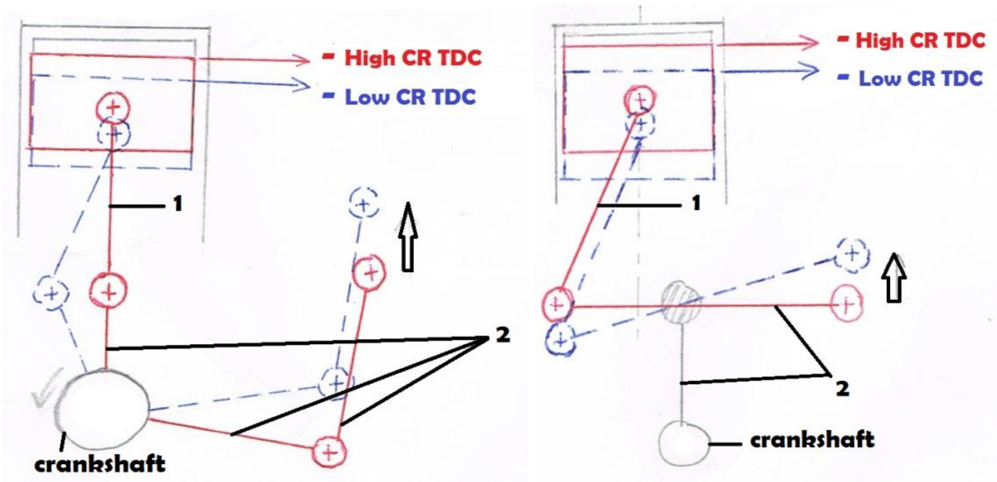


Figure 2.8 and 2.9: The mechanism of multi-link con rod

In this design, hydraulic actuator will be used to provide the force required to move the levers (upward and downward motion). This motion will move the piston to a desired height. This height (TDC position) will influence the V_{TDC}, thus, changing the CR. This method is quite simple because the design does not change the geometry of combustion chamber which can interrupt the flame flow. However, this design is subjected to higher friction force because it has a lot of moving parts. The mass balancing also can be a problem because the oscillating weight is increased (from the multi-link) thus increasing the inertial forces (Schwaderlapp et. al, 2002).

Force transmission by rack gear

The MCE-5 engine is an engine that uses force transmission by rack gear in their VCR mechanism design. The piston kinematics of this engine is identical with the conventional one with the same rod/crank ratio (Rabin et. al, 2004). The CR of this engine is in the range of 6.7:1 to 17:1. Apart from the VCR capability, nothing distinguishes the MCE-5 with conventional engine.

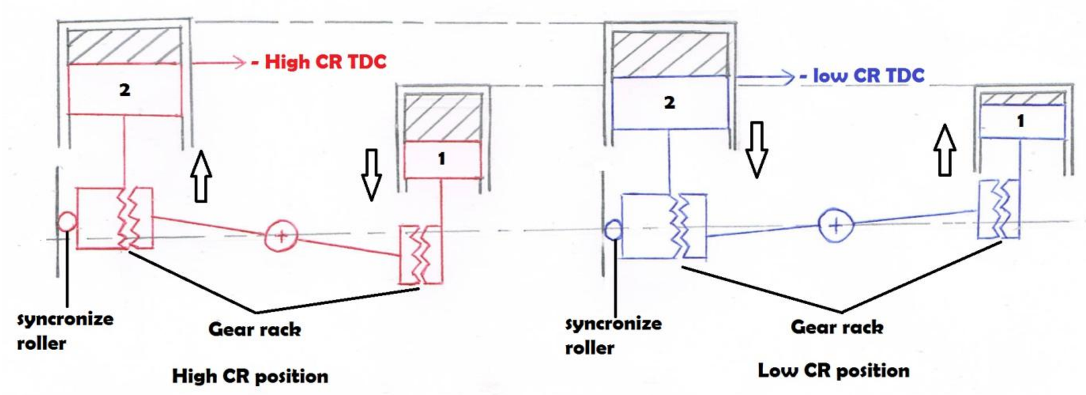


Figure 2.10: The mechanism of Force transmission by rack gear

Based on figure 2.10, in order to obtain a high CR, the control jack (1) will move downward, thus it will push the piston (2) upward resulting V_{TDC} to be decreases and the CR will be higher. When a low CR is desired, the control jack (1) will move upward making the piston (2) to move downward and V_{TDC} will increase, thus lowering the CR. The usage of gear rack and synchronized roller enable the friction losses on the conventional engines like friction generated by pistons, rings, con rod bearing and main bearings to be reduced (Rabin et. al, 2004). This is because the contact between piston skirt and the cylinder and also the radial stress exerted by the connecting rod is reduced. The connecting rod force is applied to the synchronized roller (Rabin et. al, 2004).

Movable cylinder head (slide)

In this design, the cylinder head can be moved up and down vertically as shown in figure 2.11. This design does not change the geometry of the combustion chamber.

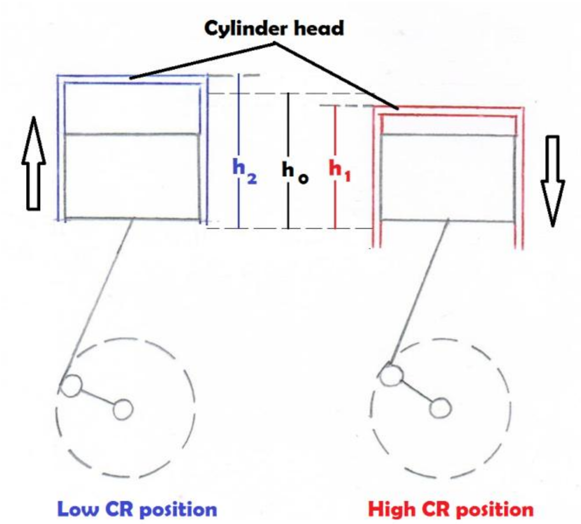


Figure 2.11: The mechanism of movable cylinder head

Based on figure 2.11, h_0 is the original height of the head, in order to decrease the V_{TDC}, the height of head must be lowered to h_1. This change will increase the CR. For the CR to be lower, the height of head must be increased to h_2. This will increase the V_{TDC}. The value of h must be determined precisely in order to get desired CR.

2.5 VCR Supporting Systems

The VCR technologies offer the opportunity to reduce a significant amount of fuel consumption (about 30% on medium to high power engines) without any reduction on the engines performance (Rabin et. al, 2004). This result is obtained by the means of downsizing and combining high supercharging with compression ratio control. According to this strategy, at low loads the CR is about 15:1 or 16:1, at full loads the CR is about 10:1 or 11:1 and high supercharging can be reached (without knocking) by setting the CR to 8:1 or 8.5:1 (Rabin et. al, 2004).

Small engine is generally more efficient than big engines, but it is not powerful enough to be used for anything other than powering small, lightweight car or motorcycle. By supercharging the intake air and forcing more air into the engine, more fuel can be injected and burned efficiently. The engine than delivers more power for every pistons stroke, which result in higher torque and horsepower output. By supercharging the engine only at greater throttle openings (when the power is really needed), the fuel economy of a small engine can be combined with the greater performance of a big engine. A normal aspirated engine with VCR capabilities can reduce fuel consumption for about 4 to 5%, which is very good compare to a normal aspirated engine without VCR capabilities. However, with the downsizing and supercharged the engine along with the VCR capability, the maximum reduction in fuel consumption (15% to 45%) can be achieved (Rabin et. al, 2004). Figure 2.12 below shows the effect of VCR and the downsizing of an engine towards fuel economy.

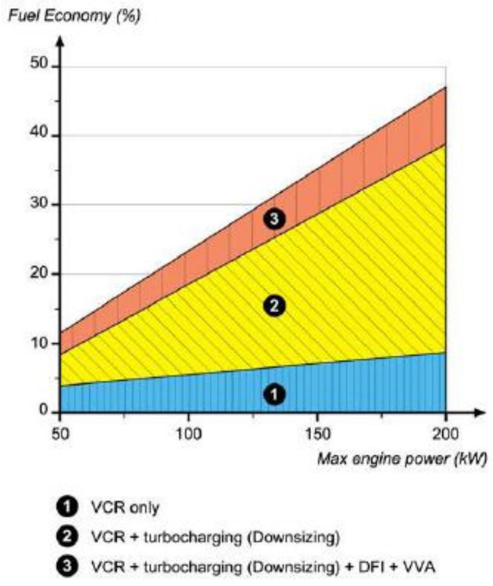


Figure 2.12: VCR strategies fuel economy

Source: Rabin et. al, 2004.

2.6 Challenges in Designing VCR Mechanism

Each concept is a compromise which has its own limitations like reduction in structure rigidity, control limit and increasing in friction losses. It is first necessary to design VCR engine that apply the most conservative approach compared to conventional engine. This allow making the most of existing ways related to combustion processes, internal aerodynamic, and pollutants emission generation. This is also allows designing high power and torque engines.

This requirement implies designing VCR engine with piston kinematics and combustion chamber shape identical to those of a conventional engine. The restriction of a conventional engine (old engine system) is also needed to be considered as it may result in increasing stress in the old engine component.

When designing a VCR engine, it is necessary to reduce some conventional engine's friction source, in order to compensate for new friction sources due to compression ratio control components.

2.7 Factor of Safety (FOS)

Factor of safety (FOS) or safety factor (SF) is the term used to describe the structural capacity of the system or component beyond the actual loads or expected loads. FOS is the ratio of the allowable working unit stress.

$$Factor\ of\ safety = \frac{Material\ \ strengt\ h}{Design\ \ load} \tag{2.2}$$

Where:

- The material strength can be measure using either the ultimate tensile strength (UTS) or yield strength.
- Design load is the force/pressure that being subjected to the system or a component.

Yield strength of material is defined as the stress at which a permanent deformation occurs (plastically deform). In order for the system or component to work properly, its FOS value must be larger than 1. This indicates that the maximum load applied to the system does not exceed the yield strength value, thus a permanent deformation does not occur or the system is safe. (Solidworks.Help 2011)

2.8 SUMMARY

In this chapter, the basics and fundamental knowledge about the internal combustion engine were discussed. We discussed mainly on the principal operations of 4-stroke and 2-stroke engine and how combustion process occurs inside the engine as well as the factor that effect the combustion process. One of the crucial components in determining the performance of an engine (compression ratio) is discussed and understands in order to manipulate it as the means to increased engine performance. Compression ratio is measure of how much the air-fuel mixture is compressed during the compression stroke of the piston. The compression ratio plays an important role in determining the efficiency of an engine. It can be said that the efficiency of an engine will increased along with the increasing of CR. However, if the CR used is too high other problems might occur, such as knocking/autoignition phenomenon. The CR also influences the fuel consumption of an engine because the energy in the fuel is better utilized when the CR is high as possible. As the fuel consumption is reduced the emission of gases like CO_2, NO_x, and HC (hydrocarbon) will also reduced. The aims of having a more energy efficient car without any reduction in the performance can be achieved by using a variable compression ratio (VCR) technology. This technology enables the CR to be change according to the engine operating condition. This is different from a conventional car which is having a fixed CR. At low engine load, a high CR should be used and at full load a medium CR is used. The variation of CR is ranging from 7:1 to 17:1. To enable high supercharging, a low CR must be used (8:1 to 8.5:1). If the VCR is used in normal aspirated engine, the fuel reduction is about 4 to 5%. The maximum potential of VCR engine can be achieved by combining high supercharging with an engine downsizing.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Chapter 3 discusses methodology of the project in general, with a specific focus on the criteria of the final design of the VCR mechanism. This chapter also discussed the methods in which the final design of the VCR mechanism will be analyzed.

3.2 Baseline Engine Design

The design of the VCR mechanism in this project is based on the YAMAHA FZ150i model engine. The actual engine was disassembled to be measured and modelled in solidworks as shown in Figure 3.1

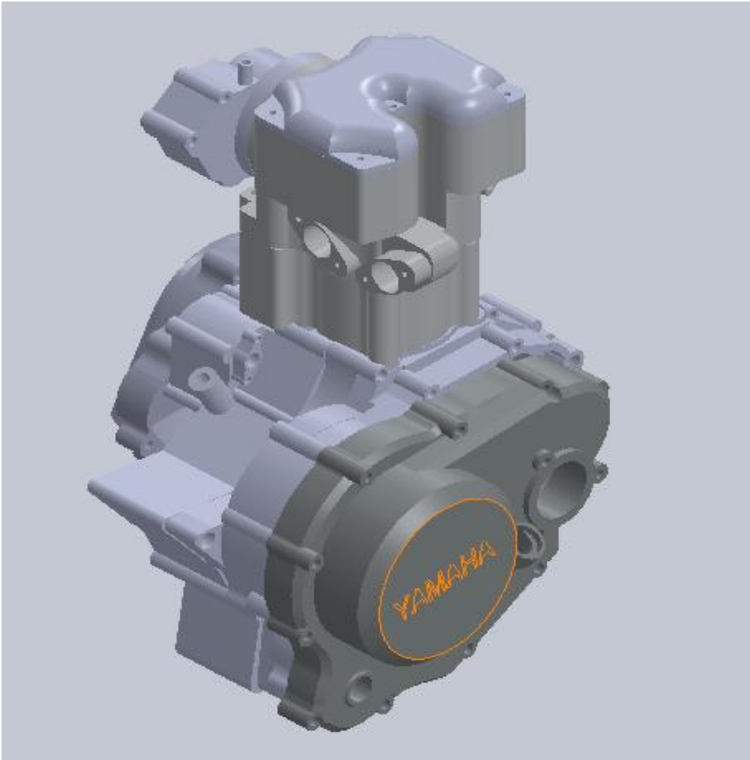


Figure 3.1: 3D model of the engine

The technical specification of the engine is as follow:

Table 3.1: Engine Specification

Engine type	Liquid-cooled 4-stroke ,SOHC, 4-valve
Cylinders	Single cylinder
Displacement	149.8 cm3
Bore × stroke	57.0 × 58.7mm
Compression ratio	10.4:1
Max. Output	11.1 kW/8500r/min
Max. Torque	13.1 N.m/7500 r/min
Starter	Electric starter and kick starter
Lubrication	Wet sump
Transmission oil volume	1.15 L
Fuel tank volume	12.0 L
Carburetion	3C1 (EFI)
Ignition	C.D.I.

Source: Yamaha, 2010

3.3 CONCEPTUAL DESIGN OF VCR MECHANISM

VCR design:

In this design, a cone shape part (VCR piston extension) is mounted on top of the piston. This part is design to have the same geometry as the upper part of the combustion chamber. This will enable the volume of combustion chamber at TDC to be decreased thus enable the engines compression ratio to be increases.

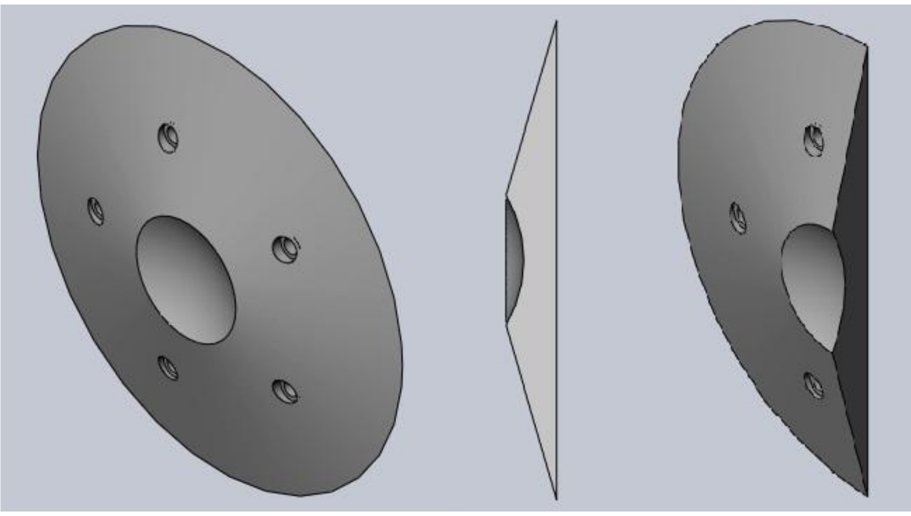


Figure 3.2: VCR piston extension

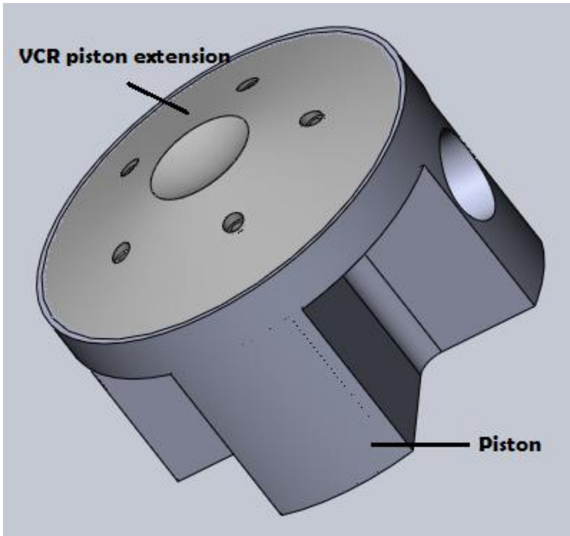


Figure 3.3: The VCR piston extension being mounted on top of piston surface

In order to increase the volume of combustion chamber, an additional plate, namely the VCR plates as in Figure 3.3 are used. This plate is design to slightly lift the engine block from its original position. As the result, the TDC position of the piston will change (lower than the original position), thus increasing the volume of combustion chamber. The thickness of the plate will determine the compression ratio.

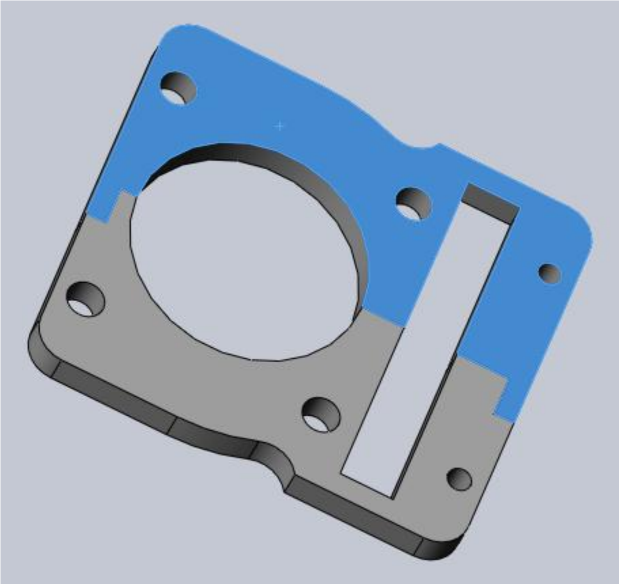


Figure 3.4: VCR plate

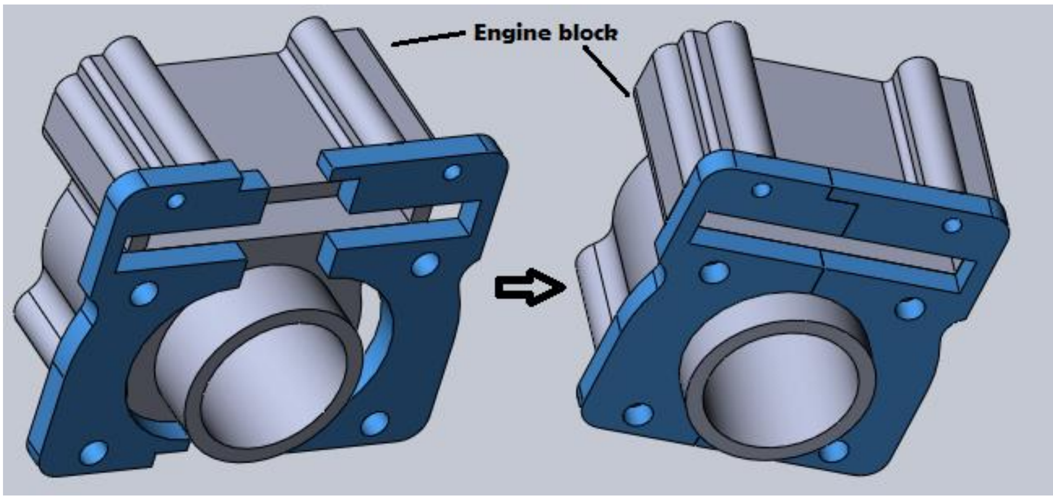


Figure 3.5: The VCR plate being attached to the engine block

The VCR parts do not interfere with the cooling passage of the engine. However, a longer timing chain requires as the engines block position changes and a slight modification on the piston require in order to mount the VCR piston extension.

3.4 Design Simulation and Analysis by Solidworksmotion

SolidworksMotion is a computer software tool that supports engineers to analyze and design mechanisms. SolidworksMotion is a module of the SolidWorks product family developed by SolidWorks Corporation. This software supports users to create virtual mechanisms that answer general questions in product design. In general, there are two types of motion problems that needed to be solved in order to answer questions regarding mechanism analysis and design that is kinematic and dynamic. Kinematics is the study of motion without regard for the forces that cause the motion. A kinematic mechanism must be driven by a servomotor (or motion driver) so that the position, velocity, and acceleration of each link of the mechanism can be analyzed at any given time. Typically, a kinematic analysis must be conducted before dynamic behaviour of the mechanism can be simulated properly.

Dynamic analysis is the study of motion in response to externally applied loads. The dynamic behaviour of a mechanism is governed by Newton's laws of motion. In this study, SolidworksMotion will be use to simulate the motion of the piston and crank mechanism with VCR parts.

Flow of analysis:

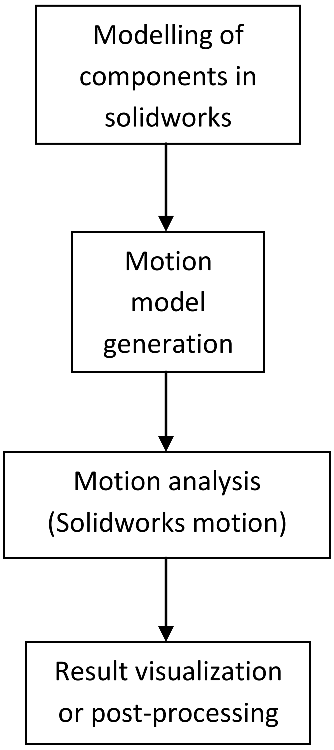


Figure 3.6: The flow of analysis

In this simulation, there are certain parameters that needed to be justified and assumption to be made in order for the simulation to be valid. The lists of the parameters are as follows:

Fix Parameters:

- Crank Diameter
- Maximum piston travel
- Bore size

Variable parameters:

- Compression ratio
- Cylindrical pressure (vary upon the variation of CR)
- Inertia of piston (additional weight of piston from VCR mechanism)

3.4.1 Objective of the Simulation

The motion simulation of the VCR mechanism will be conducted by using SolidworksMotion software. The objectives of this simulation are as follows:

1. To analyze the maximum stress concentration point at connecting rod and piston system.
2. To detect collision between parts of the mechanism
3. To obtain factor of safety (FOS) of the engine component (connecting rod, piston and piston extension (VCR))

3.5 Criteria of Final Design

Figure 3.7 shows the complete assembly of the VCR mechanism with the piston and crank system. From the figure we can see that the TDC position changes with the addition of the VCR plate. The position of TDC becomes slightly lower than original position because the head is lifted by the plate. This change in TDC will result in the increasing of the clearance volume (V_{TDC}), thus lowering the CR.

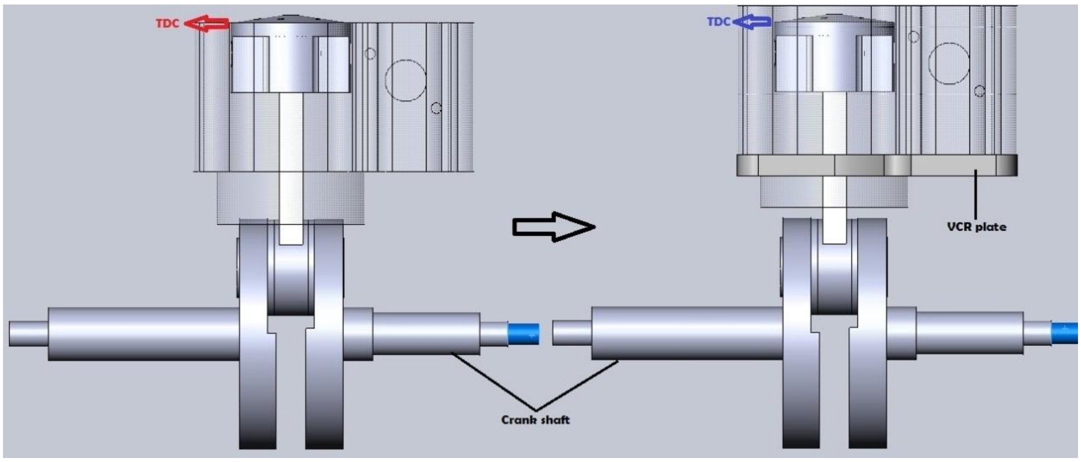


Figure 3.7: The assembly of VCR mechanism

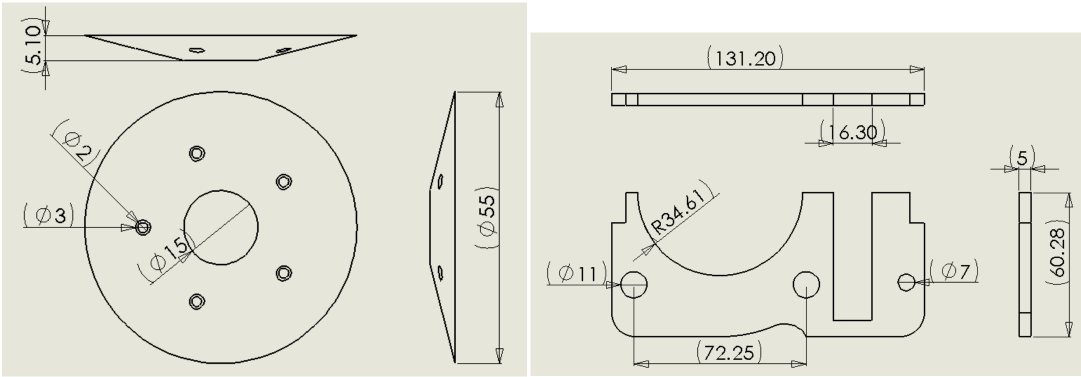


Figure 3.8: The dimension of VCR extension VCR plate

The dimension of the VCR parts is shows in Figure 3.8. This set of parts enables the CR to be changed in the range of 18:1 to 8:1. The variation in CR can be achieved by using different thickness of VCR plate as in Table 3.2.

Table 3.2: The value of CR with the changes of VCR plate thickness

Thickness of VCR plate, h (mm)	Compression ratio (CR)
No plate	18:1
0.28	16:1
0.66	14:1
1.17	12:1
1.91	10:1
3.10	8:1

The calculation of CR is as follows:

By using the formula of

$$\boldsymbol{CR} = \frac{\boldsymbol{V_{BDC}}}{\boldsymbol{V_{TDC}}} = \frac{\mathbf{v}_{\boldsymbol{d}}+\mathbf{v_c}}{\mathbf{v_c}} \tag{3.1}$$

Where:

V_c is the clearance volume

V_d is the volume of cylinder at BDC

V_c = 10.5 cc (given by manufacturer)

CR of engine is 10.4 (given by manufacturer)

$$10.4 = \frac{\mathrm{v_d} + 10.5}{10.5}$$

$$\mathrm{v_d} = 98.7\ cc$$

The volume of VCR piston extension

$V_p = ½ (A_1+A_2)h – V_{sp}$, h = 0.51 cm

$$\mathrm{A_1} = \frac{\pi\ (5.5)^2}{4} = 23.76\ \mathrm{cm^2} \quad , \quad \mathrm{A_2} = \frac{\pi(1.5)^2}{4} = 1.776\ \mathrm{cm^2}$$

$$= \frac{1}{2}(23.76 + 1.767)(0.51) = 6.48\ \mathrm{cm^3}$$

$$V_{sp} = \pi\ \frac{(1.5)^2}{4} + 0.18^2 = 1.871 cm^3$$

$$V_p = 4.969\ cm^3$$

CR with the VCR piston extension and without VCR plate:

$$\mathrm{CR_{new}} = \frac{(\mathrm{V_d} - \mathrm{V_p}) + (\mathrm{V_c} - \mathrm{V_p})}{(\mathrm{V_c} - \mathrm{V_p})} \qquad \text{(Equation 1)}$$

$$= \frac{93.731 + 5.531}{5.531} = 17.9 \sim 18$$

Therefore, the new CR is 18:1

CR with the VCR plate installed:

When desired CR is 16:1, the thickness of the plate, h_1 is 0.028 cm, with the addition of this plate, the clearance volume, V_c will increase.

Additional volume to the V_C is

$$\pi r^2 h = \pi (2.85)^2 (0.028)$$

$$= 0.714 \text{ cm}^3$$

$$V_{c\ new} = (0.714 + 10.5) - 4.969 = 6.245 \text{ cm}^3$$

By using Equation 1, CR can be calculated:

$$CR = \frac{(98.7 - 4.969) + (6.245)}{6.245}$$

= 16.0

Therefore, CR is 16.0:1

When desired CR is 14:1, the thickness of the plate, h_2 is 0.066 cm.

Additional volume to the V_C is

$$\pi r^2 h = \pi (2.85)^2 (0.066)$$

$$= 1.684 \text{ cm}^3$$

$$V_{c\ new} = (1.684 + 10.5) - 4.969 = 7.215 \text{cm}^3$$

Therefore, the CR become

$$CR = \frac{(98.7 - 4.969) + (7.215)}{7.215}$$

= 13.99 ~ 14.0

Therefore, CR is 14:1

When desired CR is 12:1, the thickness of the plate, h_3 is 0.117 cm.

Additional volume to the V_C is

$\pi r^2 h = \pi(2.85)^2(0.117)$

$= 2.986 \text{ cm}^3$

$V_{c\,new} = (2.986 + 10.5) - 4.969 = 8.517\text{cm}^3$

Therefore, the CR become

$$CR = \frac{(98.7 - 4.969) + (8.517)}{8.517}$$

= 12.01

Therefore, CR is 12:1

When desired CR is 10:1, the thickness of the plate, h_4 is 0.191cm. Additional volume to the V_C is

$\pi r^2 h = \pi(2.85)^2(0.191)$

$= 4.874 \text{ cm}^3$

$V_{c\,new} = (4.874 + 10.5) - 4.969 = 10.405 \text{ cm}^3$

Therefore, the CR become

$$CR = \frac{(98.7 - 4.969) + (10.405)}{10.405}$$

= 10.01

Therefore, CR is 10:1

When desired CR is 10:1, the thickness of the plate, h_5 is 0.310 cm. Additional volume to the V_C is

$\pi r^2 h = \pi(2.85)^2(0.310)$

$= 7.911 \text{ cm}^3$

$V_{c\,new} = (7.911 + 10.5) - 4.969 = 13.442 \text{ cm}^3$

Therefore, the CR become

$$CR = \frac{(98.7 - 4.969) + (13.442)}{13.442}$$

= 7.97 ~ 8.0

Therefore, CR is 8:1

With this design the maximum CR of the engine is 18:1 and the lowest is 8:1

In this design, there is not much modification will be done to the old system. There are few components that need to be change in order for VCR to be installed and functioning correctly. Those components are:

Timing Chain:

- A longer timing chain needed to be used because the position of head will be increased.

Piston:

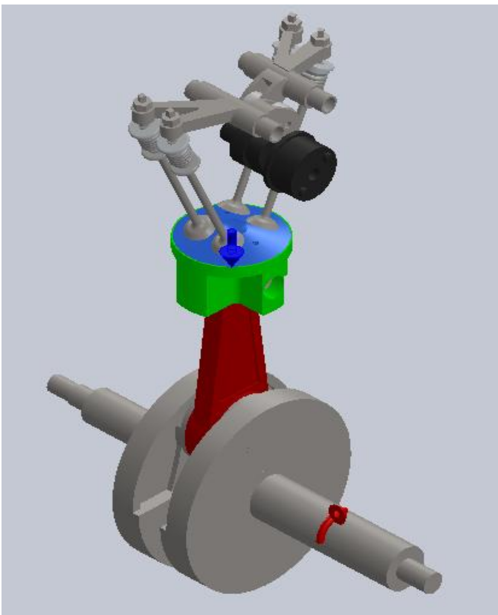
- In order to mount the VCR part 1 on the piston, 5 holes need to be drilled and threaded on top of the piston.

Fastener:

- The fastener/screw connecting cylinder block and the crankcase must be longer to enable the VCR plate to be fasten together between the block and the crankcase.

3.6 Simulation Setup

The simulation was done by using Solidworks Motion software or formally known as Cosmosmotion. The software was developed specifically to help designing a mechanism or a moving system. The simulation setups are as follow:



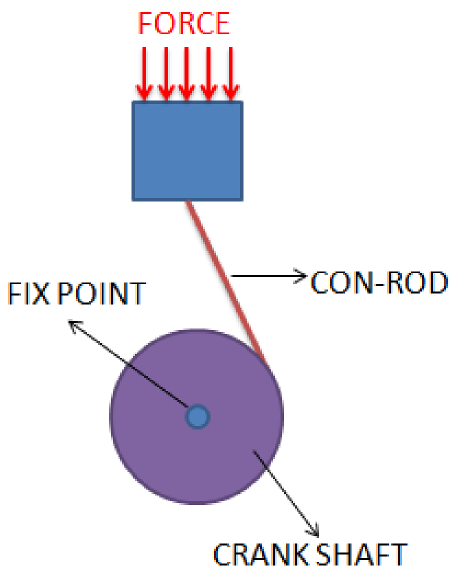


Figure 3.9 and **3.10**: The simulation setup and free body diagram of the system

In the simulation, the engine was simulated at a constant speed of 2000 rpm. To simulate the condition in which the compression ratios (CR) of the engine is changing, the force acting on the piston is varies depending of the CR. The magnitude of the force is calculated from Pressure vs Crank angle of the engine at different compression ratio. The Cylinder Pressure vs Crank angle diagram was obtained by using GTpower software.

Figure 3.11 to 3.16 are the Cylinder Pressure vs Crank angle diagram at different CR obtained from GTpower software:

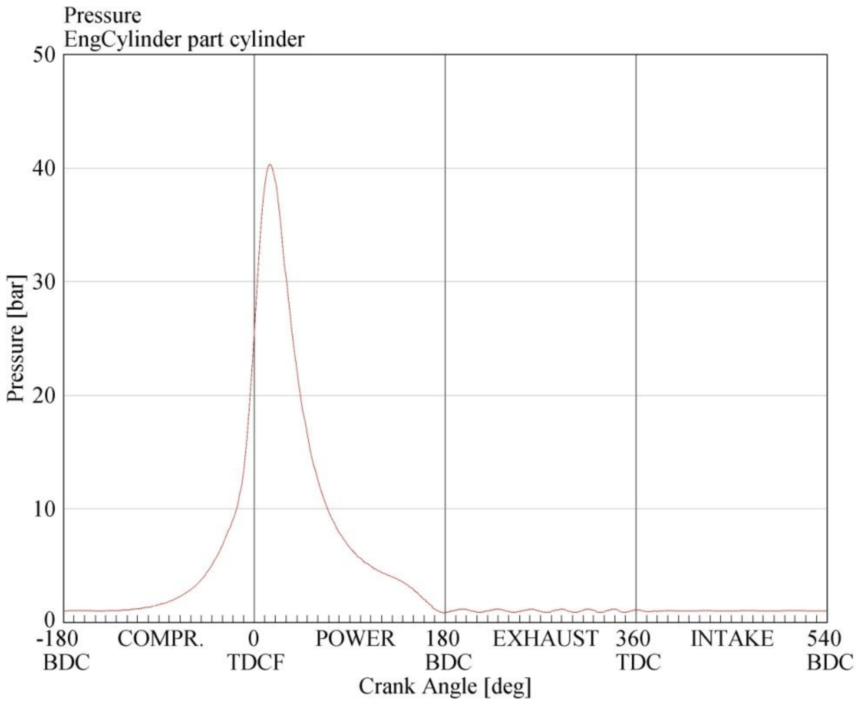


Figure 3.11: Cylinder pressure at CR of 8:1

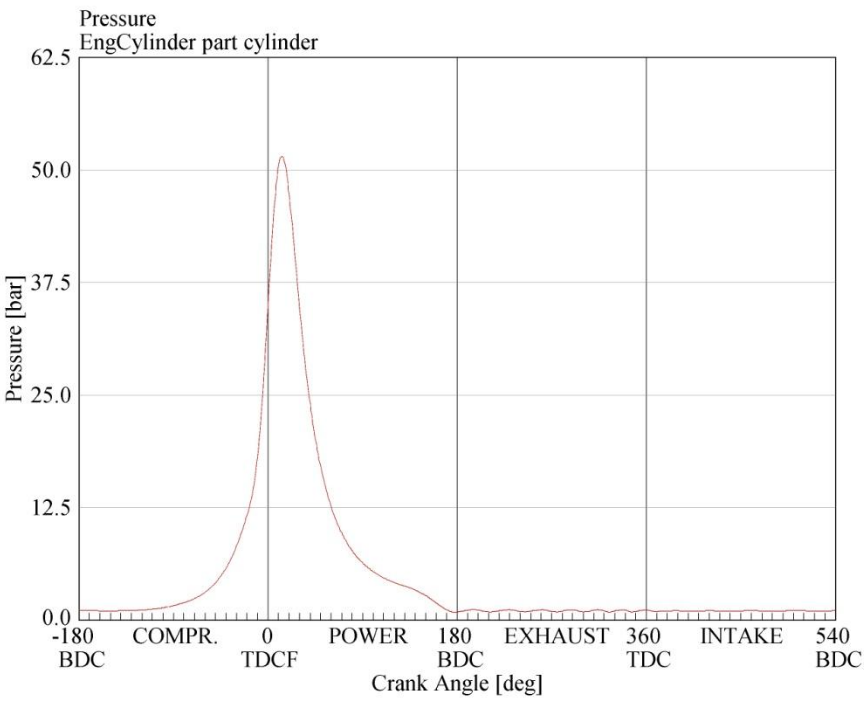


Figure 3.12: Cylinder pressure at CR of 10.4:1

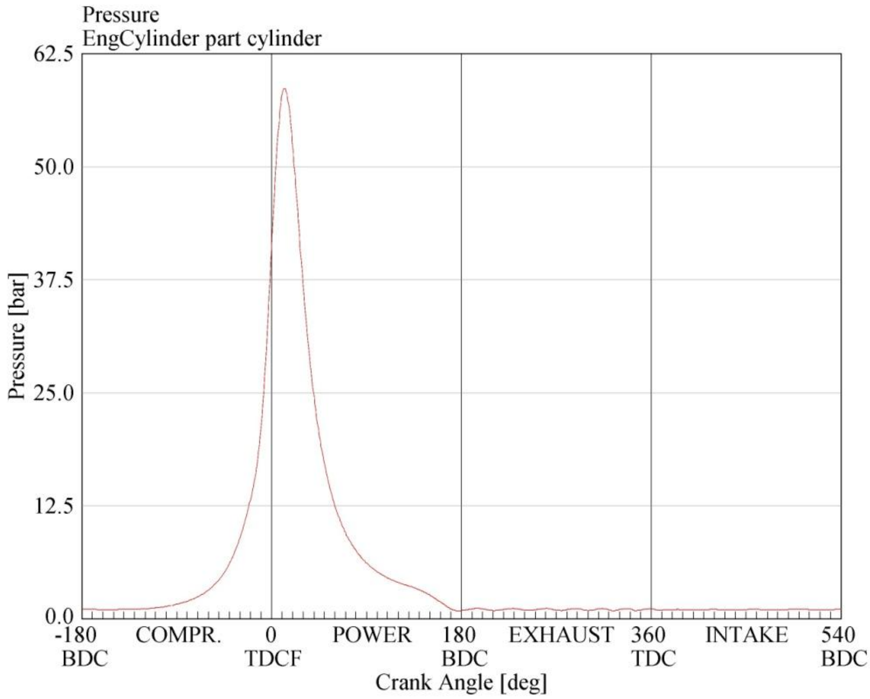


Figure 3.13: Cylinder pressure at CR of 12:1

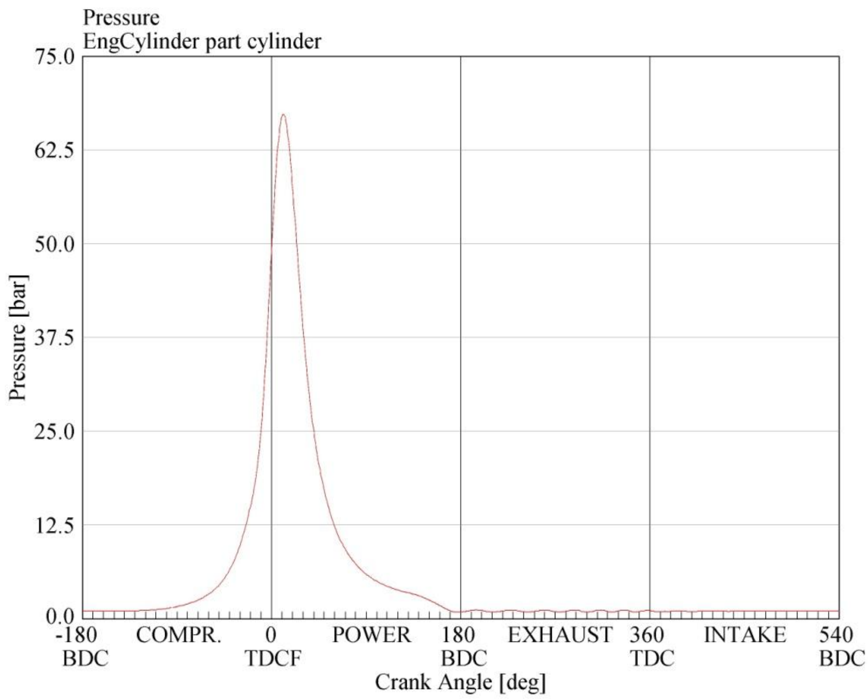


Figure 3.14: Cylinder pressure at CR of 14:1

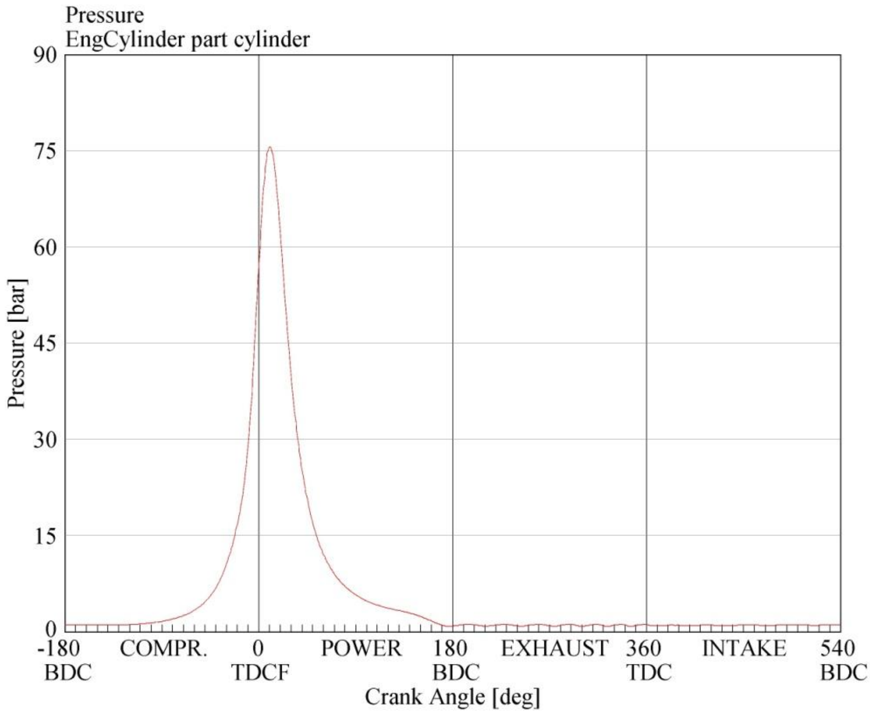


Figure 3.15: Cylinder pressure at CR of 16:1

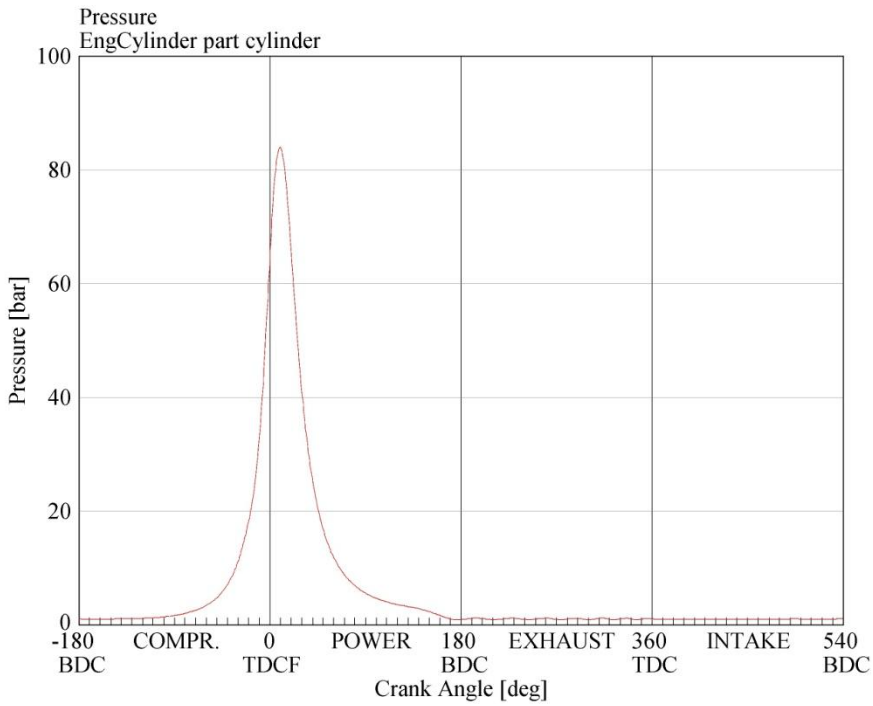


Figure 3.16: Cylinder pressure at CR of 18:1

These data were then used to calculate the force (acting on the piston) vs Crank angle diagram.

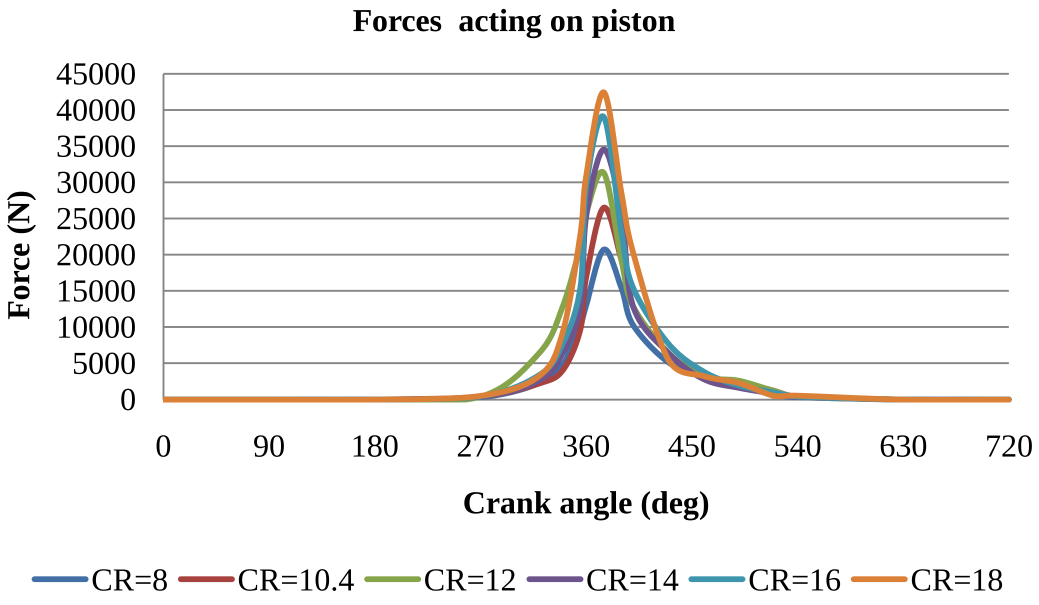


Figure 3.17: Force acting on piston at different CR

3.7 Summary

This chapter describe the flow of analysis of the mechanism. The brief explanation about the software used to conduct the analysis is also included in this chapter. Methodology will act as guidance in the analysis in order to design a good, functioning and effective mechanism.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter present the result and discussion of the motion simulation. The result are discussing the contour of stress concentration, contour of deformation and Factor of Safety (FOS) of the selected parts at constant engine speed of 2000 rpm and at different compression ratio (CR) and lastly a summary.

4.2 Stress Contour of Parts

Based on Figure 4.1(a) – (f), Figure 4.2(a) – (f) and Figure 4.3(a) – (f), the stress contour shows the point of maximum stress concentration on each part. The maximum stress concentration point occurs at the location of gudgeon pin for piston, at both end of connecting rod and at the centre of the piston extension (VCR). From these results, it is known that the magnitude of stress in the parts is increasing with CR. The stresses are at its highest when CR is 18:1, the magnitude of the stresses are 694.1Mpa, 617.6Mpa and 224.3Mpa for piston, connecting rod and piston extension (VCR) respectively. By looking at these figures, the average stress subjected to the piston is the largest follow by connecting rod and VCR piston extension.

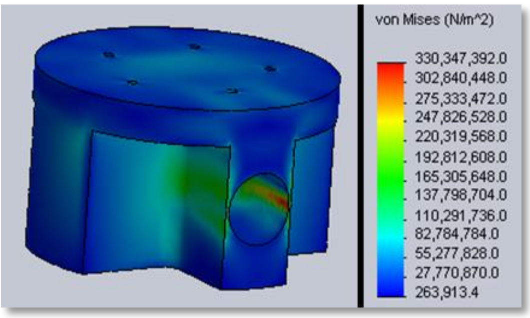


Figure 4.1(a): CR = 8:1

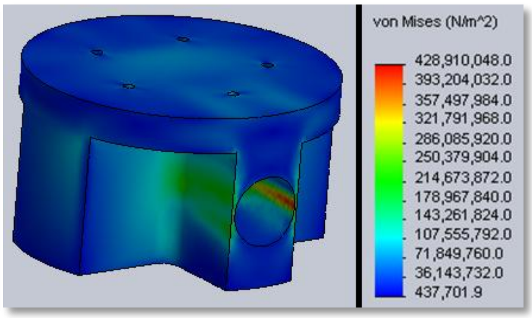


Figure 4.1(b): CR = 10.4:1

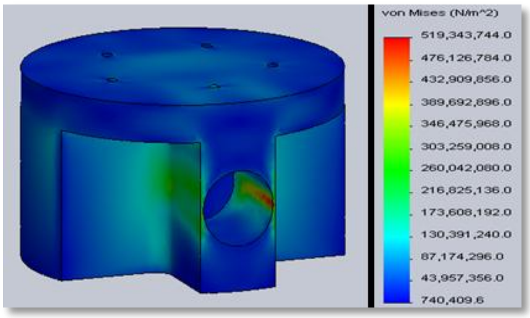


Figure 4.1(c): CR = 12:1

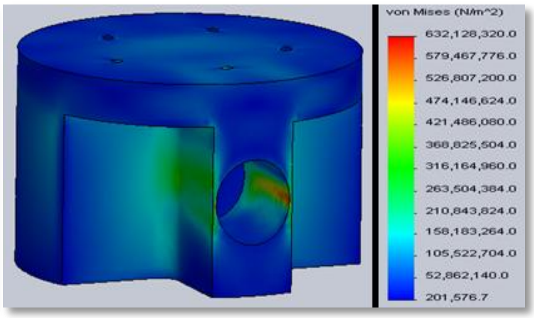


Figure 4.1(d): CR = 14:1

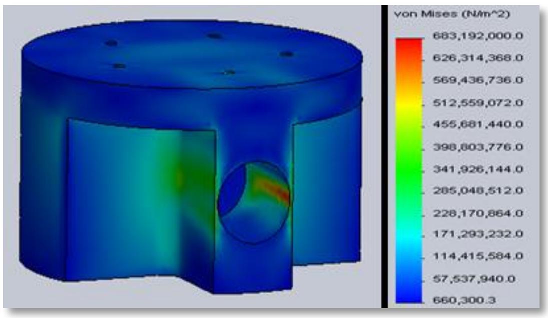


Figure 4.1(e): CR = 16:1

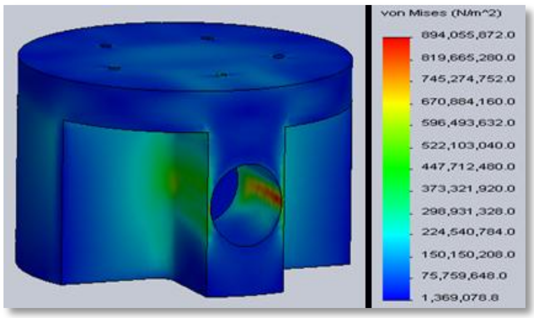


Figure 4.1(f): CR = 18:1

Figure 4.1(a) – (f): The stress contour of piston

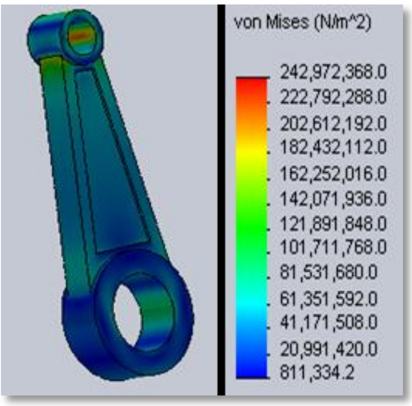


Figure 4.2(a): CR = 8:1

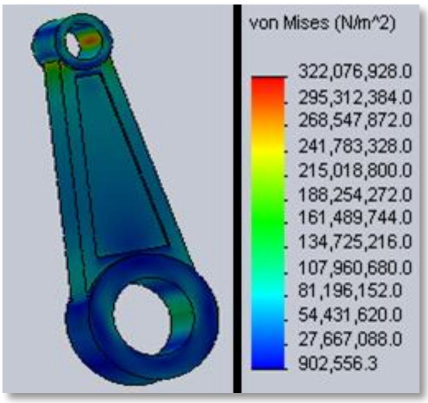


Figure 4.2(b): CR = 10.4:1

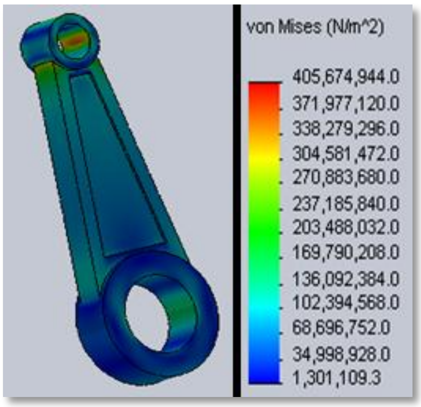


Figure 4.2(c): CR = 12:1

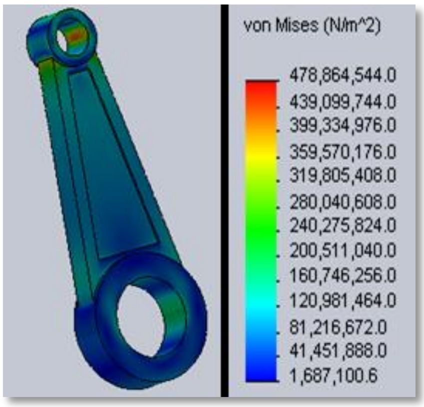


Figure 4.2(d): CR = 14:1

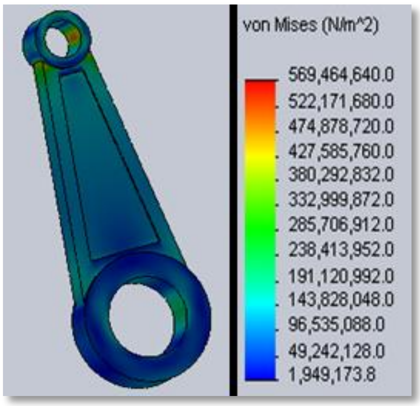


Figure 4.2(e): CR = 16:1

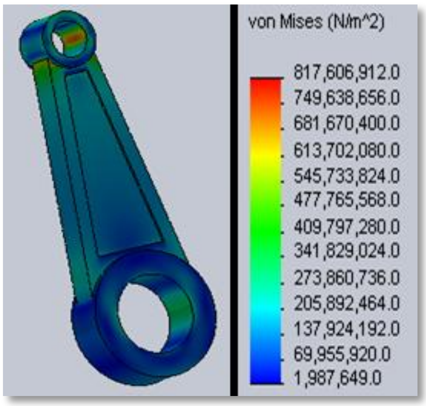


Figure 4.2(f): CR = 18:1

Figure 4.2(a) – (f): The stress contour of connecting rod

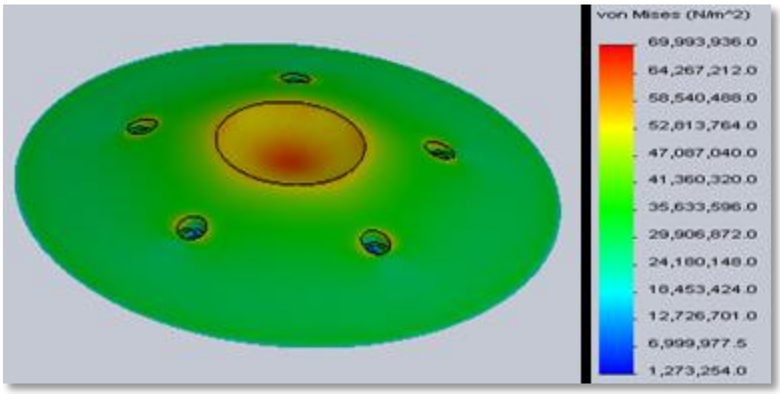


Figure 4.3(a): CR = 8:1

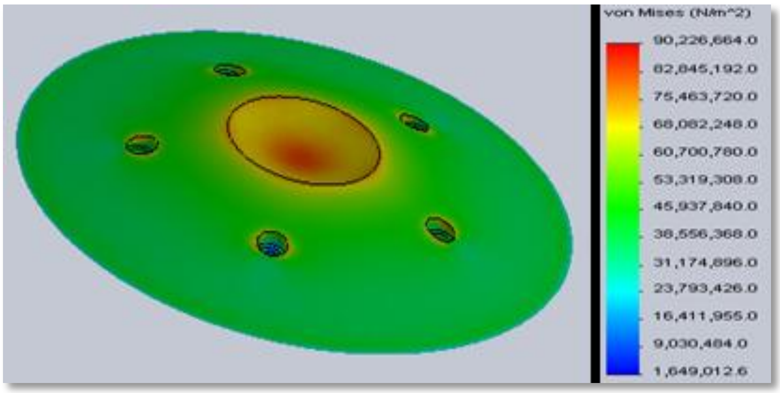


Figure 4.3(b): CR = 10.4:1

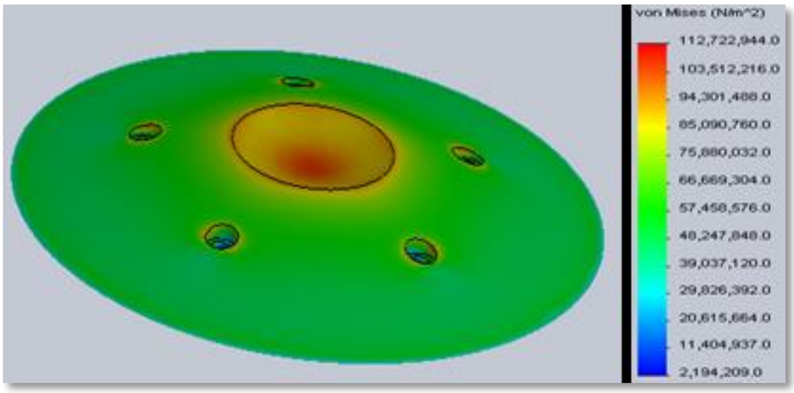


Figure 4.3(c): CR = 12:1

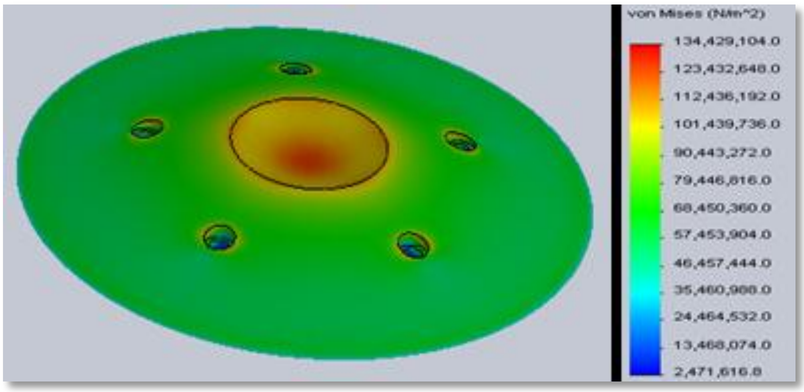


Figure 4.3(d): CR = 14:1

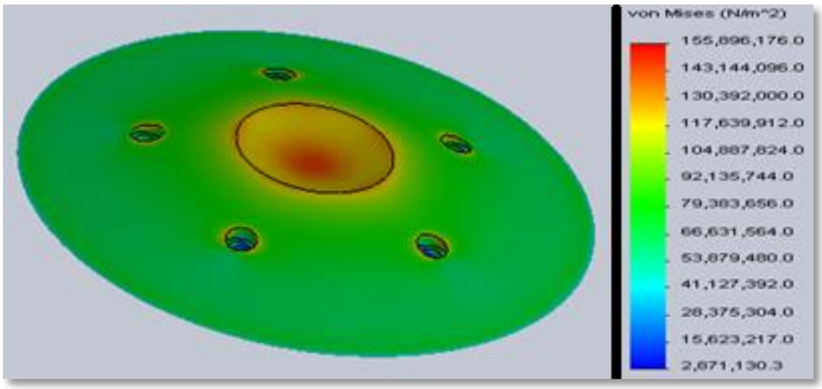


Figure 4.3(e): CR = 16:1

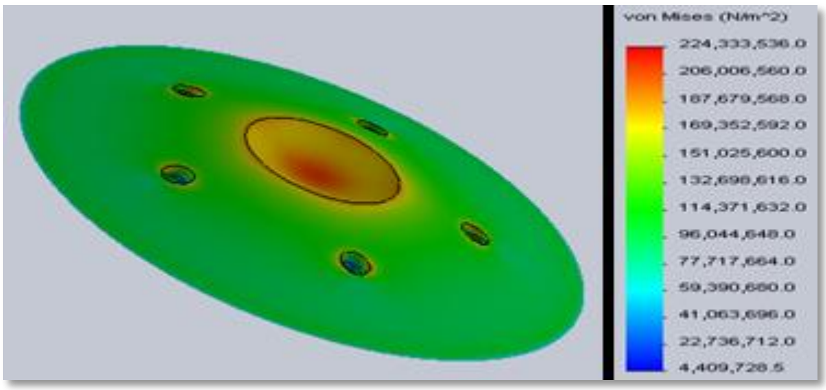


Figure 4.3(f): CR = 18:1

Figure 4.3(a) – (f): The stress contour of VCR piston extension

VCR plate and engine block:

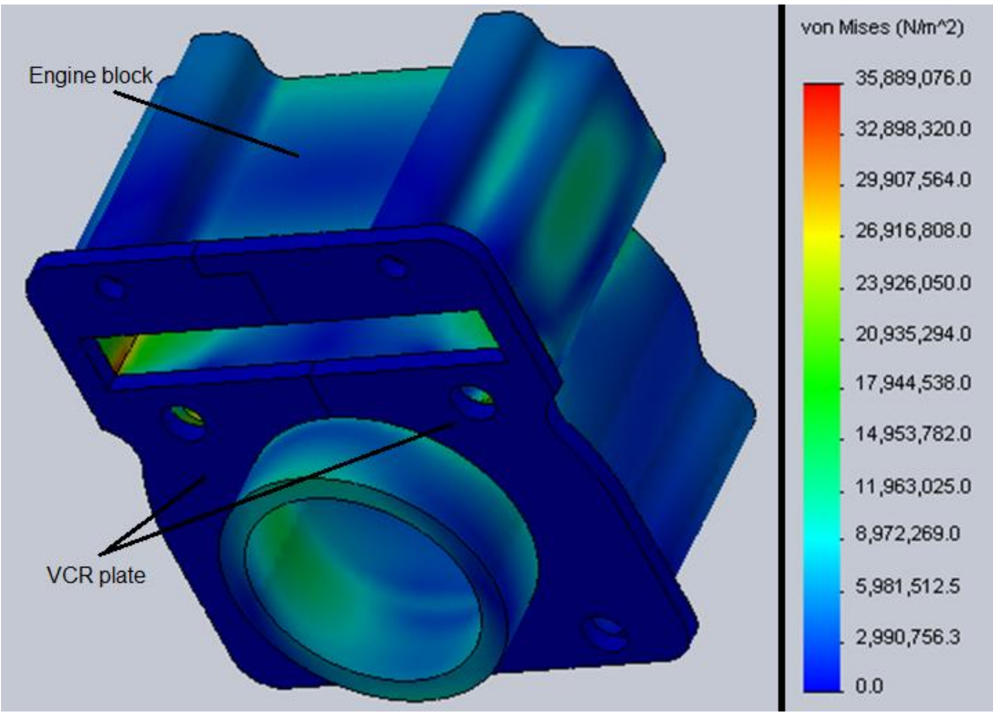


Figure 4.4: VCR plate with engine block at CR 18:1

Based on Figure 4.4, it shows that there is no stress subjected to VCR plate even at highest compression ratio and the stress subjected to the engine block is low compare to the yield strength of material of the block. The magnitude of maximum stress in engine block at CR of 18:1 is 35.9Mpa while the yield strength of aluminium alloy is 758.3Mpa. From this result, it can be concluded that the position of VCR plate between the crankcase and block will not cause damage to the engine.

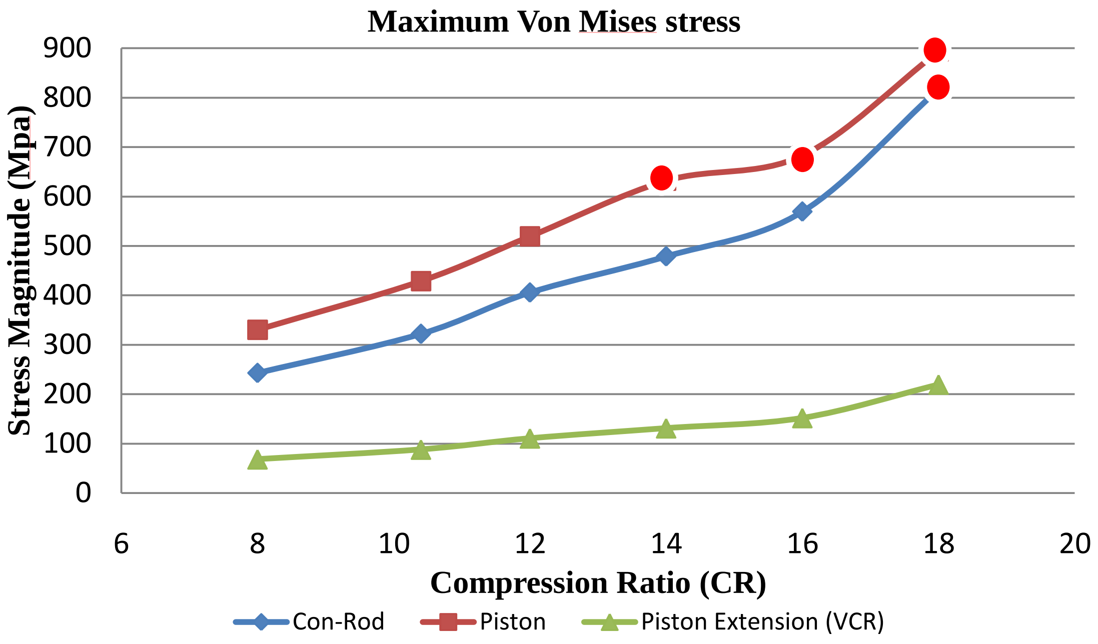
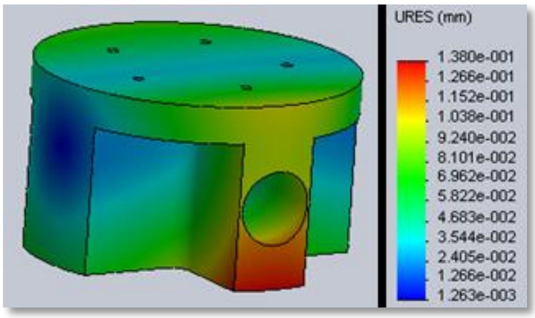


Figure 4.5: Maximum pressure stress of parts at different compression ratio

Based on Figure 4.5, it can be seen clearly that the stress in each component is increasing along with compression ratio (CR). The red point in Figure 4.5 indicates that the parts have failed. Piston, start to fail at CR of 14:1, connecting rod at CR of 18:1 while VCR piston extension does not fail. The parts fail because the stress subjected to them is greater than its yield strength of material. If the parts fail, the engine will not functioning correctly and it can also bring damage to other parts like engine block and valve.

4.3 Deformation Contour of Parts



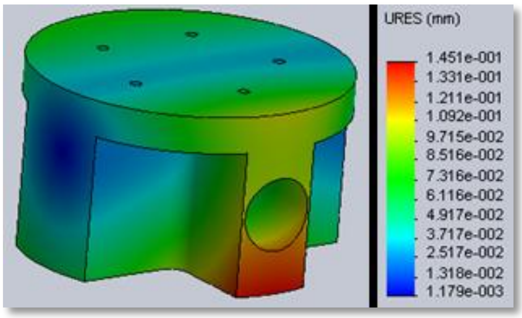
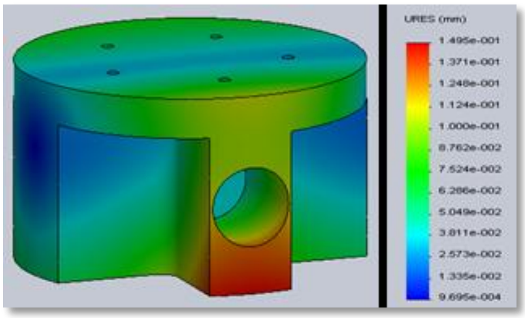


Figure 4.6(a): CR = 8:1

Figure 4.6(b): CR = 10.4:1



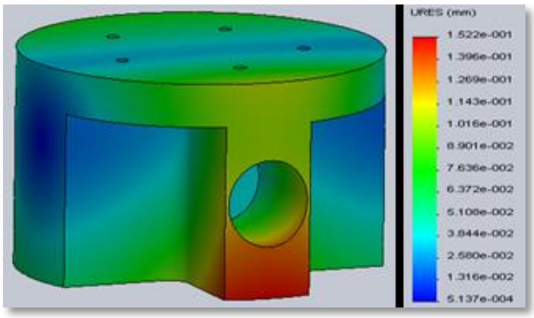
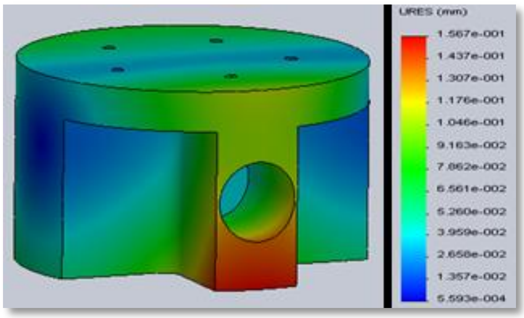


Figure 4.6(c): CR = 12:1

Figure 4.6(d): CR = 14:1



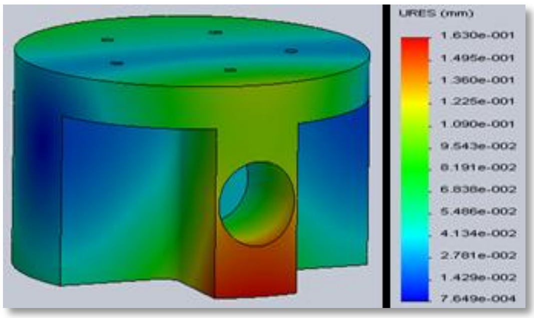


Figure 4.6(e): CR = 16:1

Figure 4.6(f): CR = 18:1

Figure 4.6(a) – (f): Deformation contour of piston

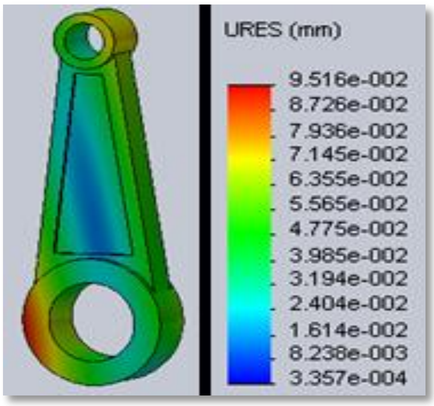


Figure 4.7(a): CR = 8:1

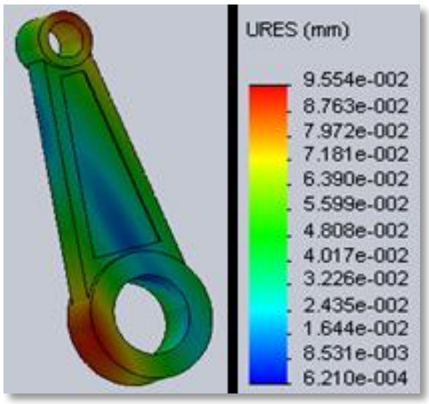


Figure 4.7(b): CR = 10.4:1

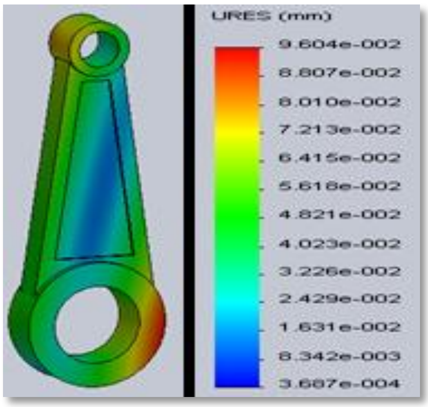


Figure 4.7(c): CR = 12:1

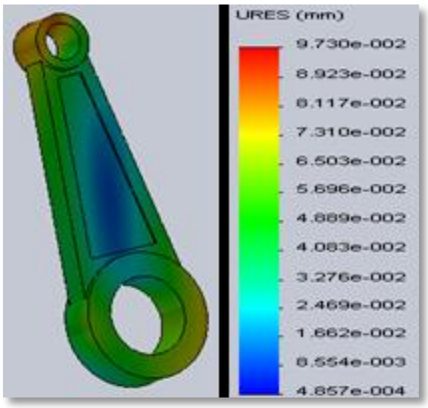


Figure 4.7(d): CR = 14:1

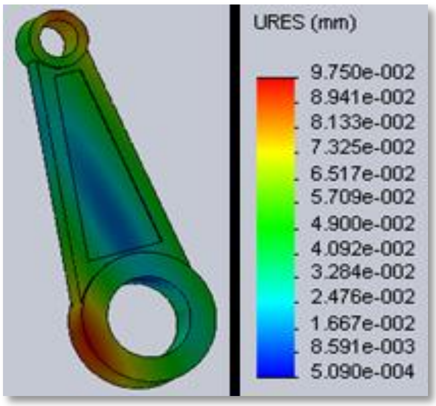


Figure 4.7(e): CR = 16:1

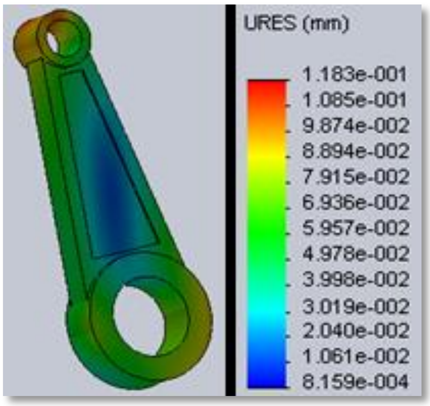


Figure 4.7(f): CR = 18:1

Figure 4.7(a) – (f): Deformation contour of connecting rod

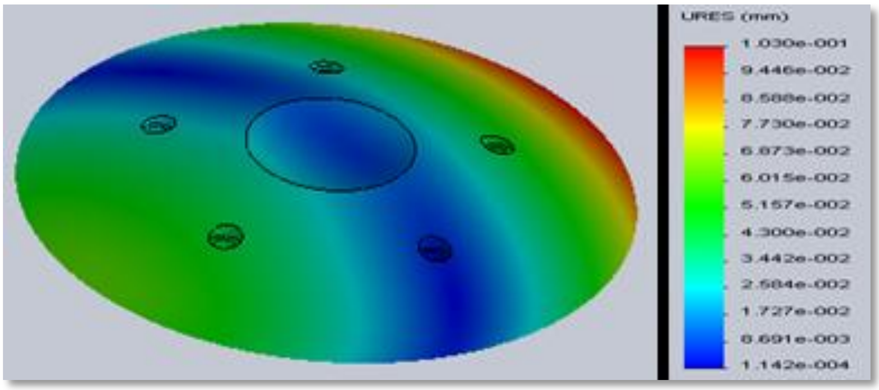


Figure 4.8(a): CR = 8:1

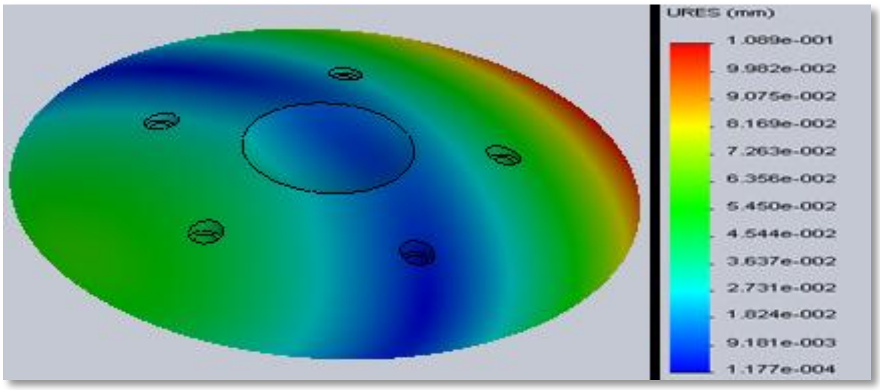


Figure 4.8(b): CR = 10.4:1

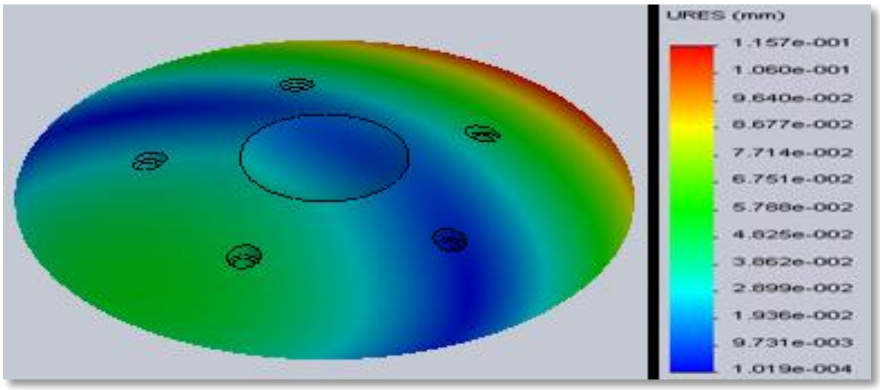


Figure 4.8(c): CR = 12:1

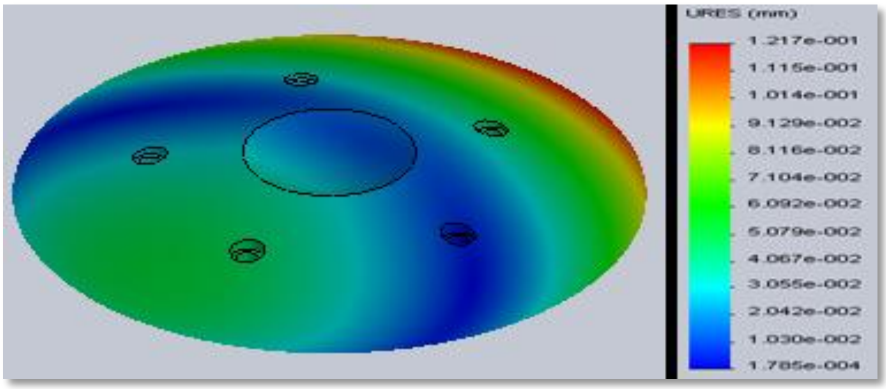


Figure 4.8(d): CR = 14:1

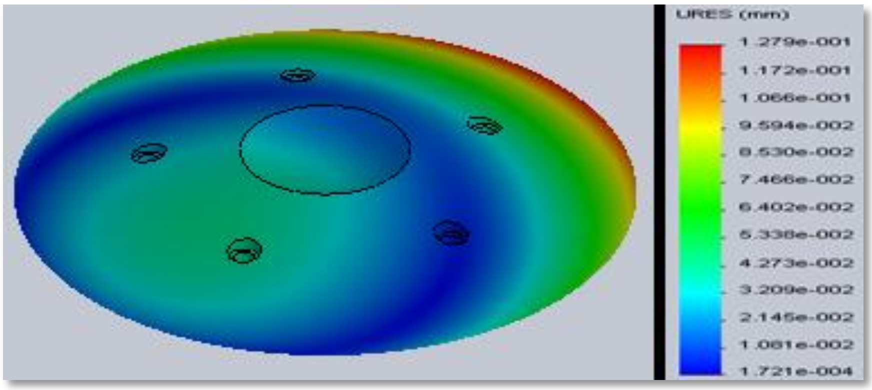


Figure 4.8(e): CR = 16:1

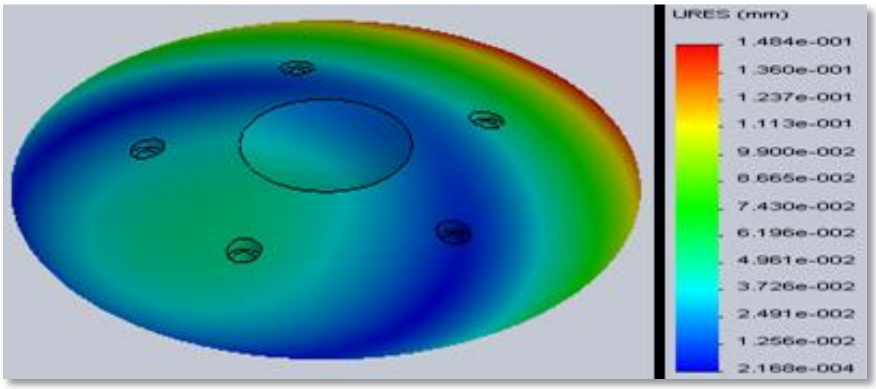


Figure 4.8(f): CR = 18:1

Figure 4.8(a) – (f): Deformation contour of VCR piston extension

Based on Figure 4.6(a) – (f), Figure 4.7(a) – (f) and Figure 4.8(a) – (f), it shows the deformation contour of parts at different compression ratio. In this study, when different CR is use to simulate the engine the engine parts will deform according to stress applied to them. The parts will elastically deform if the maximum stress applied is lower than its yield strength of material. Elastically deform means that when stress is applied, the parts will deform and it will move back to its original shape when the stress is release. At a certain point in the simulation, the stress applied is higher than the yield strength, thus the parts will plastically deform (it will not move back to original shape).

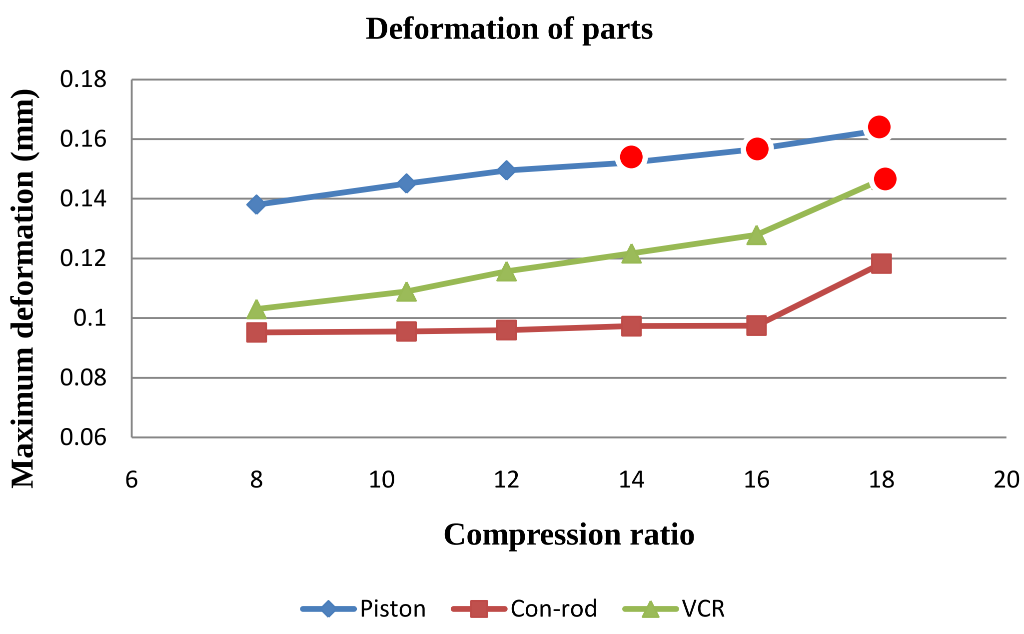


Figure 4.9: Maximum deformation of parts

Based on Figure 4.9, the maximum deformation of piston, connecting rod and VCR piston extension was shown. The figure shows that the deformation in piston is the highest. This is because the stress endured by piston is the highest. This figure also shows that the amount of deformation in each part increase along with the compression ratio. The red point in the figure shows that at that point a permanent deformation occurs or the part is plastically deformed. When the part is plastically deformed, a cracks or its shape is permanently change. This can lead to many problems. For example, when the shape of piston is change, it can lead to the increasing of friction force between piston and cylinder wall. The energy loss due to this extra friction will reduce the power deliver from engine to crankshaft.

Apart from that, the deformation or cracks in the parts can cause leakage in cylinder. Due to this leakage, the engine will lose its compression thus reducing the power and its overall efficiency. Blowby gas (unburnt fuel) also can escape through the cracks from the combustion chamber and into the crankcase. Once these gasses slip into the crankcase they can dilute into the engine causing great damage.

4.4 Factor of Safety of Parts

The factor of safety (FOS) of the parts was calculated by using the ratio of its material strength (yield strength) to maximum stress applied (design load) as in Equation 2.2. The calculations are as follows:

Piston:

Material: Alloy steel

Compression ratio (CR): 8:1

Yield strength: 620.42 Mpa

Maximum stress: 330.35 Mpa

$$FOS = \frac{620.42}{330.35}$$

= 1.88

Connecting rod:

Material: Alloy steel

Compression ratio (CR): 8:1

Yield strength: 620.42 Mpa

Maximum stress: 242.97 Mpa

$$FOS = \frac{620.42}{242.97}$$

= 2.55

VCR piston extension:

Material: Carbon steel

Compression ratio (CR): 8:1

Yield strength: 248.17 Mpa

Maximum stress: 68.36 Mpa

$$FOS = \frac{248.17}{68.35}$$

= 3.63

Table 4.1: The FOS value of the parts

CR	FACTOR OF SAFETY (FOS)		
	Con-Rod	Piston	Piston extension
8	2.55	1.88	3.63
10.4	1.93	1.45	2.82
12	1.53	1.19	2.24
14	1.30	0.98	1.89
16	1.09	0.91	1.63
18	0.76	0.69	1.13

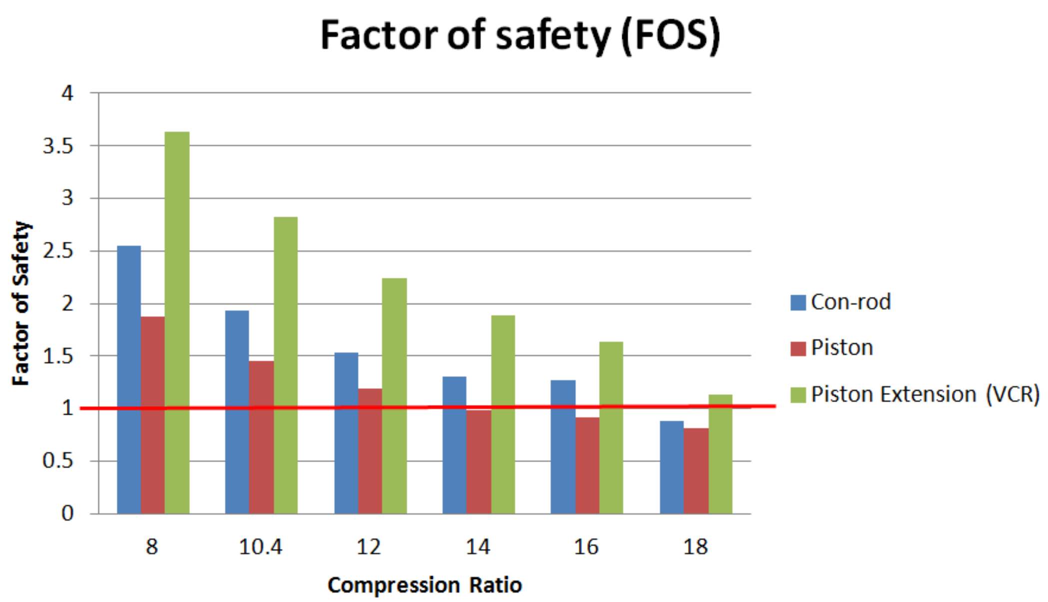


Figure 4.10: The comparison of FOS value between parts

In order for the parts to work correctly, its FOS must be greater than 1. Based on Figure 4.10, the parts with FOS value below the red line will fail at certain CR. Piston will start to fail at CR of 14:1, connecting rod at CR of 18:1 while VCR piston extension will not fail. At first the parts with FOS less than 1 would not be completely failed, small cracks might happen and overtime the crack will develop thus, the part will fail completely.

4.5 Justification of Results

4.5.1 Input Data

Since this study is only based on motion analysis, data from previous study is required. The input data (cylindrical pressure at different CR) is obtained by using GTpower software based on 4-stroke 150 cc single cylinder engine.

4.6 Result Comparison

Table 4.2: comparison of simulation data for connecting rod with previous study

Parameters	Current study	Previous study
CR	8:1	
Max. Cylindrical pressure (Mpa)	4 @ 2000 rpm	5 @ 2800 rpm
Material	Alloy steel	CK45 steel
Yield strength of material (Mpa)	620.42	585
Max. Von misses stress (Mpa)	242.97	202
FOS	2.55	2.896

Based on Table 4.2, there is the summarized of the result of stress for connecting rod with previous study (Mohammad et. al, 2011).

4.7 SUMMARY

This chapter has presented and discussed the simulation data for stress, deformation and factor of safety (FOS) for each part at different compression ratio by motion analysis using Solidworksmotion.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusions

After successfully finished the simulation and analyzing the result, a few conclusions can be drawn from this study. Firstly, a simple mechanism of Variable Compression Ratio (VCR) was designed and simulated. From the simulation we know that to the CR of the engine can safely be increased up to 12:1 without modifying existing parts.

Secondly, maximum magnitudes of stresses in each component were determined. Those magnitudes were 694.1Mpa, 617.6Mpa and 224.3Mpa for piston, connecting rod and piston extension (VCR) respectively. The simulation also shows no collision between existing parts and the VCR parts. This indicates that the mechanism can safely be used.

Lastly, the Factor of Safety (FOS) of piston, connecting rod and VCR piston extension were calculated and based on the FOS values we can conclude that piston and connecting rod will fail if the CR is increased more than 12:1

5.2 Recommendations

By looking at the FOS value of the parts, piston and connecting rod must be redesign in order to operate under higher CR. Different material with higher value of yield strength can be used to redesign both parts in order for it to withstand higher cylindrical pressure. Apart from that, in redesigning process of the parts extra material can be added at the critical point of stress concentration (change the thickness at that point).

Because of FOS value for pressure stress was a little critical (near to 1) for connecting rod and piston at certain CR. A fatigue analysis and thermal analysis of these parts is proposed.

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