EXPERIMENTAL STUDY OF SIX-STROKE ENGINE FOR HEAT RECOVERY

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EXPERIMENTAL STUDY OF SIX-STROKE ENGINE FOR HEAT RECOVERY

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
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I certify that the project entitled “Experimental Study of Six-Stroke Engine for Heat Recovery” is written by Lukman Nul-Hakem Bin Mohd Yusop. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. I herewith recommend that it be accepted in partial fulfillment 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 concurently submitted for award of other degree.

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DEDICATION

I specially dedicate to my beloved parents

Mohd Yusop Bin Derani and Nurhawaty Bt. Mohd Jara

And those who have guided

and motivated me for this project

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First and foremost I offer my sincerest thanks to my supervisor Dr. Maisara Mohyeldin Gasim Mohamed who has supported me thorughtout my final year project with patience and knowledge. And now, I had successfully accomplished my final year project by this semester.

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May Allah with His Generosity pay your kindness, andall good deeds.

Thank You

ABSTRACT

This thesis describe about modifying of engine from four stroke engines to six stroke engines. Two more additional strokes are the fifth stroke, which called water injection stroke while the last stroke is called exhaust stroke. Besides, the stroke engine also known as engine two-stroke, four-stroke and also six-stroke which are new things for us. Some modification has to do at the conventional four-stroke to six-stroke. Whereas some of them are modification at the camshaft, which is gear to contact between camshaft and crankshaft with ratio 3:1, shape of plunger, head cover engine and add more other components such as water injector and pump to make the system operate well. After the modification, performance results outcomes are compare with the conventional four-stroke engines. Unfortunately, this engine is not running as well as expected when some problems occur at few part of the engine. To fix the entire problems, analysis has been undertaken to improve some part of the followers, especially since his main problems in their engines. For the future work, the follower must be upgrading the level to get the best design and strength to make sure this engine running well.

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ABSTRAK

Tesis ini menerangkan tentang pengubahsuaian pada enjin empat lejang kepada enjin enam lejang. Dua lejang tambahan adalah pada lejang kelima, yang dipanggil lejang suntikan air manakala lejang yang terakhir dipanggil lejang ekzos. Selain itu, enjin lejan dikenali sebagai enjin dua lejang, empat lejang dan juga enam lejang adalah sesuatu yang baru untuk kita. Manakala sebahagian adalah pengubahsuaian pada aci sesondol, gear yang menyambung di antara aci sesondol dan aci engkol dengan nisbah 3:1, bentuk pelocok, penutup kepala enjin dan ada komponen tambahan seperti suntikan air dan pump untuk membuat sistem itu beoperasi dengan baik. Selepas diubahsuai, hasil keputusan prestasi yang akan membandingkan dengan enjin empat lejang konvensional. Malangnya, enjin ini tidak beoperasi seperti mana yang diharapkan apabila berlaku beberapa masalah berlaku di beberapa bahagian enjin. Untuk menyelesaikan seluruh masalah, analisa telah diambil untuk memperbaiki beberpa bahagian seperti pelocok, terutamanya memberi permasalahan utama kepada enjin. Untuk kerja masa hadapan, pelocok ini harus dinaiktarafkan untuk mendapat reka bentuk yang menarik dan ketahanan untuk memastikan enjin ini beroperasi dengan baik.

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LIST OF SYMBOLS

g_r	Gear Ratio
Cd	Center Distance
d_g	Diameter Gear
d_p	Diameter Pinion
N_g	Number of Teeth in Gear
N_p	Number of Teeth in Pinion
ϕ^n	Normal Pressure Angle
φ	Helical Angle
N	Number of Teeth
d	Pitch Diameter
P_d	Diameter Pitch
P_d^n	Normal Diameter Pitch
a	Addendum
b	Dedendum
c	Clearance
d_o	Outside Diameter
d_r	Root Diameter
h_t	Total Depth
h_k	Working Depth

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

One of the most difficult challenges in engine technology today is the urgent need to increase thermal efficiency. Six-stroke is one of the solutions for this problem. In the first approach, the engine captures the heat loss from the four-stroke Otto cycle or diesel cycle and uses it to power an additional power and exhaust stroke of the piston in the same cylinder. The pistons in this type of six-stroke engine go up and down six times to complete one cycle in a combustion engine. Fresh water which injected into the cylinder after the exhaust stroke is quickly turned to superheated steam, which causes the water to expand to 1600 times its volume and force piston down for an additional stroke and can reduce the temperature of the engine. As well as extracting power, the additional stroke cools the engine and removes the need for a cooling system making the engine lighter and giving 40 % increased efficiency.

1.2 PROBLEM STATEMENT

Nowadays, all the conventional internal-combustion engines are running in two-stroke and four-stroke. To convert the engine to run in six-stroke, there is a need to do some modification like camshaft modification, crankshaft to camshaft ratio and introducing a new water injection system.

1.2 OBJECTIVES

- To modify the conventional four stroke engine to a six-stroke.
- To compare the new engine performance with conventional one.

1.3 SCOPES

- Characteristic study of two-stroke engine, four-stroke engine and six-stroke engine.
- Crankshaft and camshaft gear design and modification part of the six-stroke engine.
- Run test six-stroke engine and identify the problem at this engine also fix the problem.
- Design new triangle follower and do analysis base on material.
- Carry out performance test.
- To analyze data that has been obtained from the performance test.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

An internal-combustion engine is any engine that operates by burning its fuel inside the engine. In contrast, an external combustion engine burns its fuel outside the engine like in a steam engine. The majority of the actual internal-combustion engines, operating on different cycle have one common feature, combustion occurring in the cylinder after each compression, resulting in gas expansion that acts directly on the piston (work) and limited to 180 degrees of crankshaft angle.

The two-stroke internal-combustion engine was first designed by Dugald Clerk. Operation of a two-stroke engine needs only one revolution to complete the cycle. It means that for each movement, it has two cycles running together. The stroke is called the stroke up and stroke down. Thus, from this operation, the engine called two-stroke.

The four-stroke internal-combustion engine was first designed by the Nikolaus August Otto. The basic operating principle of this engine is the conversion of heat energy liberated by the combustion of the fuel into mechanical energy, which rotates the crankshaft. The names of the stroke from the start of the stroke are intake stroke, compression stroke, power stroke and finally exhaust stroke. To complete this operation, there is a need two cycles.

The objective of developing this engine is to improve the efficiency and reduce the emission. The six-stroke engine already developed since 1990s and many concepts of this six-stroke engine has been developed. The concept of the six - stroke is different depending on the who is the creator of the six-stroke engine. The first approach of the concept is to get an additional power and exhaust stroke of the piston in the same cylinder. For the second approach is using a second opposed piston in each cylinder, which moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle.

2.2 TWO-STROKE ENGINE

The two-stroke cycle of an internal-combustion engine has been only two-stroke (linear movements of the piston) instead of four, although the same four operations (intake, compression, power, exhaust) still occur. It is usually found in applications like lawn movers, mopeds, small outboard motors, etc.

2.2.1 Description of Two-Stroke Engine

The two-stroke internal combustion engine need two movements, which is called stroke up as a first stroke and stroke down called as second stroke. The detail operation is:

i) First Stroke – Intake and Compression

As shown in Figure 2.1, on the up to stroke the top side of the piston is compressing an air/fuel mixture in the cylinder. At the same time, the bottom side of the piston pulls another fresh charge of air/fuel mixture into the crankcase through a one-way valve called reed valve. Near the top of the stroke, the compressed air/fuel above the piston is ignited by the spark plug and begins to burn. The rapidly burning fuel expands and begins forcing the piston down.

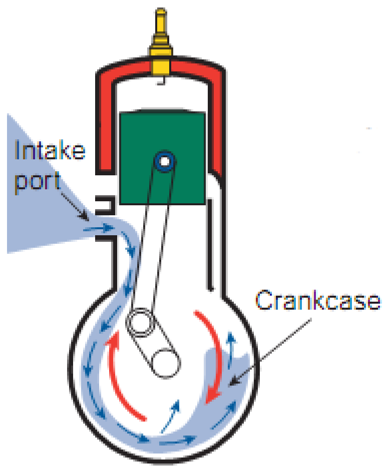


Figure 2.1: Intake and Compression

Source: Jack Erjavec (2009)

ii) Second Stroke – Power and Exhaust

As shown in Figure 2.2, on the down "power" stroke the piston is forced towards the crankcase reducing its volume and creating a positive pressure. As it continues downward travel, it starts first to uncover the exhaust ports. Exhaust gas begins to rush out of the cylinder. Then the intake ports are uncovered. The fresh air/fuel charge in the crankcase is forced into the cylinder and continues to push the remaining exhaust gases out.

The two-stroke process of purging exhausted gases from the cylinder and filling it with a fresh air/fuel charge is called scavenging. Two-stroke engine use two different scavenging methods, cross-scavenging and loop scavenging. Both differing designs have particular advantages.

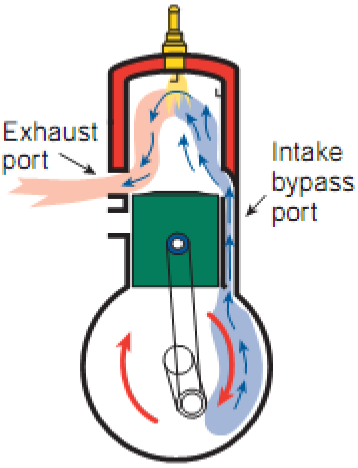


Figure 2.2: Power and Exhaust

Source: Jack Erjavec (2009)

2.2.2 Advantages and Disadvantages of Two-Stroke Engine

Advantages of two stroke engine:

- Two stroke engines do not have valves, simplifying their construction.
- Two-stroke engine fire once every revolution (four stroke engine fire once every two revolutions). This gives two-stroke engine a significant power boost.
- Two-stroke engine are lighter, and cost less to manufacture.
- Two-stroke engine has the potential for about twice the power in the same size because there are twice as many power strokes per revolution.

Disadvantages of two Stroke Engines:

- Two-stroke engines don't live as long as four-stroke engines. The lack of a dedicated lubrication system means that the parts of a two-stroke engine wear-out faster. Two-stroke engines require a mix of oil in with the gas to lubricate the crankshaft, connecting rod and cylinder walls.
- Two-stroke engine fuel can be expensive.
- Two-stroke engines do not use fuel efficiently, yielding fewer miles per liter.
- Two-stroke engines produce more pollution. From:
    - The combustion of the oil in the gas. The oil makes all two-stroke engines smoky to some extent, and a badly worn two-stroke engine can emit more oily smoke.
    - Each time a new mix of air/fuel is loaded into the combustion chamber, part of it leaks out through the exhaust port.

2.3 FOUR-STROKE ENGINE

The four-stroke engine is probably the most common engine type nowadays. It powers almost all cars and trucks.

It consists of four-stroke, one cycle operation is completed in four movement stroke of the piston. That is one cycle complete in every two revolutions of the crankshaft. Each stroke consists of 180^0 of crankshaft rotation and hence a cycle consists of 720^0 of crankshaft rotation.

In a four-stroke engine, an explosive mixture is drawn into the cylinder on the first stroke and is compressed and ignited on the second stroke; work is done on the third stroke, and the products of combustion are exhausted on the fourth stroke.

2.3.1 Description of the Four-Stroke

A four-stroke internal combustion engine has to do four things to complete one cycle as discussed below:

1. Intake/Admission stroke – In Figure 2.3, the crankshaft rotates and pulls the piston down in the cylinder which creates a partial vacuum in the cylinder. Since the intake valve is open, air is pulled through the carburetor where it also picks up fuel. At the end of the intake stroke, the camshaft rotates to a low spot on the lobe which allows the valve spring to close the intake valve.

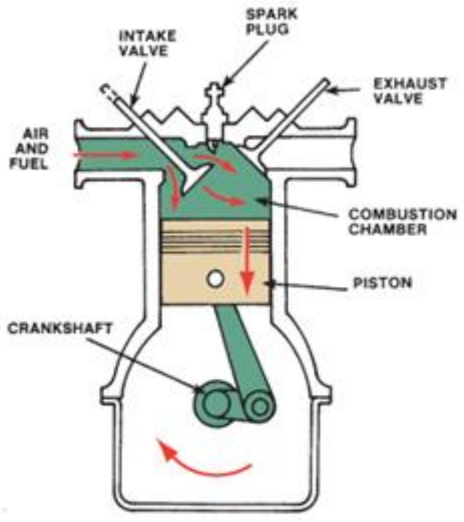


Figure 2.3: Intake/Admission Stroke

Source: Jack Erjavec(2009)

2. Compression stroke – In Figure 2.4, it compresses the fuel air mixture. During this stroke, both the intake and exhaust valve are closed.

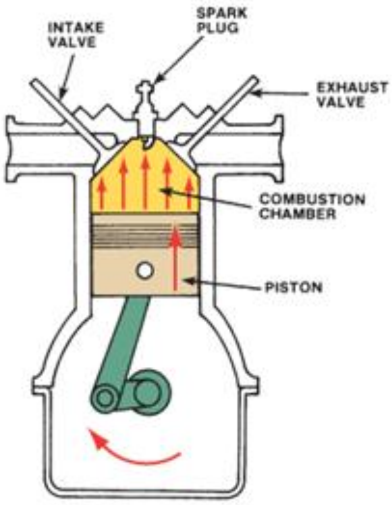


Figure 2.4: Compression Stroke

Source: Jack Erjavec (2009)

3. Power stroke – In Figure 2.5, just before the piston/crankshaft reaches top dead center (TDC), the spark plug fires and the fuel/air mixture is ignited. The heated gasses expand very rapidly and force the piston down (turning the crankshaft in the process). This is the only part of the cycle where power is produced.

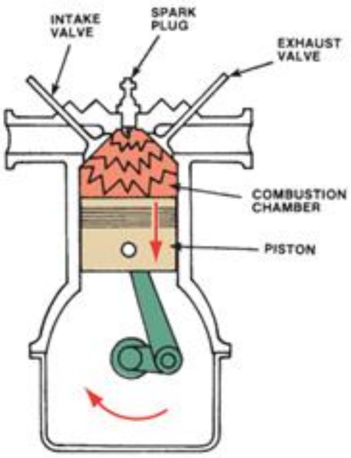


Figure 2.5: Power Stroke

Source: Jack Erjavec (2009)

4. Exhaust stroke – In Figure 2.6, at the beginning of the stroke, the exhaust valve is opened by the camshaft. When the piston is forced back up by the crankshaft, the burned fuel/mix is forced past the exhaust.

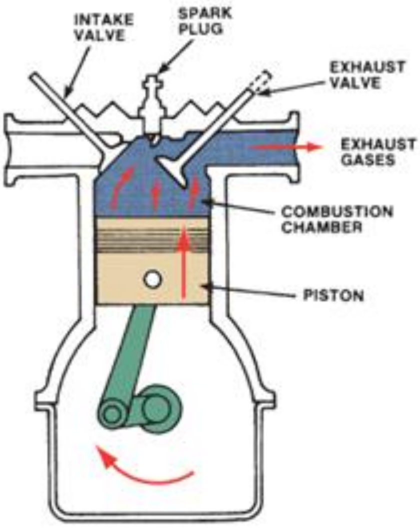


Figure 2.6: Exhaust Stroke

Source: Jack Erjavec (2009)

2.3.2 Advantage and Disadvantage of Four-Stroke Engine

Advantage of four stroke engine;

- Can produce far more power than two-stroke engine because they can be made much larger.
- Pollute less than two stroke
- More efficient use of gas.

Disadvantage of 4 stroke engine:

- Low power to weight ratio.
- More moving parts, not suitable for high speed.
- More number of stroke per circle.
- High service and overhaul cost due to more parts.

2.4 SIX-STROKE ENGINE

The six-stroke engine is a type of internal-combustion engine based on the four-stroke engine, but with additional complexity to make it more efficient and reduce emissions. Two different approaches of the six-stroke engine has been developed since the 1990s;

1. In the first approach, the engine captures the heat loss from the four-stroke Otto cycle or Diesel cycle and uses it to power an additional power and exhaust stroke of the piston in the same cylinder. The designs use either steam or air as the working fluid for the additional power stroke. The pistons in this type of six-stroke engine go up and down six times for each injection of fuel. There are two power strokes:
    - One with fuel, the other with steam or air. The currently notable designs in this class are the Crower six-stroke engine, invented by Bruce Crower in the U.S.
    - The Bajulaz engine by the Bajulaz S.A. Company of Switzerland; and the Velozeta Six-stroke engine built by the College of Engineering, at Trivandrum in India.

2. The second approach to the six-stroke engine uses a second opposed piston in each cylinder that moves at half the cyclical rate of the main piston, thus giving six piston movements per cycle. Functionally, the second piston replaces the valve mechanism of a conventional engine but also increases the compression ratio. The currently notable designs in this class include two designs developed independently: the Beare Head engine, invented by Australian Malcolm Beare,

and the German Charge pump, invented by Helmut KottmannGriffin six-stroke engine. (S.N. Gurukulam Collage of Engineering)

The 6 stroke internal combustion engine is an advance over the existing four-stroke which employs the same principle as that of the four-stroke. The 5th stroke or the second power stroke used the heat evolved in the exhaust stroke (directly or indirectly) as the heat required sudden expansion of the secondary fuel (air or water) which pushes the piston downward for the 2nd power thereby rotating the crankshaft for another half cycle. As heat evolved in the 4th stroke is not wasted, the requirement for a cooling system is eliminated.

Here the fuel is injected once in every three complete cycles of the crankshaft which is anytime better than four-stroke where fuel is injected once in two complete cycles of the crankshaft. It should be noted that efficiency of the six-stroke is more than the existing four-stroke. Two major types of secondary fuels used in the 5th stroke are air and water. Many types of six-strokes were being designed on these two fuels of which few important types will be discussed.

Advantages of six-stroke engine;

- Thermal efficiency reaching 50%. (30% of the actual internal combustion engine).
- Fuel consumption reduced by more than 40%.
- Reduction of chemical, noise and thermal pollution.
- Two expansions (work) through six strokes.
- The cooling system is eliminated.
- Direct injection and optimal fuel combustion at every engine speed.
- Multiple fuels.

2.5 TYPES OF SIX-STROKE ENGINE

Many types of six-stroke engine were invented. The types and design depend on and who create and develop the engine. For development of six-stroke engine, many theories and applications have to. There are six the type of six-stroke engine is as discussed below:

2.5.1 Griffin Six-Stroke Engine

The key principle of the “Griffin Simplex” as shown in Figure 2.7 was a heated exhaust jacked external vaporizer, into which the fuel was sprayed. The temperature was held around 550 ^{o}F (288 ^{o}C), sufficient to physically vaporize the oil not to be breaking it down chemically. This fractional distillation supported the use of heavy oil fuels, the unusable tar and asphalts separating out in the vaporizer. Hot bulb ignition was used, which Griffin termed the “Catathermic Igniter”, a small isolated cavity connected to the combustion chamber. The spray injector had an adjustable inner nozzle for the air supply, surrounded by annular casing for the oil, both oil and air entering at 20lbs sq in pressure, and being regulated by a governor.

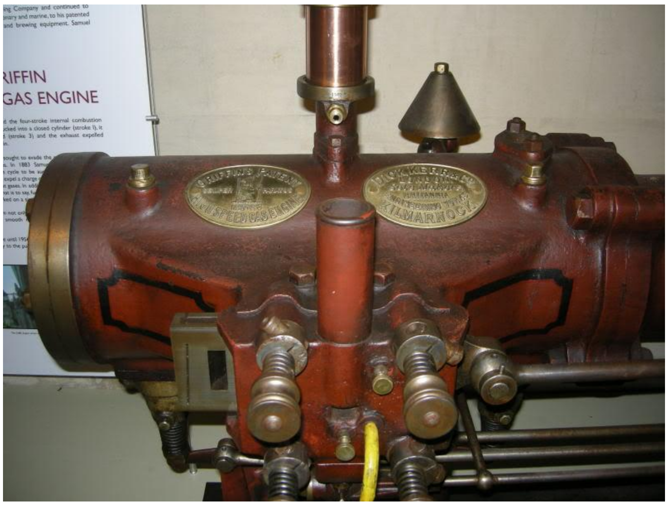


Figure 2.7: Griffin Six-Stroke Engine

2.5.2 Bajulaz Six-Stroke Engine

The Bajulaz six stroke engine as shown in Figure 2.8 is similar to a regular combustion engine in the design. There are however modifications to the cylinder head, with two supplementary fixed capacity chambers, a combustion chamber and air preheating chamber above each cylinder, the injection of fuel begins an isochoric burn which increase the thermal efficiency compared to a burn in the cylinder.

The high pressure archive is then released into the cylinder to work the power or expansion stroke. Meanwhile, a second chamber which blankets the combustion chamber has its air content heated to a high degree of heat passing through the cylinder wall. This heated and pressurized air is then used to power an additional stroke of the piston. The advantages of the engine include reduction in fuel consumption by at least 40%, two expansion strokes in six-stroke, multi-fuel usage capability, and dramatic reduction in pollution.

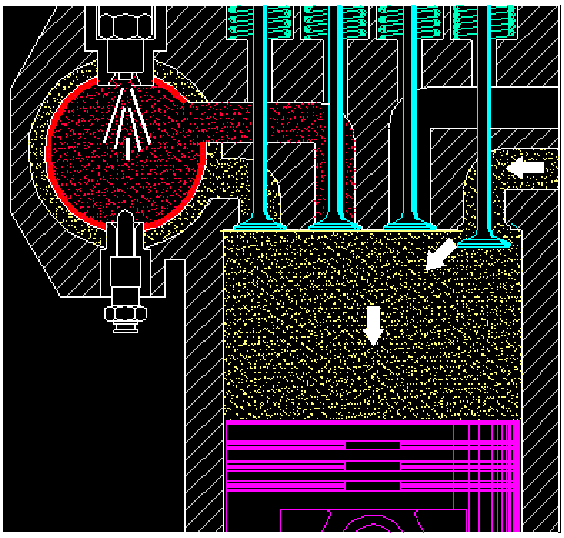


Figure 2.8: Bajulaz Six-Stroke Engine

Source: Bajulaz S.A 2007

2.5.3 Velozeta Six-Stroke Engine

In a Velozeta engine as shown in Figure 2.9, during the exhaust stroke, fresh air is injected into the cylinder, which expands with heat and therefore, forces the piston down for an additional stroke. The valve overlaps have been removed and the two additional strokes using air injection provide for better gas scavenging. The engine seems to show a 40% reduction in fuel consumption and dramatic reduction in air pollution. Its specific power is not less than that of a four-stroke petrol engine. An altered engine shows a 65% reduction in carbon monoxide pollution when compared with the four-stroke engine from which it was developed.

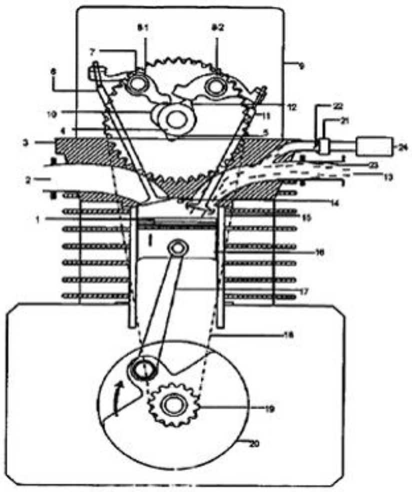


Figure 2.9: Velozeta Six-Stroke Engine

2.5.4 Crower Six-Stroke Engine

In six stroke engine developed in the U.S. by Bruce Crowner as shown in Figure 2.10, fresh water is injected into the cylinder after the exhaust stroke, and is quickly turning to superheated steam, which causes the water to expand to 1600 times its volume and forces the piston down for an additional stroke. This design also claims to reduce fuel consumption by 40%.

Figure 2.10: Crower Six-Stroke Engine

2.5.5 Beare Head

The term “Six Stroke” was coined by the inventor of the Beare Head, Malcom Beare shown in Figure 2.11. The technology combines a four stroke engine bottom end with an opposed piston in the cylinder head working at half the cylinder rate of the bottom piston. Functionally, the second piston replaces the valve mechanism of a convectional engine.

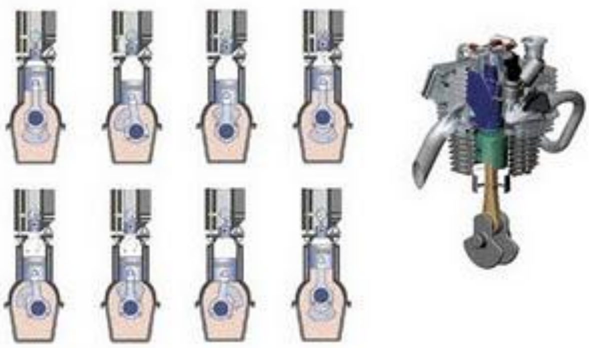


Figure 2.11: Beare Head

2.5.6 Charge Pump Engine

In this engine, similar in design to the Beare head, a “piston charger” replaces the valve system. The piston charger charges the main cylinder and simultaneously regulates the inlet and the outlet aperture leading to no loss of air and fuel in the exhaust. In the main cylinder, combustion takes place every turn as in a two-stroke engine and lubrication as in a four-stroke engine. Fuel injection can take place in the piston charger, in the gas transfer channel or in the combustion chamber. It is also possible to charge two working cylinders with one piston charger. The combination of compact design for the combustion chamber together with no loss of air and fuel is claimed to give the engine more torque, more power and better fuel consumption.

The concept of Six Stroke Engine seems to be rather eco-friendly and low fuel consuming which can fulfill the needs of the near future. A lot of experiments are being conducted in order to improve the efficiency and workability of the engine.

CHAPTER 3

MODIFICATION OF CONVENTIONAL FOUR-STROKE ENGINE TO SIX-STROKE ENGINE

3.1 INTRODUCTION

To make six-stroke engine from the conventional four-stroke engine, there must be a few modifications for new parts of the engine to ensure the six-stroke engine is running successfully. In this chapter, the type of modifications are discussed in detail which including the crankshaft to camshaft ratio modification, camshaft modification, follower/plunger modification, cylinder head modification and water injection system.

3.2 CRANKSHAFT TO CAMSHAFT RATIO MODIFICATION

In a conventional four-stroke engine, the gear at crankshaft must be rotated at 720^{o} while the camshaft must be rotated at 360^{o} to complete one cycle of the combustion engine. But for the six-stroke engine, the gear on the crankshaft must be rotated at 1080^{o} while for the camshaft is rotating about 360^{o} to complete one cycle engine. Hence their corresponding gears are having teeth 3:1. From the figure 3.1 show that the different gear at regular engine is running in the four stroke engine at ratio 2:1 and make a modification at six stroke engine then, at the modification gear show to contact between the crankshaft and the camshaft at ratio 3:1. The gear on the crankshaft has 18 teeth and the camshaft gear is 54 teeth. The type of gear used is a helical gear because this type of gear is useful for high-speed and high power application, quite at high speed.

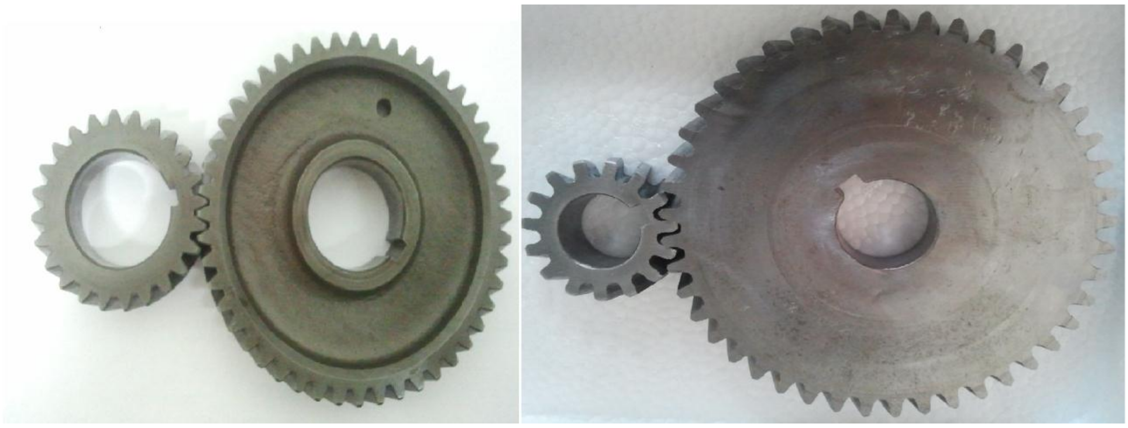


Figure 3.1: Crankshaft and Camshaft Gear Modification: (a) Conventional Gear Design, (b) New Gear Design

To design the gear, there is a need for some calculations make it easy to choose whether which one of the gears suitable to put in the engine. Helical gear the best type of gear because this type of gear is useful for high-speed and high power application, also reasonable for a high speed. To calculate gear are shown as below:

Gear Ratio (g_r) = 1:3
Center Distance (Cd) = 3.6 in
Diameter Gear (d_g) = 5.4 in
Diameter Pinion (d_p) = 1.8 in

Example of Calculation:
Find N_g,
N_p= 18 teeth
Gear ratio is expressed as in Eq. (3.1)

$$g_r = \frac{N_g}{N_p} \tag{3.1}$$

Where g_r = Gear Ratio
N_g = Number of Teeth in Gear
N_p = Number of Teeth in Pinion

$$N_g = g_r N_p$$

$$N_g = 3 X 18$$

$$N_g = 54 \, teeth$$

The present of the helix angle aids in the avoidance of interface. The minimum of pinion teeth that can be used, mating with any size gear, without interface concern is written as follows:

$$N_1 > \frac{2k \cos \varphi}{\sin^2 \emptyset} \tag{3.2}$$

The Value generate from this equation are summarized into Table 3.1.

Table 3.1: Minimum Helical Gear Teeth to Avoid Interface

Helix Angle	**Normal Pressure Angle, $\emptyset^n$** 14.5^0	**20^0**	**25^0**
0 (spur gear)	32	17	12
5^0	32	17	12
10^0	31	17	12
15^0	29	16	11
20^0	27	15	10
22.5^0	25	14	10
25^0	24	13	9
30^0	21	12	8
35^0	18	10	7
40^0	15	8	6
45^0	12	7	5

Source: David H.Myszka (2011)

From the table show above, the value taken from normal pressure angle (ϕ^n) from the pinion teeth is 14.5^o.

Find helical angle (φ),

The pitch diameter is given by the same expression used for spur gear is,

$$P_d = \frac{N_p}{d_p} \tag{3.3}$$

But if the normal pitch is involved, it is a functional of the helix angle.

$$d = \frac{N}{P_d} = \frac{N}{P_d^n \cos\varphi} \tag{3.4}$$

Where d = Pitch Diameter, (in)

N= Number of Teeth

P_d = Diameter Pitch, (in^{-1})

P_d^n = Normal Diameter Pitch,(in^{-1})

φ = Helical Angle, deg

The center distance is using the analogy from equation (3.3),

$$c_d = \frac{d_g+d_p}{2\ \cos\varphi} = \frac{N_g+N_p}{2\ \mathrm{P_d^n} \cos\varphi} \tag{3.5}$$

The normal diameter pitch should confirm to the standard listed in Table 3.2. The value of normal diameter is equal to 12 were selected due the gear used is helical gears.

Table 3.2: Standard Diameter Pitch

Coarse Pitch		Fine Pitch	
2	6	20	80
2.25	8	24	96
2.5	10	32	120
3	12	40	150
4	16	48	200
		64	

Source: David H.Myszka (2011)

$$c_d = \frac{N_g + N_p}{2\ \mathrm{P_d^n}\cos\varphi}$$

$$3.6 = \frac{18 + 54}{2(12\cos\varphi)}$$

$$\varphi = cos^{-1}\frac{10}{12}$$

$$\varphi = 33.557°$$

From the trigonometric equation, find the diameter pitch using the below equation.

$$P_d = P_d^n cos\ \varphi \tag{3.6}$$

$$P_d = 12cos\ 33.557$$

$$P_d = 10in^{-1}$$

Table 3.3: Result Calculation from Different Number of Pinion Teeth

Pinion Teeth N_p	**Gear Teeth N_g**	**Normal Pressure Angle, ϕ^n**	**Normal Diameter Pitch,P_{nd}**	**Helix Angle Φ^o**	**Diameter Pitch $P_d(in^{-1})$**
12	36	14.5	12	56.25	6.67
15	45	14.5	12	46.02	8.33
18	54	14.5	12	33.56	10
21	63	14.5	12	13.54	11.67

From the above result based on Table 3.3, the value of addendum, dedendum and clearance of helix gear can be found. While the Table 3.4 below shown that the formulation of course-pitch and fine-pitch are given.

Table 3.4: Formulas for Addendum, Dedendum and Clearance

Parameter	**Symbol**	**Coarse pitch (P_d< 20in^{-1})**	**Fine pitch (P_d> 20in^{-1})**	**Metric Volume system**
Addendum	a	$1/P_d$	$1/P_d$	1.00 m
Dedendum	b	$1.25/P_d$	$1.200/P_d + 0.002$	1.25 m
Clearance	c	$0.25/P_d$	$0.200/P_d + 0.002$	0.25 m

Source: B.J. Hamrock, S.R.Schimd, Bo Jacobson (2005)

As the Coarse pitch is selected, the value of diameter pitch (P_d) result is less than 20 in^{-1}. It is shown as Table 3.4 above.

For example, the value of addendum, dedendum and clearance that based on the result above which is P_d is equal to 10 (P_d= 10). The calculation is show as below,

$$a = \frac{1}{P_d} = \frac{1}{10} = 0.1$$

$$b = \frac{1.25}{P_d} = \frac{1.25}{10} = 0.125$$

$$c = \frac{0.25}{P_d} = \frac{0.25}{10} = 0.025$$

Once the addendum, dedendum and clearance are identified, the other number of parameters can be obtained and know that the diameter of pinion is 1.8 in. There are:

$$\text{Outside diameter: } d_o = d_p + 2a \qquad (3.7)$$

$$d_o = 1.8 + 2\,(0.1)$$

$$d_o = 2.0 \text{ in}$$

Root diameter: $d_r = d_p - 2b$ (3.8)

$d_r = 1.8 + 2\ (0.125)$

$d_r = 1.55$ in

Total depth: $h_t = a + b$ (3.9)

$h_t = 0.1 + 0.125$

$h_t = 0.225$

Working depth: $h_k = a + a = 2a$ (3.10)

$h_k = 0.1 + 0.1$

$h_k = 0.2$

Table 3.5: Result Basic Gear Geometry

Pinion Teeth Np	**Gear Teeth Ng**	**Diameter Pitch Pd(in^{-1})**	**Addendum a**	**Dedendum b**	**Clearance c**	**Outside Diameter do**	**Root Diameter dr**	**Total Depth h_t**
12	36	6.67	0.15	0.187	0.037	2.1	1.425	0.337
15	45	8.33	0.12	0.15	0.03	2.04	1.5	0.27
18	54	10	0.1	0.125	0.025	2	1.55	0.225
21	63	11.67	0.086	0.107	0.021	1.971	1.586	0.193

The Table 3.5 above was described the result of basic geometry. The suitable gear is chosen in the six-stroke engine. As information, gear is functioning as contact between camshafts to crankshaft that rotate the engine. So, from the Figure 3.2 has shown the illustrated position of all results that based on the Table 3.5 above.

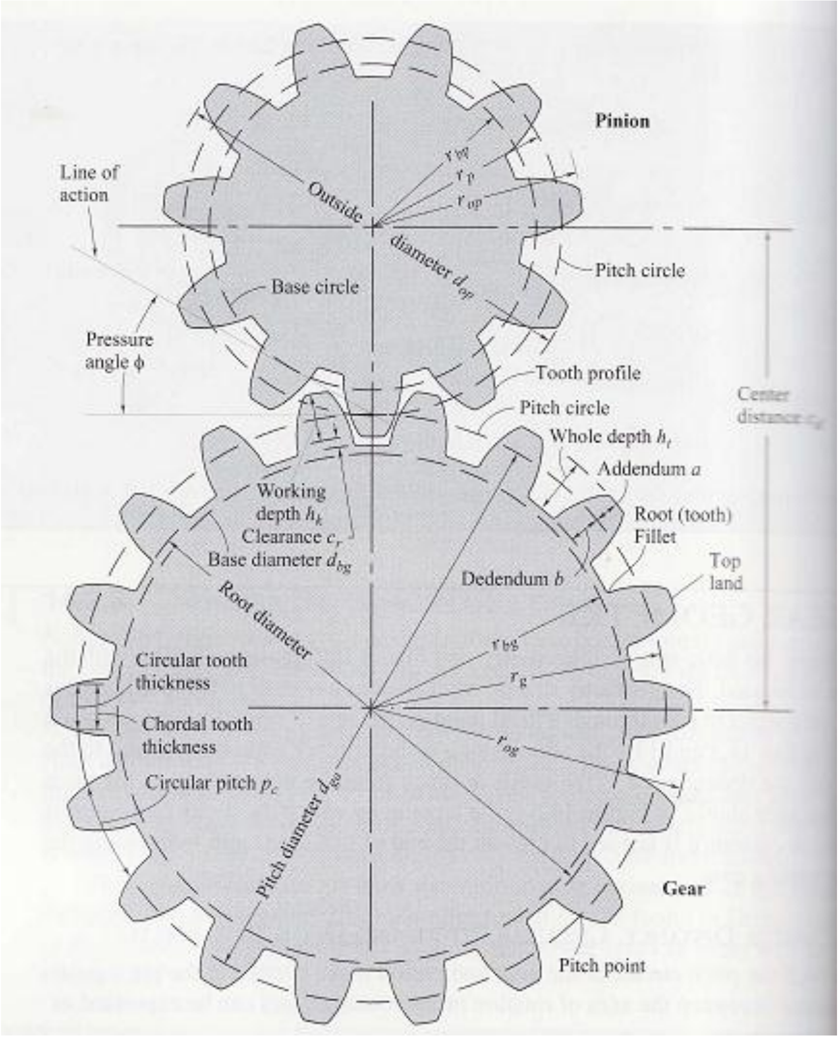


Figure 3.2: Basic Geometry Gear

Source: B.J. Hamrock, S.R.Schimd, Bo Jacobson (2005)

At the center pinion there is a hole to put the crankshaft and also the key to secure rotating element. The total diameter is 1.28in. Based on the table 3.5, it can illustrate the suitable gear that should be used based on root diameter value. To avoid a failure occur when the gear is running, the 18 teeth pinion is selected compared to the 12 or 15 teeth used. It is due to the distance between root diameter and the diameter of the hole for the shaft.

Table 3.6: Gear Specification Detail

Item Spesification	Size
Diameter Pitch (Pd)	10 (1/in)
Number of Teeth for Pinion (N1)	18
Number of Teeth for Gear (N2)	54
Pressure Angle (ϕ)	14.5°
Helical Angle (ψ)	33.557°
Pitch Diameter D1	1.8 in
Pitch Diameter D2	5.4 in
Inner Shaft Diameter for the Pinion	1 in
Inner Shaft Diameter for the Gear	1.2 in

3.3 CAMSHAFT MODIFICATION

In the six stroke engine, the 360 degrees of the cam have been divided into 60 degrees among the six-strokes. The valve provided at the exhaust has two lobes to open the cam at a fourth stroke to move out of the burned fuel/mix is forced past the exhaust and the second lobe open valve to move out of the steam water. From that the Figure 3.3 has shown the difference between of the cam shaft for both four-stroke and six-stroke and also the profile camshaft. Detail of the drawing regarding to the camshaft attached in appendix A. For the good strength of material that used to fabricate the camshaft, it must be treated with the heat treatment process to keep any thrust or force from the follower when engine operating.

a

b

Figure 3.3: Cam Shaft: (a) Four-Stroke Camshaft, (b) Six-Stroke Camshaft

Figure 3.4 shows the flow chart to manufacture the camshaft from the cylinder steel and plate steel. The process until to become a six-stroke camshaft through by using the CNC process to make a shape that need. After CNC process, the part has assembly process using a compress machine to make one part and lastly make a heat treatment process to add the strength at the camshaft.

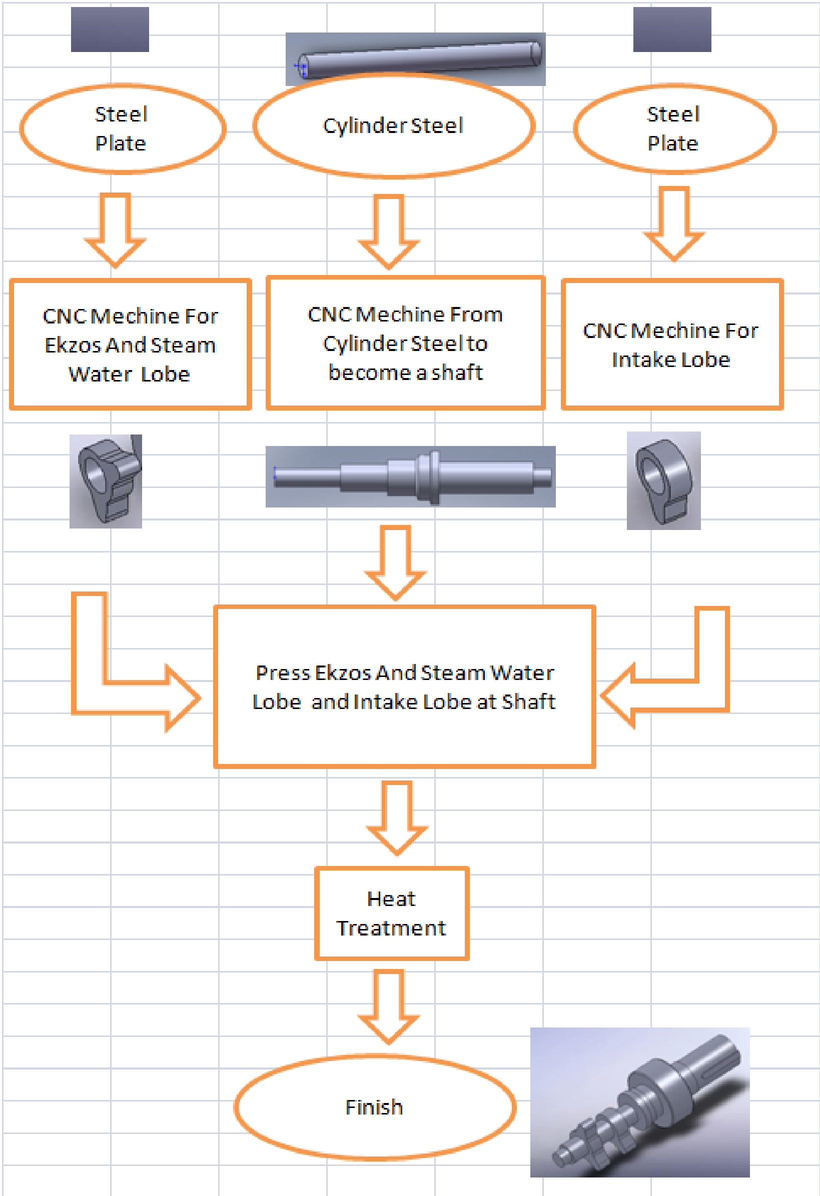
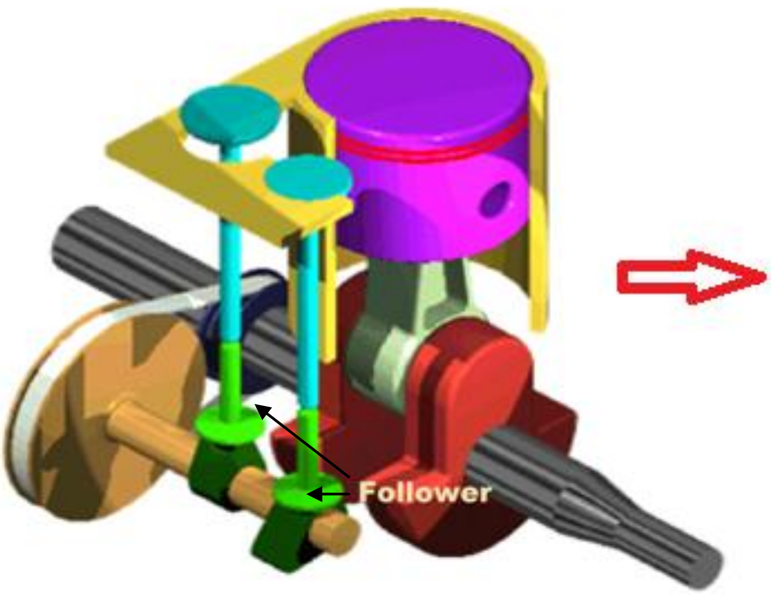


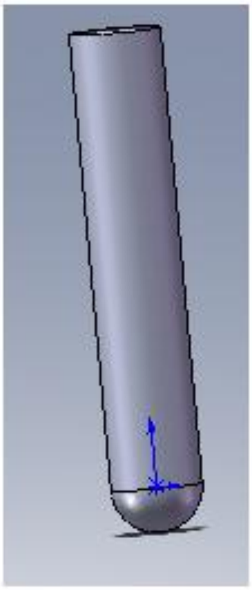
Figure 3.4: Flow Chart of Cam Manufacture

3.4 FOLLOWER/PLUNGER MODIFICATION

From Figure 3.5, the bottom shape of a regular follower has the plat pattern. This existing follower shape only suitable for the four-stroke camshaft without any problem and make this engine operating smooth. However, after doing the modification at the camshaft for operates this six-stroke engine, the follower must do some modification to change from the flat shape to semi spherical. For the follower using the flat shape, there are not working properly because this type unsuitable with the lobe at the camshaft and hard to operate this engine. The functional for new semi spherical follower can eliminate noisy because the profile camshaft is not smooth. The Figure also shows the follower shape after modification.



a



b

Figure 3.5: Follower After Modification: (a) Existing Follower, (b) Semi Spherical Follower

3.5 CYLINDER HEAD MODIFICTION

From the Figure 3.6 show, the cylinder head needs to fill water injector to spray water in the combustion chamber for operating the six-stroke engine. The regular cylinder head only places the spark plug. However, for operating the six stroke engine, the cylinder head must make another hole to put the water injection to spray directly in combustion. The sleeve was making too tight with the water sprays between head cylinder and water injector. The dimension sleeve is for outer diameter 26.4mm, the inner diameter is 16.9mm and the length is 64mm. The stoppers also make it to eliminate water spray extracted when high-water pressure injects at the chamber.

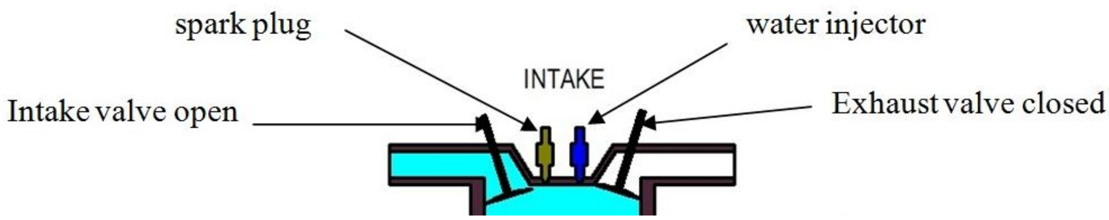


Figure 3.6: Illustrate Water Injector Place

3.6 WATER INJECTION SYSTEM

Two extra strokes are added to the customary internal combustion engine four stroke Otto cycle, which makes a six stroke engine. A third down-stroke is a "steam stroke" and a third up-stroke exhausts the expanded steam while venting heat from the engine.

The engine cold starts on the Otto cycle, coasting through the fifth and sixth strokes for a short period. After the combustion chamber temperature reaches approximately 400 degrees Fahrenheit (200 °C), a mechanical operation phase in the fifth and sixth strokes. Just before the fifth stroke, water is injected directly into the hot combustion chamber via the supporting engine, creating steam and another power stroke. The phase change from liquid to steam removes the excess heat of the combustion stroke forcing the piston down (a second power stroke).

As a substantial portion of engine heat now leaves the cylinder in the form of steam, no cooling system radiator is required. A proportion of the energy that is dissipated in conventional arrangements by the radiator in a water-based cooling system has been converted into additional power strokes. From the Figure 3.7 shows the degree of water to start injector in the combustion chamber.

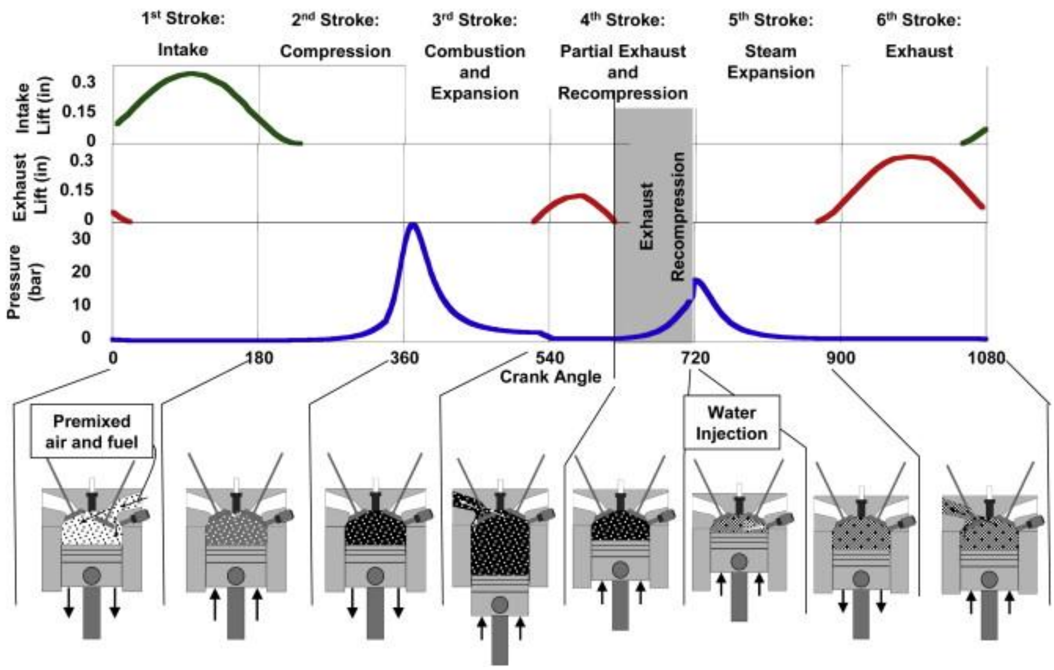


Figure 3.7: Degree of Water Injector

CHAPTER 4

ENGINE STARTING PROBLEM

4.1 INTRODUCTION

To modify the engine from four stroke engine to six stroke engine is not easy as other expected because the normal engine must do some transformation especially at the camshaft and the gear in which connecting between crankshaft and camshaft. Some design and calculation also must be considerate to make a successful engine. The electric motor 240V DC also included to support the operation of the engine until the engine reaches the idling speed. (Calvin collage, 2010) But when the six stroke engine starts to operate, some components have some problem which will be discussed later.

4.2 FOLLOWER/PLUNGER PROBLEM

From the regular follower, it has the flat shape at the bottom. Then the shape of a follower has some change because to suit the shape of the camshaft. When the engine is running, the follower deformed because of the force from the camshaft. To fix this problem, the follower must be given heat treatment process to add the strength to the follower. But to make an ideal follower so that the camshaft runs, the diameter of the semi hemisphere has to change about two times. For the second follower modified, suitable with the lobe profile of the camshaft, as shown in Figure 4.1.

Nevertheless, this shape also gives the problem when engine operating because the friction in between surface lobe camshaft and surface of the follower. It also can affect at the follower when the engine is rotating and make some of the change of deformation as shown in Figure 4.2.

The latest design is placed the cylinder bearing at the bottom follower shown in Figure 4.1. The bearing can bear a load between two moving parts with the minimum amount of friction and smoother movement when follower contact at the camshaft. Detail of the drawing regarding to the follower is attached in appendix B.

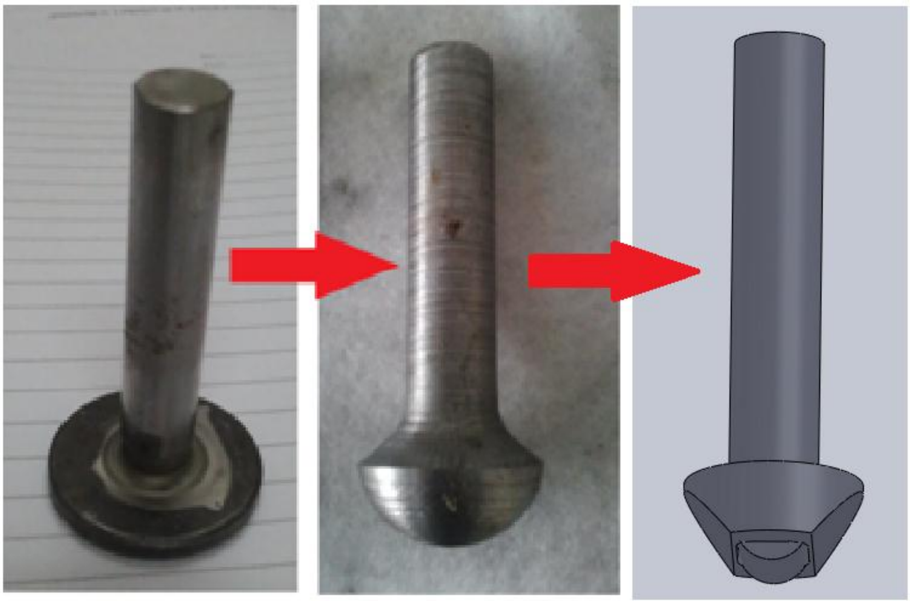


Figure 4.1: Follower Modification

Figure 4.2: Follower Deformation

Deformation of the semi spherical follower led to produce a new design of follower called triangle head follower with bearing at the tip to ensure smooth contact during its operation. Appendix B shows detail technical drawing of the new follower design. The new design has been suggested to be analyzed before come out with final component for lab testing. The analysis has been conducted by using Solidworks in two different types of analysis: motion analysis and stress analysis in dynamic condition.

Figure 4.3 shows drawing model of the engine internal part which comprises of piston, connecting rod, camshaft, crankshaft and camshaft gear, follower, intake valve and exhaust valve.

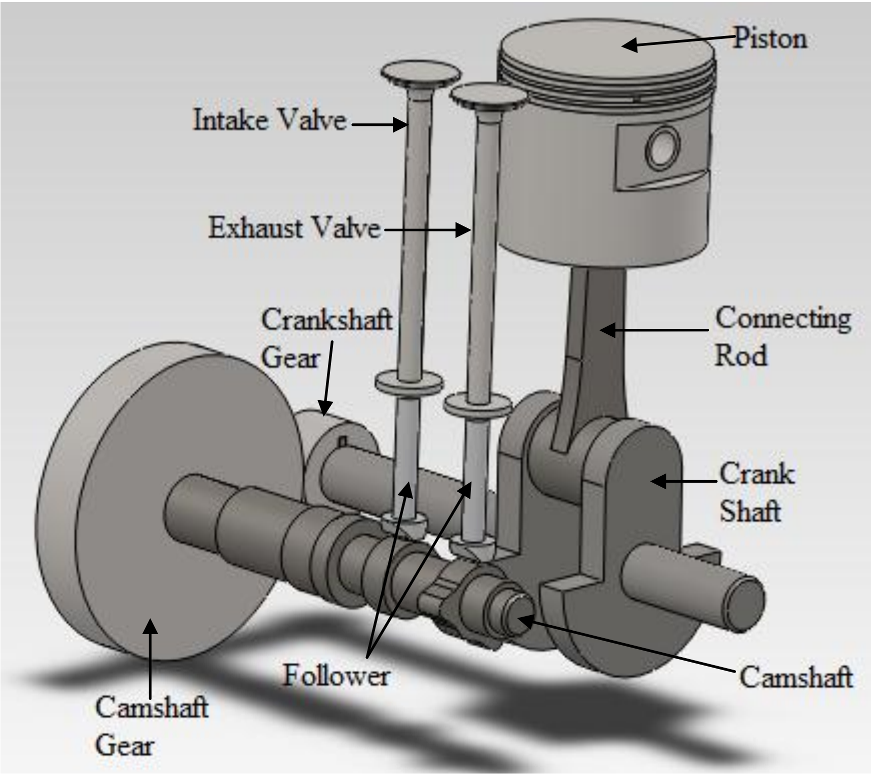


Figure 4.3: Six-Stroke Engine

Pressure Volume (P-V Diagram) data must be provided in this software in order to carry out the simulation. Figure 4.4 show P-V diagram of six-stroke engine. That has been obtained by group project. The standard bearing is placed at the bottom of follower. For this simulation is conducted at 3000 rpm at the engine rotation. There are two types of simulation for different material that have conducted as discussed below:

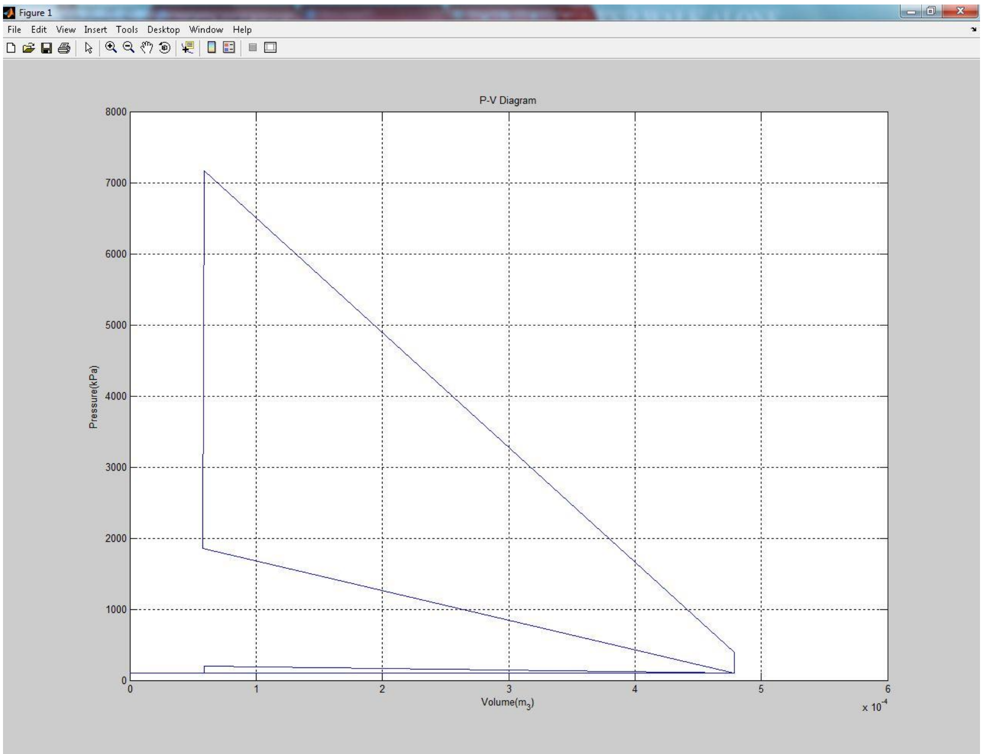


Figure 4.4: PV-Diagram Six Stroke engine

i) First Analysis

For the first simulation, material for the follower is using Mild Steel and Bearing material properties is taken from manufacturer data (NSK). Table 4.1 tabulated the properties of the material.

Table 4.1: Material Properties of the first analysis (Mild Steel and Bearing)

Material Properties	**Mild Steel (AISI 1015 Steel, Cold Drawn (SS)**	**Bearing (AISI E52100)**
Elastic Modulus (N/m^2)	2.05E+11	2.1E+11
Poission's Ration (N/A)	0.29	0.3
Shear Modulus (N/m^2)	80000000000	80000000000
Mass Density (kg/m^3)	7870	7810
Tensile Strength (N/m^2)	385000000	2240800000
Yield Strength (N/m^2)	325000000	2033950000
Thermal Conductivity (W/(m.K))	52	46.6
Specific Heat (j/(kg.K))	486	475

Figure 4.5, shows result of stress analysis that has been too conducted on the follower by using material Mild Steel. The maximum value of stress is 21903418 N/m^2. Compare at the yield strength Mild steel at value 325000000 N/m^2, this material and design suitable to assemble in the engine and factor of safety distribution (FOS) show the value of 11.84.

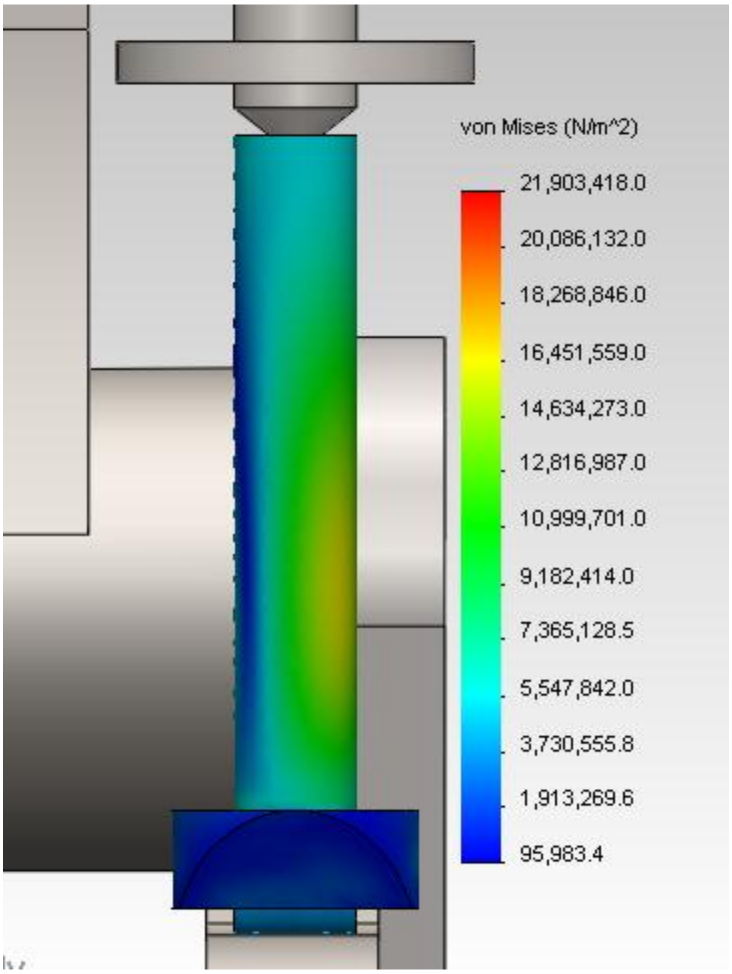


Figure 4.5: Result Mild Steel Follower Stress

ii) Second Running

For the second simulation analysis of the follower, material and properties that has been used is tabulated in Table 4.2.

Table 4.2: Material Properties of the second analysis (Stainless Steel and Bearing)

Material Properties	**Stainless Steel (AISI 202)**	**Bearing (AISI E52100)**
Elastic Modulus (N/m^2)	2.0684E+11	2.1E+11
Poission's Ration (N/A)	0.3	0.3
Shear Modulus (N/m^2)	772210000	80000000000
Mass Density (kg/m^3)	7854.7	7810
Tensile Strength (N/m^2)	515000000	2240800000
Yield Strength (N/m^2)	275000000	2033950000
Thermal Conductivity (W/(m.K))	16.2	46.6
Specific Heat (j/(kg.K))	500	475

From the Figure 4.6, it shows that the result of stress analysis at the follower using material Stainless Steel is 23933404 N/m^2. Compare at the yield strength Stainless Steel at the value of 275000000 N/m^2, this material and design also suitable to be implemented in the engine and factor of safety distribution (FOS) show the value of 11.49 is obtained.

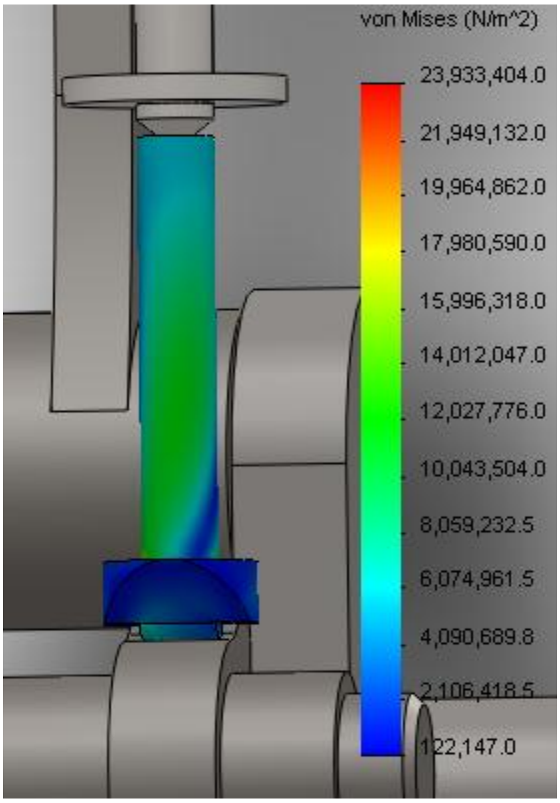


Figure 4.6: Result Stainless Steel Follower Stress

Compared with the value of the both materials Mild Steel and Stainless Steel, the best is Mild Steel. It is because, this material of material Mild Steel cheaper than the Stainless steel and available in market. From factor of safety distribution (FOS) of both, Mild Steel gave the better strength than the stainless steel at FOS value of 11.84.

4.3 FOLLOWER TRACK/GUIDE

The follower track also has the problem which is the effect of the follower deformation. From the figure 4.7, it shows the crack of the follower track. To fix this problem, the sleeve is made and placed on the broken follower track. It is due, when an engine running, the lobe camshaft has given some amount of force at the follower. The follower shape also not matching with the cam lobe. Otherwise the cam lobe is always not in connection between a follower and face of cam lobes. The effect of this problem, follower starting to bend and the wall of the follower track also affected by follower, and finally, it started to crack and broken.

Figure 4.7: Sleeve at Follower Track

4.4 CAMSHAFT

When the engine starts to run for a few minutes, many problems occur at the camshaft. The lobes of the camshaft were moving and make the angle position to push the valve. Thus, the engine cannot run properly. To fix this problem, we have to weld at the between contact of shaft and lobe. Unfortunately, the welding once again has broken back. The next solution is making a hole and pin to support lobe at the shaft and eliminate the lobe rotation. It is because, the camshaft made from a few parts that gathered to make a new camshaft. Hence, the camshaft cannot support the force by the follower and engine moving. The best way is to make a new camshaft as one piece shown in Figure 4.9. From the Figure 4.8 focused on the place of the welding mark as red box and place on the pin mark as a yellow circle.

Figure 4.8: Welding and Pin at Camshaft.

Figure 4.9: New Camshaft as a One Piece

4.5 STARTING PROBLEM

A common four stroke engine is able to sustain its cycles after a few full revolutions of the driveshaft. This is frequently initiated by the user pulling on a starter cord. It is anticipated that the six-stroke engine designed here will require a larger number of revolutions to begin sustaining itself. For this purpose, a starter motor assembly has been designed. The starter motor will turn the driveshaft at idling speed until the engine is able to accelerate under its own power. At this point, the motor is turned off and the engine runs independently but still turning the motor. The starter motor has a large DC motor with a built in speed control box. The assembly includes sprockets that provide a 2:1 speed reduction. (Calvin collage, 2010). From this report, there are needs of electric motor to support engine operation where the engine has to start operation. From regular engine four-stroke with ratio of 2:1, the minimum revolution starts at 450 RPM. When the regular engine four-stroke changes to six-stroke with ratio 3:1, the starter motor must rotate more than usual. This is because of the change of gear ratio. Then, our engine no need electric motor to support operation because of the regular starter can support this operation but take a longer time than usual to reach the starting point.

The first objective is achieved successful to modify the conventional four stroke engine to six stroke engine. The engine also can start easily without using an electric motor to support the operation. When the engine starts to run, it still has a few problems. The solutions were given to fix that problem.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

To modify the conventional four-stroke engine to the six-stroke engine was not easy as other expected because it needs to modify all the internal parts of the engine especially camshaft and gear which it has a link between the crankshaft and camshaft. Some dimension and calculation must be considerate to make sure the engine is running successfully. The timing graph also must be started at the beginning to manage the engine operation, especially when injects a water in the chamber. This is for making the valve opening to ensure the engine is running smoothly and give more power.

The most important part is follower, which need extra research because the major problem at this engine is at the follower. To make the best design to match with camshaft, a lot of things must consider. Especially shape of the bottom follower. It is used to support force given by the camshaft lobe and finishing the process to have the follower move very smooth on the track.

We hope that our project can make this engine running successfully. It takes almost more than one year to make a research to make the system run the engine well.

5.2 RECOMMENDATION AND FUTURE WORK

To make a successful operating engine, the process must begin with the drawings. From the drawing, we can design easily because we know about engine drawing and empty space to match with the new part. Also concentrate on the part which the problem occurred in the engine especially at follower and must do the best design to ensure follower operates properly.

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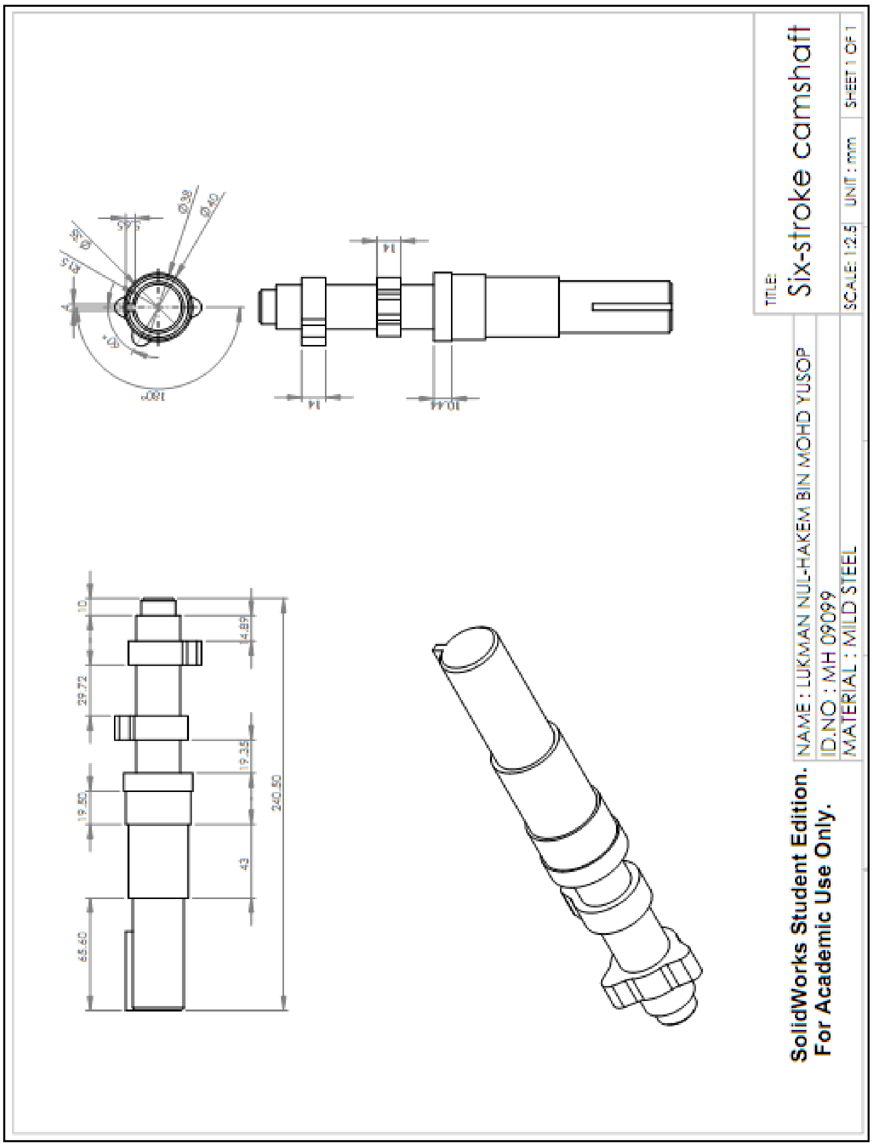
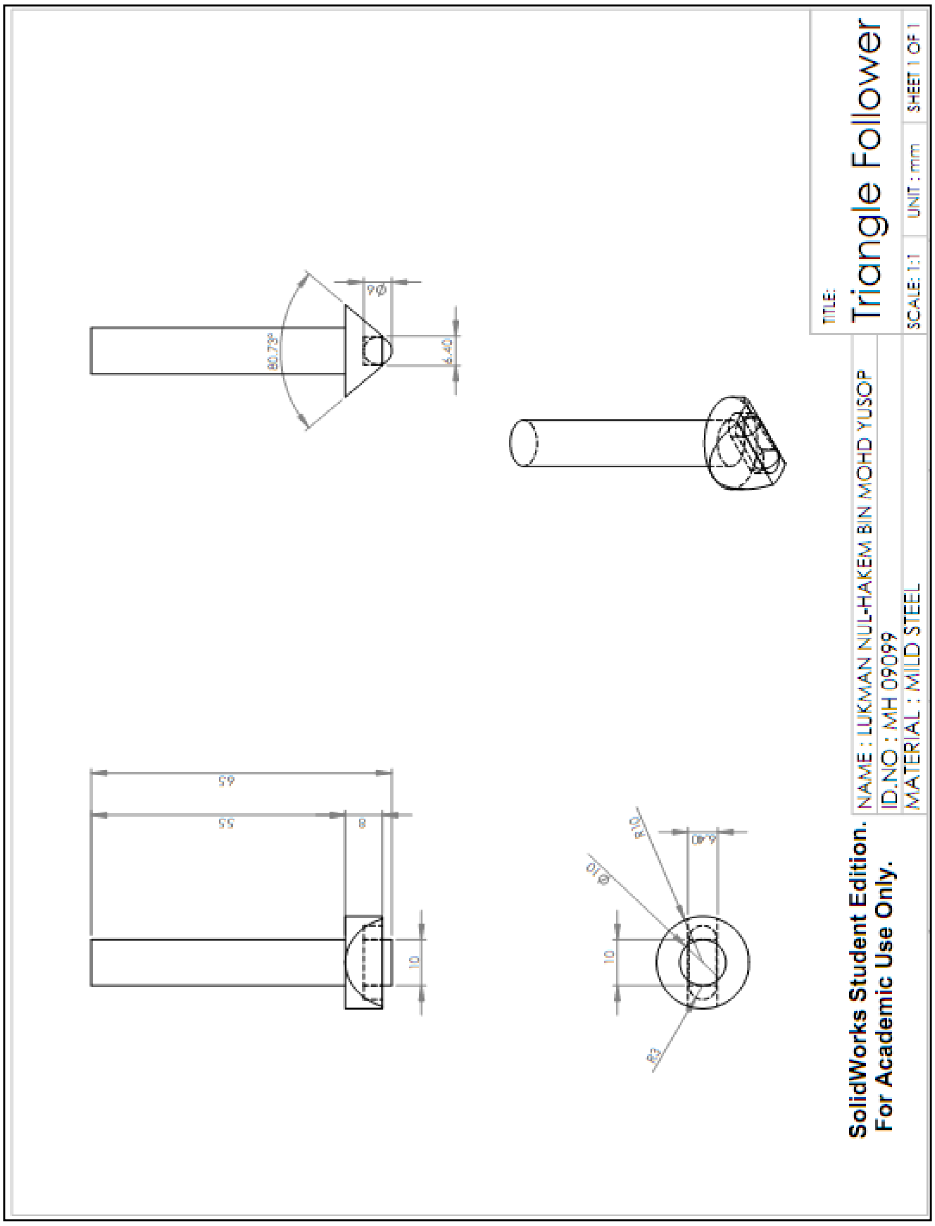
APPENDICES

APPENDIX A



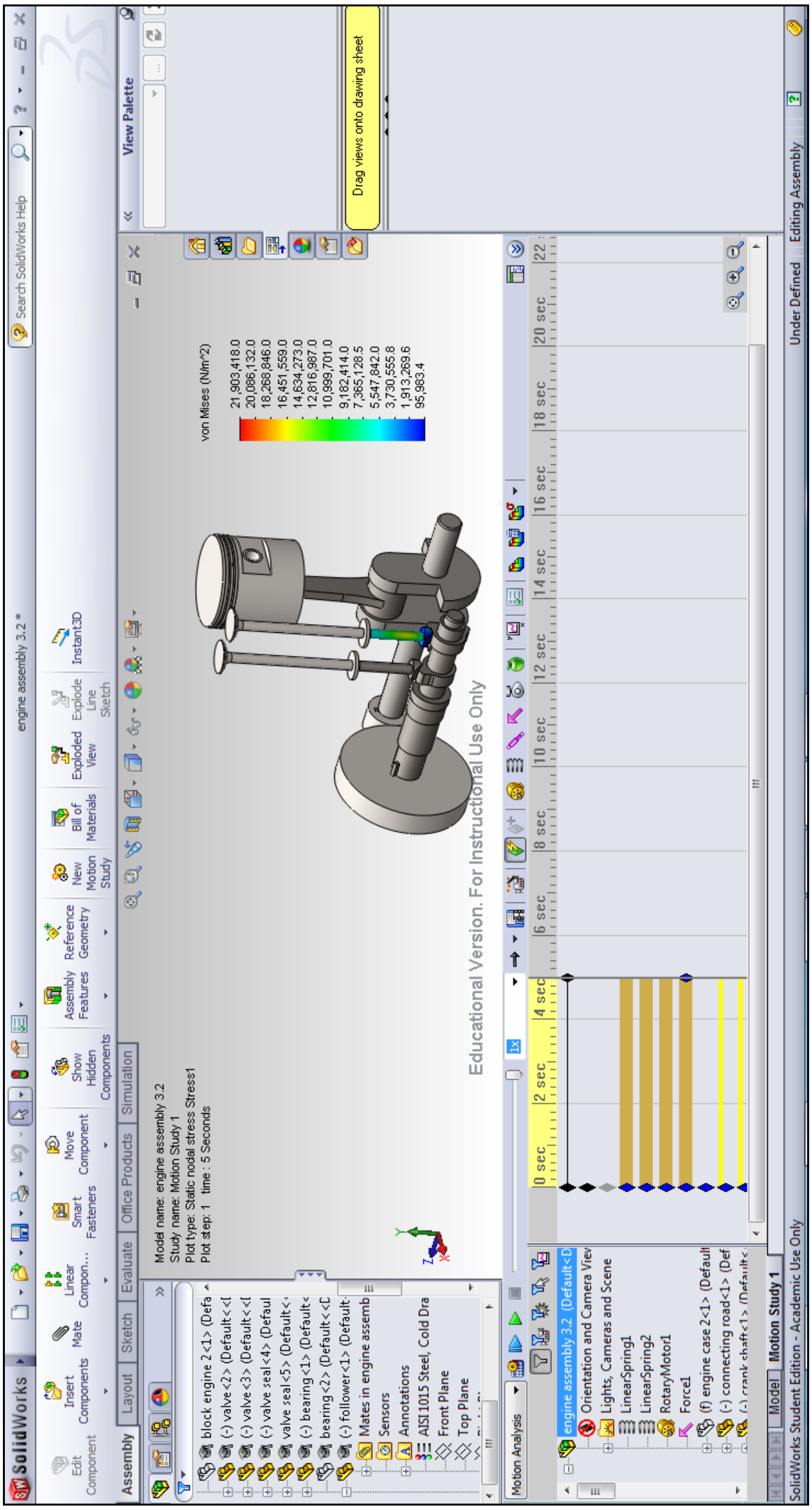
Six-Stroke Camshaft Technical Drawing

APPENDIX B



Triangle Follower Technical Drawing

APPENDIX C



Engine Simulation