CAMSHAFT DESIGN FOR A SIX-STROKE ENGINE

MOHD NURUNNAJMI BIN AMAT JANJI

Report submitted in partial fulfillment of the requirements
for the award of Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

JUNE 2012

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “Camshaft Design for A Six-stroke Engine” is written by Mohd Nurunnajmi Bin Amat Janji. 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.

MR. MOHD YUSOF BIN TAIB

Examiner | Signature

SUPERVISOR'S DECLARATION

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

Signature :

Name : DR. MAISARA MOHYELDIN GASIM

Position : SENIOR LECTURER

Date : 5th JUNE 2012

STUDENT'S DECLARATION

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

Signature :
Name : MOHD NURUNNAJMI BIN AMAT JANJI
MATRIC ID : MA09100
Date : 5th JUNE 2012

DEDICATION

I specially dedicate to my beloved parents
and those who have guided
and motivated me for this project

ACKNOWLEDGEMENT

First and foremost, the deepest sense of gratitude to the God, who guide and gave me the strength and ability to complete this final year project successfully. Infinite thanks I brace upon Him. I would like to express my sincere gratitude to my supervisor Dr. Maisara Mohyeldin Gasim for his continuous guidance, support and encouragement, which gave me huge inspiration in accomplishing this research. His practice of professional ethics and conducts which encourages me to become confident and competent person to work individually as well as in group with minimal supervision.

Besides that, I also took this opportunity to thank Mr.Asmizam who helped me in preparing the measurement equipments. He also very supportive in exploring the features and utilization of equipments. Other than that, Mr.Mohd Yusuf Taib, who reviewed and certified that my thesis is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. Not forgot to thank the panels who critics the outcome of this research besides providing some suggestions to improve the discussion and conclusion as well. I would also like to express my deepest appreciation to my parents whom always support and motivate me to complete this research and thesis. I also owe a depth of gratitude to my university friends who shared their knowledge and ideas that lead to the completion of this thesis.

Finally, to individuals who has involved neither directly nor indirectly in succession of this research with thesis writing. Indeed I could never adequately express my indebtedness to all of them. Hope all of them stay continue support me and give confidence in my efforts in future. Thank you.

ABSTRACT

An internal combustion engine generally utilizes a conventional four stroke process including an intake stroke, compression stroke, expansion stroke, and exhaust stroke and in addition to this four stroke process, adds a secondary process having two additional strikes for scavenging process employs a fresh air intake stroke and a fresh air exhaust stroke to exhaust any remaining burnt and unburnt gases from the combustion chamber. A six-stroke internal combustion engine with reciprocating pistons wherein the six strokes are the admission of air, the first compression accompanied or followed by a possible cooling, a second compression followed by a combustion, the first expansion producing also a usable work and finally the discharge of the combustion gases, this engine, whose combustion is either with gasoline version or diesel version will included preferably a multiple of five non-uniform cylinders, and will have an energy efficiency of up to 30% higher than that of a four-stroke internal combustion. This study was focused to fabricate the six-stroke engine camshaft by using the variety machining such as conventional lathe machine, milling machine and EDM wire cut. This also limited to the modelling of the camshaft using computer aided design (CAD) and computer aided manufacturing (CAM). At the end of the study, there have results and discussions about camshaft problem and measured stress that exert to the camshaft. Result are taken from the different material which is mild steel (AISI 1080) and stainless steel (AISI 202). Data showed that stainless steel is greater than mild steel as a conclusion.

ABSTRAK

Enjin pembakaran dalaman amnya menggunakan proses konvensional empat lejang termasuk strok pengambilan, lejang mampatan, lejang pengembangan dan lejang ekzos dan tambahan kepada proses empat lejang ini, menambah satu proses sekunder yang mempunyai dua proses tambahan untuk mengaut proses menggunakan pengambilan udara segarstrok dan ekzos udara segar lejang ekzos di mana-mana baki gas terbakar dan tak terbakar dari kebuk pembakaran. Sebuah enjin enam lejang pembakaran dalaman dengan omboh salingan di mana enam lejang adalah pengakuan udara, pemampatan pertama yang disertai atau diikuti dengan penyejukan yang mungkin, mampatan kedua diikuti oleh pembakaran, pengembangan pertama menghasilkan juga kerja yang boleh diguna dan akhirnya pelepasan gas pembakaran, enjin ini, yang pembakaran sama ada dengan versi petrol atau diesel versi termasuk sebaik-baiknya yang dibahagikan lima silinder tak seragam, dan akan mempunyai kecekapan tenaga sehingga 30% lebih tinggi daripada empat-lejang enjin pembakaran dalaman. Kajian ini telah memberi tumpuan untuk mmembuat camshaft enam lejang dengan menggunakan pelbagai mesin seperti mesin larik konvensional, mesin pengisar dan potong wayar EDM. Ini juga terhad kepada pemodelan camshaft dengan menggunakan rekabentuk bantuan komputer (CAD) dan pembuatan terbantu komputer (CAM). Pada akhir kajian ini, ada keputusan dan perbincangan mengenai masalah camshaft dan tekanan yang diukur . Keputusan yang diambil dari bahan yang berlainan yang merupakan keluli ringan (AISI 1080) dan keluli tahan karat (AISI 202). Data menunjukkan bahawa keluli tahan karat adalah lebih baik daripada keluli lembut sebagai kesimpulannya.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

The term six stroke engine describes two different approaches in the internal combustion engine, developed since the 1990s, to improve its efficiency and reduce emissions. In the first approach, the engine captures the waste heat from the four stroke Otto cycle or Diesel cycle and uses it to get an additional power and exhaust stroke of the piston in the same cylinder. Designs either use steam or air as the working fluid for the additional power stroke. 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 over the normal Otto or Diesel Cycle. The pistons in this six stroke engine go up and down six times for each injection of fuel. These six stroke engines have 2 power strokes: one by fuel, one by steam or air. The currently notable six stroke engine designs in this class are the Crower's six stroke engine, invented by Bruce Crower of the U.S.A; the Bajulaz engine by the Bajulaz S A company, of Switzerland; and the Velozeta’s Six-stroke engine built by the College of Engineering, at Trivandrum in India.

The second approach to the six stroke engine uses 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. Functionally, the second piston replaces the valve mechanism of a conventional engine and also it increases the compression ratio. The currently notable six stroke engine designs in this class include two designs developed independently: the Beare Head engine, invented by Australian farmer Malcolm Beare, and the German Charge pump, invented by Helmut Kottmann.

Thermal comfort of human being is highly associated with the environment and physical appearances of each individual. Measurement of thermal comfort must be given attention to give comfort for workers in industries. The factors of environment give the effect to the health, comfort and performance of the workers. The productivity will increase as the workers feel comfortable with working environment.

1.2 PROBLEM STATEMENT

Six stroke cylinders give a positive effect on the engine performance. In order to improve the efficiency, the camshaft of the engine must be modified and differ with four-stroke engine. In this study it focuses the cam lobe at the intake and exhaust flow.

1.3 OBJECTIVE OF STUDY

The objectives of this study are:

a) To design and analyze the camshaft that can be work with six-stroke engine.
b) To fabricate the camshaft by using CNC machine.

1.4 SCOPE OF STUDY

Basically the scope of the project is functioning as a guidance to achieve the objective. This study is limited to the modelling the camshaft of six-stroke engine using computer aided design codes (CAD). Thus for the fabrication, it will use the computer aided manufacturing (CAM) and work with CNC machine. After fabrication of the camshaft have been done, then analysis using FEA Algor used to analyze the stress on the camshaft.

1.5 STRUCTURE OF REPORT

This report is consists of five chapters. The first chapter is introduction about the research study. It includes the background of study, problem statement, objectives, scopes, and the structure of report.

Next chapter focuses on the literature review based on the previous studies of six-stroke engine. Besides that, this chapter includes the study on internal combustion engine that have been related to the engine, the stroke of the six-stroke engine and global warming up that reduced by using the six-stroke engine. So, this chapter has major influences to increase better understanding on this research study and is very helpful to design the methodology of study.

Chapter 3 describes the methodology of the measurement at selected materials. The flow chart of this research is presented with potential arising issues with the preventive action plans. The methods and procedures are described in general. The location of studies and details of subjects involved in this study are explained. Besides that, the details of instruments and machining used and the steps on utilization of the measurement devices are briefly described. Other than that, the data analysis method is also explained at the end of this chapter.

The results and discussions are presented in next chapter. The measured stresses of the camshaft included von mises stress, minimum principal direction stress, maximum principal direction stress and the best material must be chose. Finally, the outcome of this study was compared between mild steel (AISI 1080) and stainless steel (AISI 202).

The final chapter of this thesis consists of conclusion of this research study. The overall combustion engine been ascertained with some recommendation for improvements proposed.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, there were explanation about history of four strokes and six stroke engines included the basic of internal combustion engine. It also has the information about green technology that avoids the global warming up. Graph attached to give a model of illumination for both stroke.

2.2 INTERNAL COMBUSTION ENGINE

An engine is a device which can transforms one form of energy into another form. However, while transforming energy from one form to another, the efficiency of conversion plays a significant role. Normally, most of the engines convert thermal energy into mechanical work and therefore they are called heat engine.

Heat engine is a device which transforms the chemical energy of a fuel into thermal energy and utilizes the thermal energy to perform useful work. Thus, thermal energy is converted to mechanical energy in a heat engine. Heat engines can be classified into two categories which is internal combustion engines (IC engines) and external combustion engine (EC engines).

2.3 SIX-STROKE ENGINE

The six-stroke engine is a type of internal combustion engine based on the four-stroke engine, but with additional complexity intended to make it more efficient and reduce emissions. According to its mechanical design, the six-stroke engine with external and internal combustion and double flow is similar to the actual internal reciprocating combustion engine.

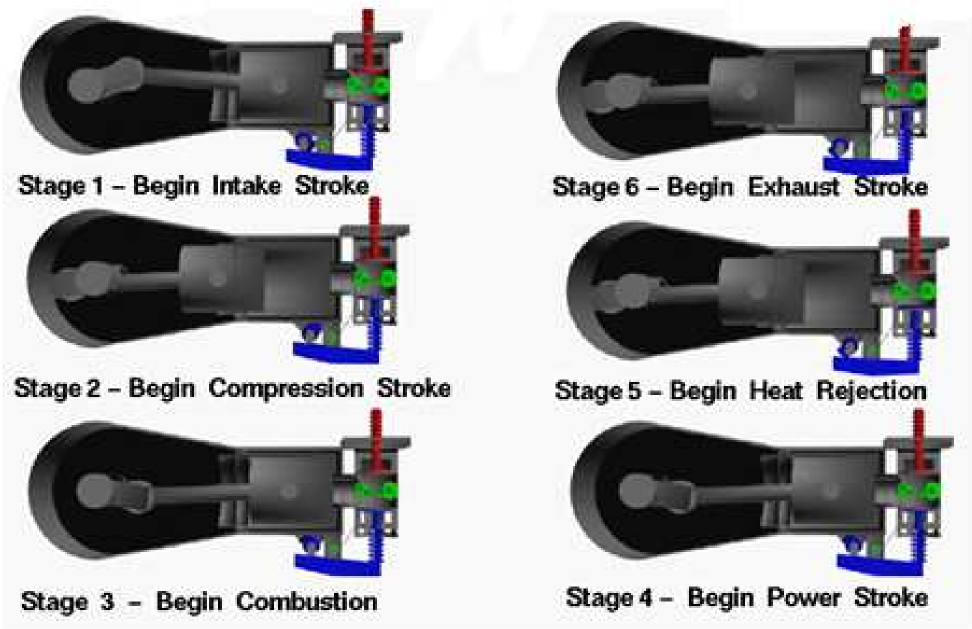


Figure 2.1: Six-stroke engine

Source: NASA

2.4 ADDITIONAL STROKE

To summarize in graphical form on Figure 2.3, there were representative valve lifts and resultant representative combustion chamber pressure traces are superimposed versus crank angle where the proposed exhaust recompression and water injection are explicitly shown.

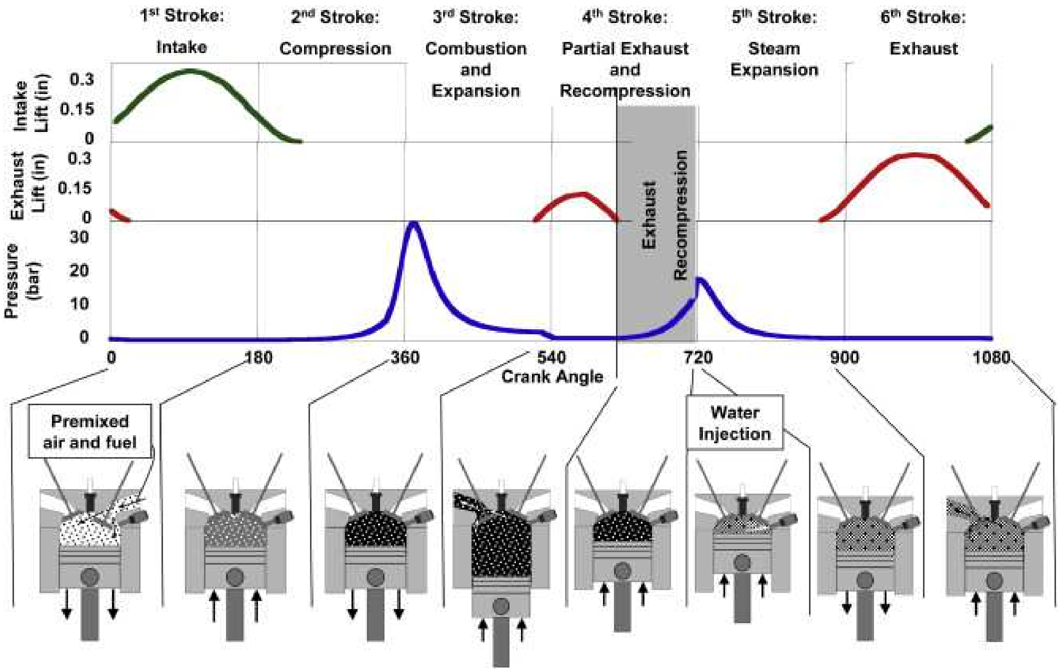


Figure 2.2: Example of exhaust valve events and cylinder pressure for the six-stroke cycle

Source: Hardenberg and Horst O. (1999)

2.4.1 Recompression

An additional assumption that the recompression process is isentropic from State 1 to State 2 yields the additional state property required by the State Postulate of Thermodynamics for a simple compressible system to determine completely the thermodynamic properties at State 2. The work required by the recompression process is thus known for a given crank angle closing.

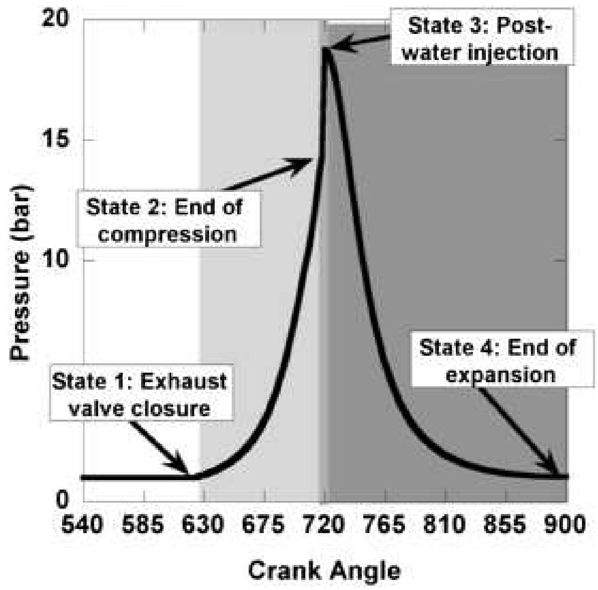


Figure 2.3: Pressure trace schematic for exhaust recompression and steam injection showing thermodynamic states

Source: Merriam-webster.com. (2010)

2.4.2 Water Injection

The identity of mass conservation was employed to equate the mass at State 3 to the mass at State 2 and the mass of the injected water. Now that the two properties of internal energy and specific volume are known at state point 3, the thermodynamic state is uniquely determined. Thus the temperature and pressure at the start of the additional power stroke are known.

2.4.3 Additional Power Stroke Expansion

Because there is no mass flow across the combustion chamber control volume during the expansion process and assuming that the recompression process is adiabatic. An additional assumption that the expansion process is isentropic from State 3 to State 4 yields the additional state property required by the State Postulate to determine completely the thermodynamic properties at State 4. The work output from the expansion process can be calculated.

2.4.4 Effect of the additional two strokes

The net work is the expansion work less the recompression work. The net mean effective pressure (MEP) of the early exhaust valve closure and water injection (the fourth and fifth strokes) is then determined by dividing the expansion work of the fifth stroke less the compression work of the fourth stroke by the displacement volume. Although having the units of pressure, the MEP is a measure of the performance of any engine irrespective of size or volumetric displacement. Condensation during an expansion is generally undesirable because of potential equipment damage due to droplet erosion and also because of the resultant decrease in specific volume. An increase in specific volume results in desirable expansion work.

2.5 SIX-STROKE ENGINE REDUCING GLOBAL WARMING UP

2.5.1 Global Warming

Global warming refers to the rising average temperature of Earth's atmosphere and oceans and its projected continuation. In the last 100 years, Earth's average surface temperature increased by about 0.8 °C with about two thirds of the increase occurring over just the last three decades. Warming of the climate system is unequivocal, and scientists are more than 90% certain most of it is caused by increasing concentrations of greenhouse gases produced by human activities such as deforestation and burning fossil fuel. These findings are recognized by the national science academies of all the major industrialized countries.

2.5.2 Six-stroke Prevents Global Warming

Researcher had state that with an innovative six-stroke engine, the engine shows 40% reduction in fuel consumption and dramatic reduction in pollution. Its specific power is not less than that of a four-stroke petrol engine. The engine can run on almost any fuel, petrol and diesel to LPG. An altered engine shows a 65% reduction in CO pollution when compared with the four stroke engine that was used to develop the Six-Stroke engine.

2.5.3 Six-Stroke Operating With Hydrogen

There are no prospects for engines using hydrogen as fuel to be put to practical use due to significant small output, knocking, and backfire. An object of the present invention is to obtain a stable automobile engine at high drive that can be commercially put to practical use. A hydrogen-only 6-stroke engine realizing high output by 6-strokes for premixing two to seven atmospheric pressure or high pressure hydrogen and air at equivalent weight, spraying the pre-mixture into a cylinder cooled by filling the cylinder with cold air in advance, spraying, compressing, and exploding the mixture, discharging the mixture from a lower exhaust hole, and discharging remaining waste gas from an upper exhaust hole is proposed.

A hydrogen-only 6-stroke engine for spraying oil or emulsion while charging with positive static electricity at high pressure by an injector spark plug arranged at an upper lid in a cold air suction stage of a first stroke, thereby adsorbing the oil or the emulsion to an in-cylinder wall and an auxiliary at the upper lid of negative pole.

A hydrogen-only 6-stroke engine including an injector spark plug having a function of an injector and a spark plug through a hole at an upper lid, in which a metal rod having a needle pin at a distal end is inserted to a hollow metal tube with a spray hole at a lower end, a fixture at an end of the metal rod is hit by soft iron tube that raises and lowers the hollow metal tube and the needle pin by the magnetism of a solenoid coil to raise and lower or open and close the needle pin, oil or emulsion injected at 50 to 100 atmospheric pressure from the upper part of the metal tube is sprayed into the cylinder, high voltage of an anode is applied through the upper part of the metal tube, and spark is generated by an instruction of an ECU.

2.6 MODIFICATION OF FOUR-STROKE TO SIX-STROKE ENGINES

There have some parts required modification such as camshaft, crank to camshaft ratio and water injection. A camshaft is a rod or shaft to which cams are attached. Cams are non circular wheels, which operate the cylinder valves of an internal combustion engine. The camshaft is also used to operate other gear-driven engine components. Camshaft design can determine whether the camshaft can help the engine produce heavy torque or higher RPMs. The cams on the camshaft operate the intake and exhaust valves of the engine.

The original angular speed of the camshaft is one-half that of the crankshaft, such that the camshaft rotates once for every two revolutions (or four strokes) of the crankshaft. The six stroke camshaft has been designed to turn one revolution every three revolutions (or six strokes) of the crankshaft. The six stroke design does not use the existing spur gears, but has straight tooth gears on all three shafts. The reduction ratio has been determined to be a 29-58 tooth pair of gears for a 1:2 reduction between the crankshaft and the reduction shaft and 20-30 tooth pair of gears for a 2:3 reduction between the reduction shaft and the camshaft. This gives an overall gear reduction of 1:3 between the crankshaft and the camshaft.

Integral to the design of the six stroke engine is the injection of water into the cylinder. Since the six stroke design does not include a camshaft, the water injection must be electronically controlled. The water injection system consists of three main components, the injector, the water pressurizing system, and the electronic control system.

2.7 CAMSHAFT PARTS

There have variety parts of the camshaft such as main journal, lobes, and ends. The Main Journals hold the cam in place as it spins around. Cam bearings are placed around the main journals to prevent the cam from damaging the block in case of malfunction in the engine.

The lobes create the cam's lift and duration. Lift is the distance the valve is open and duration is how long the valve will stay open. An example would be cams have a .429 intake lift and a .438 exhaust lift and duration of 203 degrees on the intake and 212 degrees on the exhaust. The intake valve would be lifted .429" and stay open for 203 degrees of the cams rotation and the exhaust would be lifted .438" and stay open for 212 degrees of the cams rotation. The rear end of the cam has a gear that turns the distributor of the engine keeping the ignition timing in tune with the rest of the engine, while the front of the cam bolts up the timing chain keeping the cam timed with the crankshaft.

The four-stroke process that occurs in car's engine is as follows: intake, compression, power, exhaust. While the crankshaft's position, crankshaft's stroke and rod length ultimately determine where the piston will be in the cylinder at any given degree of rotation, it's the camshaft that determines the position of the intake and exhaust valve during all four strokes. An engine's camshaft is responsible for the valve timing in the engine. Proper valve timing is critical for any four-stroke automotive engine to operate at maximum efficiency. When the valves open, how high the valves open (lift), and for how long they stay open (duration) all determine the performance characteristics of the engine. In the performance symphony, the camshaft is the conductor of valve events. It orchestrates which instruments play (intake or exhaust valves), when they play (opening and closing events) and how loud they play (valve lift).

For every action, there is always a reaction. From a performance standpoint, the faster a valve opens and reaches full-lift, the better. Why? Horsepower is directly related to how much air and fuel can be stuffed into the cylinder. Air and fuel can't get into the cylinder unless the valves are open. Camshafts that quickly open the valves are said to have an aggressive lobe profile. Unfortunately, the laws of physics govern the maximum amount of possible valve acceleration or "aggressiveness." If the camshaft profile tries to accelerate the valve too fast, excessive wear or valve train problems can occur. When returning a valve to its seat, a camshaft once again cannot do this too fast or the valve slams into the valve seat (sometimes valves even bounce off the seat). Most modern cam designs optimize valve acceleration rates by designing camshafts with asymmetric lobes.

2.8 CLASSIFICATION OF CAM MECHANISM

We can classify cam mechanisms by the modes of input/output motion, the configuration and arrangement of the follower, and the shape of the cam. We can also classify cams by the different types of motion events of the follower and by means of a great variety of the motion characteristics of the cam profile. The classification of cam mechanism is based on the figure:

i. Knife-edge follower (Figure 2.4a).
ii. Roller follower (Figure 2.4b,e,f).
iii. Flat-faced follower (Figure 2.4c).
iv. Oblique flat-faced follower.
v. Spherical-faced follower (Figure 2.4d).

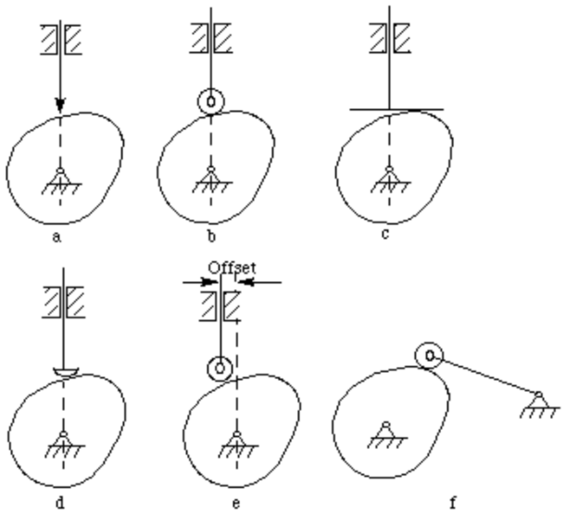


Figure 2.4: Classification of Cam Mechanism

Source: Hunt K.H (1971)

2.9 CAM SHAPE

There have variety of cam shape such as plate cam, grooved cam and end cam. The concept of the plate cam is the follower moves in a plane perpendicular to the axis of rotation of the camshaft. A translating or a swing arm follower must be constrained to maintain contact with the cam profile. This is a plate cam with the follower riding in a groove in the face of the cam according to the figure 2.5. End cam has a rotating portion of a cylinder. The follower translates or oscillates, whereas the cam usually rotates. The end cam is rarely used because of the cost and the difficulty in cutting its contour. The cams of the cam shaft are placed considering the following:

i. Sequence of the power strokes.
ii. Timing at which the valve should open in relation to the piston position.
iii. Timing at which the exhaust valve should open in relation with the timing of opening of inlet valve.
iv. Timing at which the other cylinder should start working.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The camshaft is the most crucial part of an internal combustion engine. Its main function is to control the valve timing, thereby allowing the intake valve to open at the right time for feeding air and fuel mixture into the engine. Camshafts are basically the lobes, which are fitted in the engine of a vehicle for giving the exhaust enough time to escape out of the combustion space. Automobile uses two basic types of camshafts namely flat tappet shaft and roller tappet shaft. The other types of camshafts are race camshaft, overhead camshaft, double overhead camshaft, exhaust camshaft, and intake camshaft. The camshafts installed in automobiles are mostly constructed of modular cast iron and are induction hardened for preventing wear and tear. Other materials used for making camshafts are steel, stainless steel, copper, bronze, and brass. The different types of auto parts of camshaft include camshaft locking plates, camshaft bearing and more.

3.2 DESIGN AND MANUFACTURE OF CAMSHAFT

Design is the process by which the needs of the customer or the marketplace are transformed into a product satisfying these needs. Design is to formulate a plan for the satisfaction of a specified need and also to solve a problem. If the plan results in the creation of something having a physical reality, the product must be functional, safe reliable, competitive, manufacturability, and marketable (Shigley and Mischke, 2003).

3.3 DESIGN OF CAM PROFILE

Design of the cam profile is very crucial and it is designed on the basis of the following.

a) The distance the valve should move towards the piston.
b) The time for which the valve should remain open.
c) After the valve stays open it should take the same time for closing which it had taken while closing.

The dual lobe is used instead of the single lobe as the valve should be operated two times in one cycle. The second lobe on the cam is placed at 120º degrees from the original lobe in the direction of rotation of the camshaft.

3.3.1 Four-stroke Camshaft Profile

Figure 3.1 describe the four-stroke camshaft has a 90 degree of angle. It means the circle was divided by four thus the cam of camshaft just included there. The camshaft has two lobes, one for the intake valve and one for the exhaust valve.

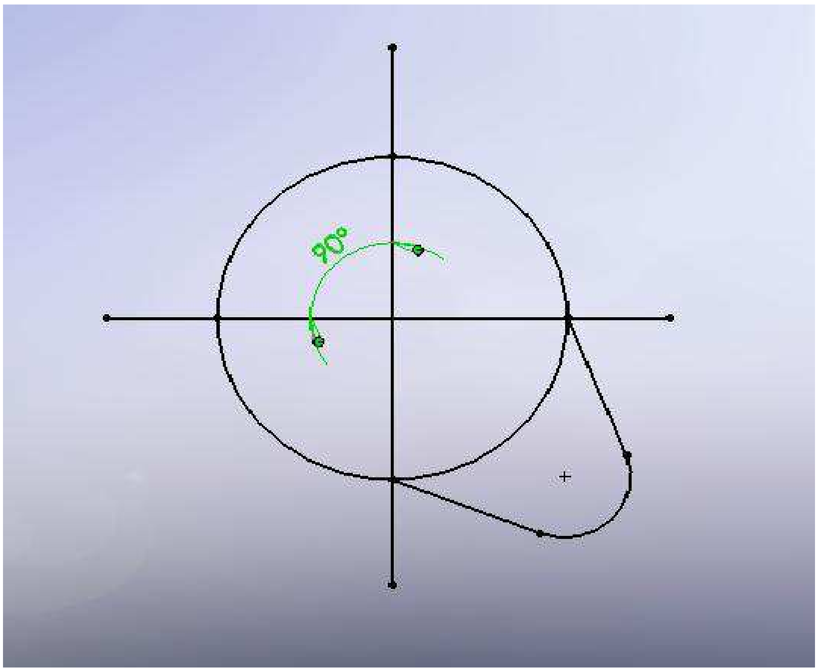


Figure 3.1: Angle of 4-stroke camshaft

The camshaft is shown in Figure 3.2. Each lobe is in contact with a flat follower pushrod which moves a rocker arm inside of the head. The other side of the rocker arms pushes the valve inside of the cylinder. A valve spring returns the valve back to the original position.

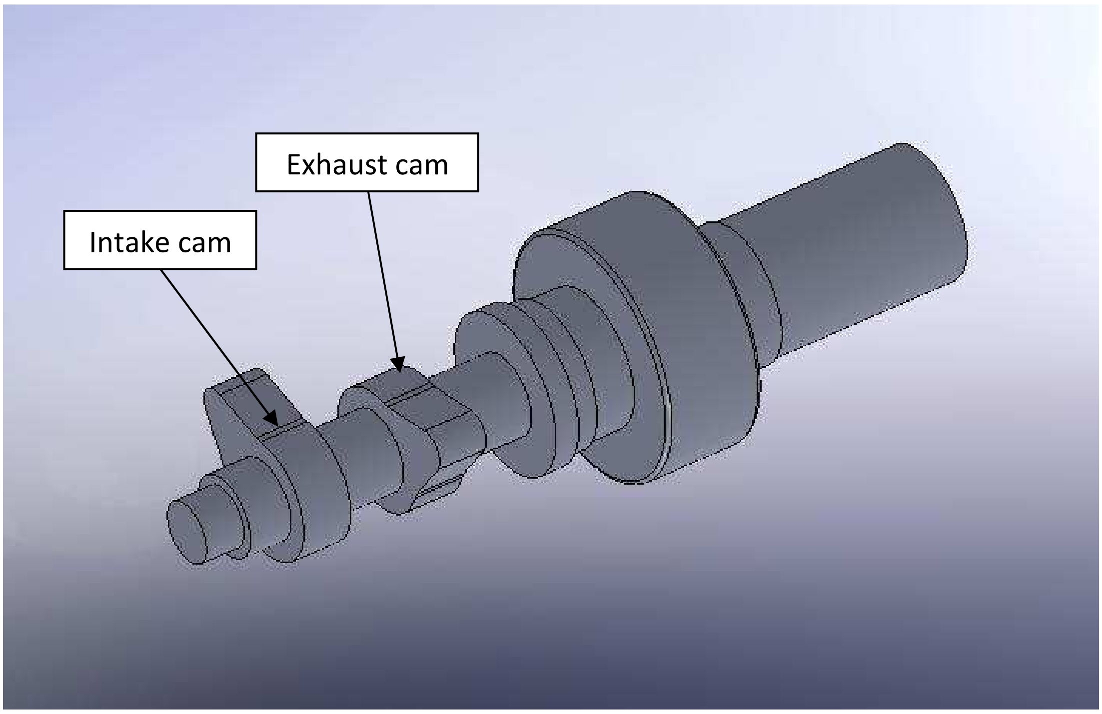


Figure 3.2: Design of four-stroke camshaft

To properly replicate the original four strokes in the new six stroke engine, the original camshaft has been reverse engineered to determine the proper valve lift profile, shown in Figure 3.3. This profile shows the valves' lift at any angular position of the crankshaft. This has been found by attaching a wheel to the crankshaft with laser cut notches at every angle. At every five degree rotation of the crankshaft, the intake and exhaust valves' lift has been recorded. These findings have been used to determine the necessary valve lift in the six stroke valve control system design

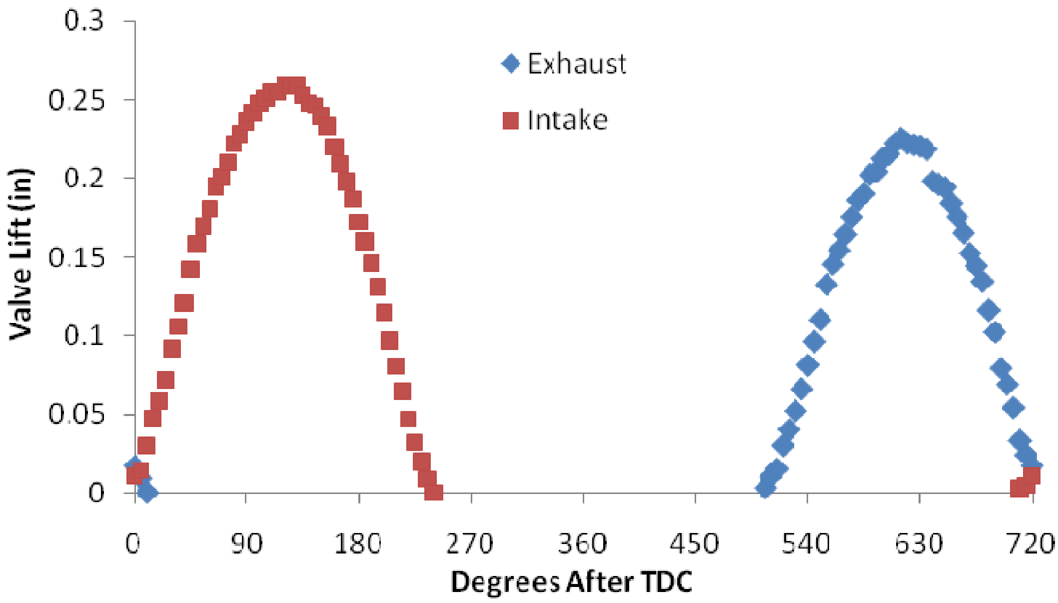


Figure 3.3: The original valve lift profile

Source: Marc Eberlein (1998)

3.3.2 Six-Stroke Camshaft Profile

Figure 3.4 describe the six-stroke camshaft has a 60 degree of angle. It means the circle was divided by six thus the cam of camshaft just included there.

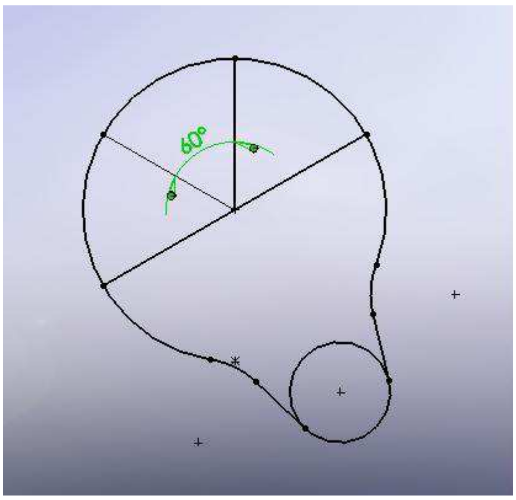


Figure 3.4: Angle of 6-stroke camshaft

A new camshaft and gearing system has been designed for the six stroke engine. As discussed previously, the original camshaft is geared to turn one revelation every two revolutions of the crankshaft. The six stroke camshaft has been designed to turn one revolution every three revolutions of the crankshaft. Being a pushrod engine, the camshaft is geared directly to the crankshaft. This makes it impossible to change the number of teeth on each shaft to achieve the correct speed due to size constraints. Because of this, the design calls for a third shaft to be installed and a double reduction gearing system to be used. This new gear reduction system is compared to the original system as shown in Figure 3.5.

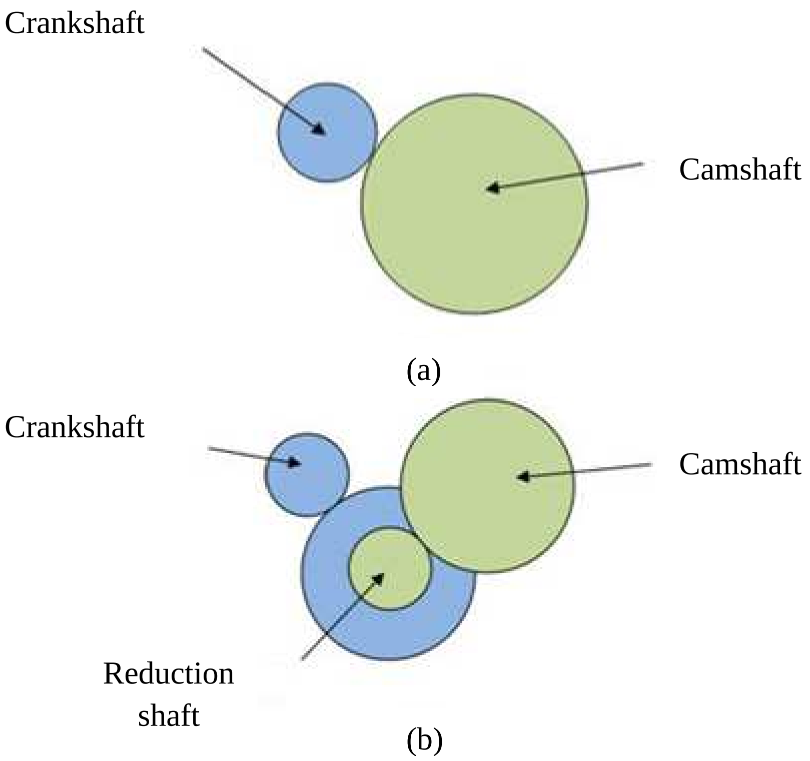


Figure 3.5: (a) The original gear reduction, and (b) the new gear reduction

Source: Calvin College (May 12, 2010)

The six stroke design does not use the existing spur gears, but has straight tooth gears on all three shafts. The reduction ratio has been determined to be a 29-58 tooth pair of gears for a 1:2 reduction between the crankshaft and the reduction shaft and 20-30 tooth pair of gears for a 2:3 reduction between the reduction shaft and the camshaft. This gives an overall gear reduction of 1:3 between the crankshaft and the camshaft.

The idler gear design causes the camshaft to rotate in the opposite direction of the original camshaft. This issue has been addressed by the six stroke camshaft design. The six stroke design has the lobes on the cams 2/3 the size of, and at opposite angles of the four stroke cams.

3.4 CAMSHAFT DRAWING

The exhaust cam has been designed to have two lobes, one for each exhaust stroke. The first exhaust lobe opens the exhaust valve to release the combustion products and the second lobe opens the exhaust valve to release the water expansion products. The shaft has been extended to allow room for a cam for the injector. The cam design has been drawn in AutoCAD and SolidWorks Cam. The model of the six stroke cam is shown in Figure 3.6.

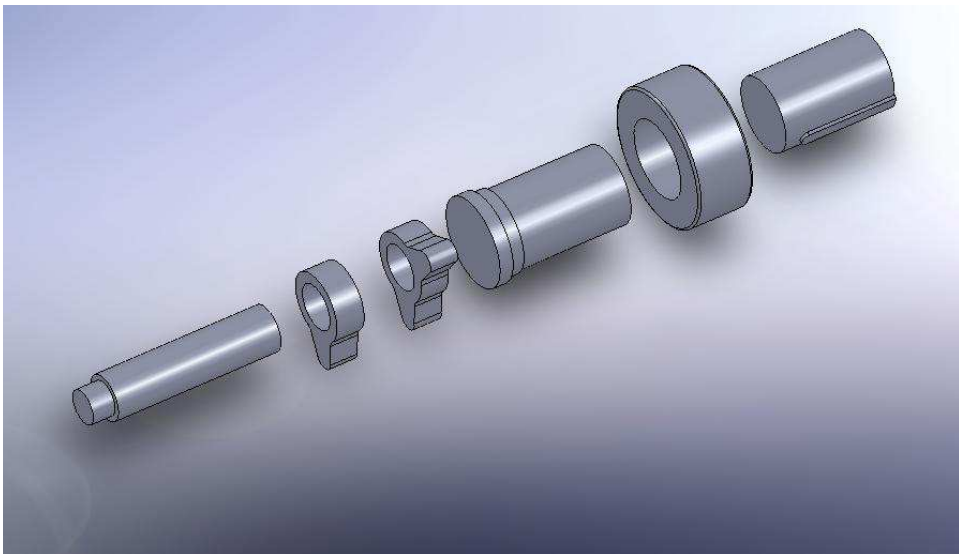


Figure 3.6: Exploded view

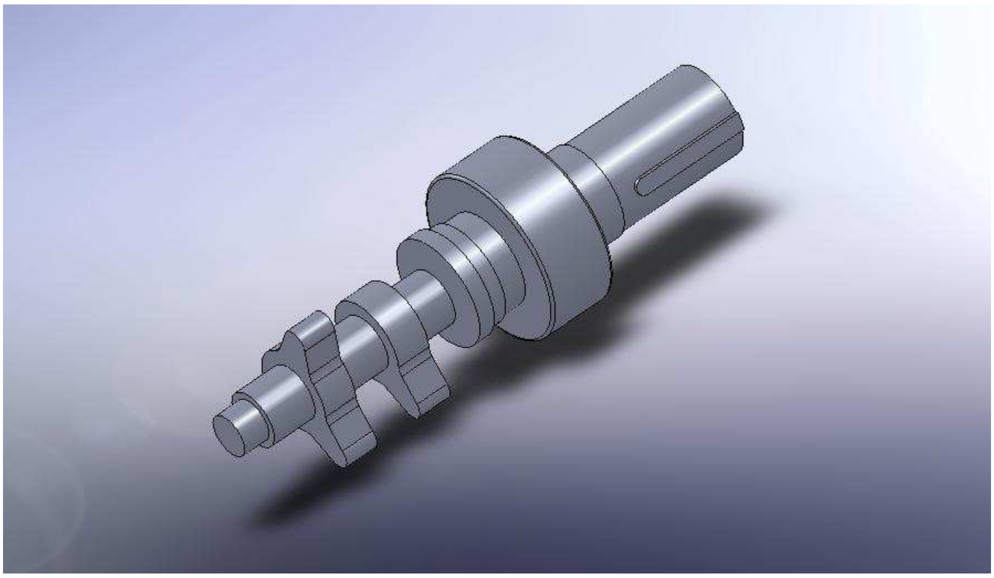


Figure 3.7: Full assembly

For this project, there are only one design options that have been considered for camshaft fabrication. The only one design calls a machining process. It aims to get the experience of making a camshaft and fulfil the needs of this project. Thus, this saves money and allows for several attempts at achieving the correct timing. In this design, a steel shaft is used as the base and machined down to fit the existing bearings in the crankcase.

3.5 RAW MATERIAL

Due to fabricate display camshaft, the raw material used for this project is low carbon steel. The steel chose due the characteristics of the steel such as good formability and weldability, low strength, low cost. For these projects materials, camshaft needs:

i. 1 unit of round bar steel and
ii. 3 units of flat bar steel.

The sizing of round bar steel is 55mm diameter and 250mm height (Figure 3.8). For the sizing of flat bar steel is 50mm x 50mm x 18mm (Figure 3.9).

Figure 3.8: Round bar steel

Figure 3.9: Flat bar steel

3.6 FABRICATION

There are explanation about three different machine used in fabrication of the six-stroke engine camshaft which is lathe machine, milling machine and EDM wire cut.

3.6.1 Lathe Machine Procedures

i. Cleaning - The first and last procedure in any machining operation. Without clean equipment and tools, the accuracy of the finished product diminishes quickly.

ii. Holding the work piece - There are several types of holding devices used on the engine lathe. There are three-jaw chuck and four-jaw chuck.

iii. Tooling - Tools must be clamped securely to the tool post regardless of what type of tool is being used. The tools must be adjusted so that their cutting edge is at the height of the exact centre of the work piece.

iv. Machine Controls - Many factors must be considered when determining the correct speed, (RPM), and feed rates. Some of these are:

  a. Type of material being machined.
  b. Desired finish to the work piece.
  c. Condition of the lathe.
  d. Rigidity of the work piece.
  e. Smaller diameters are less rigid.
  f. Shape and size of the work piece.
  g. Size and type of tooling being used.

3.6.2 Milling Machine Procedures

There are some general procedures that must be followed when using the conventional milling machine. Some of these are:

i. Before setting up a job, be sure that the work piece, table, the taper in the spindle and the arbour or cutter shank are free from chips, nicks, or burrs.
ii. Do not select a milling cutter of larger diameter than is necessary.
iii. Check the machine to see if it is in good running order and properly lubricated, and that it moves freely, but not too freely in all directions.
iv. Consider direction of rotation. Many cutters can be reversed on the arbour, so be sure you know whether the spindle is to rotate clockwise or counter clockwise.
v. Feed the work piece in a direction opposite the rotation of the milling cutter (conventional milling).
vi. Do not change feeds or speeds while the milling machine is in operation.
vii. When using clamps to secure a work piece, be sure that they are tight and that the piece is held so it will not spring or vibrate under cut.
viii. Use recommended cutting oil liberally.
ix. Use good judgment and common sense in planning every job, and profit from previous mistakes.
x. Set up every job as close to the milling machine spindle as circumstances will permit.

3.6.3 EDM Wire Cut Procedures

The process of EDM has many benefits since the work piece and electrode never touch, no cutting forces are generated this makes EDM will suited to produce fragile parts that cannot take the stress of conventional machining, burr free edges, intricate details, superior surfaces.

The EDM process also has its limitations. The metal removal rates are low compared to conventional metal cutting processes. Complex materials require lead-time for fabrication and are consumable while cutting and the work piece materials must be conductive.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter's objective is to illustrate the result of the camshaft fabrication. Process showed application of the CAD and CAM software that significant to the shaft and cams draft. Besides that, the machining process with application few of machining such as lathe machine, milling machine and CNC wire cut were indicated into this chapter. A little calculation used to setting the RPM of the machine. Then, the stress analysis is used using FEA Algor software. Consequently, a large part of this project will be thoroughly documenting all the calculations and modifications. All of the progress and processes will be discussed and made public.

4.2 RESULT OF CAMSHAFT DESIGN MODIFICATION

Camshaft is design according a few of characteristics. In this design, a steel shaft is used as the base and machined down to fit the existing bearings in the crankcase. The lobes have been designed in Autodesk Solid Work to be cut from steel slightly oversized and ground down for more accuracy. The cams are then assemble with the shaft and make a hole through the shaft and cam. Thus, a pin used to fix the cam onto the shaft at the proper angle. The gear is placed on the shaft and uses a key to lock it into position with a pair of setscrews to secure it. This allows for easy removal and modification.

There are 3 different cams developed which is intake cam, exhaust cam and water injection cam. Figure 4.1, 4.2, 4.3 illustrate the cam drawing.

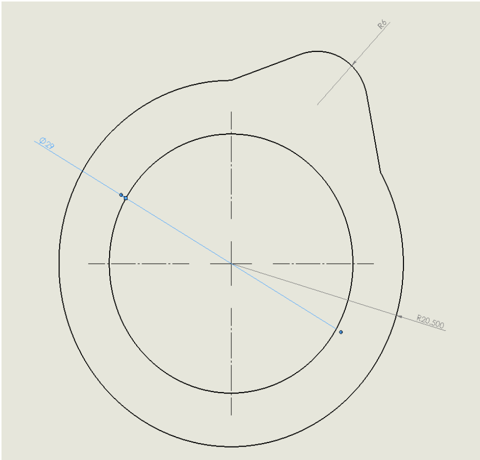


Figure 4.1: Intake cam

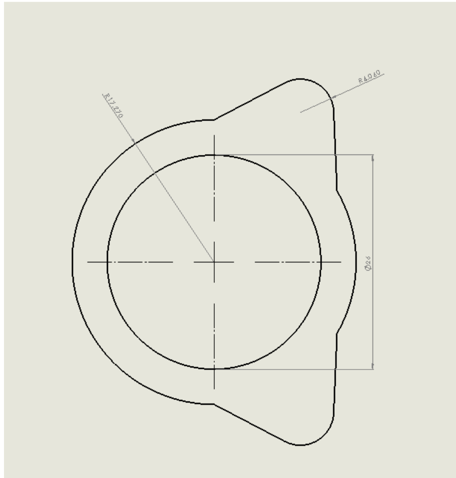


Figure 4.2: Exhaust cam

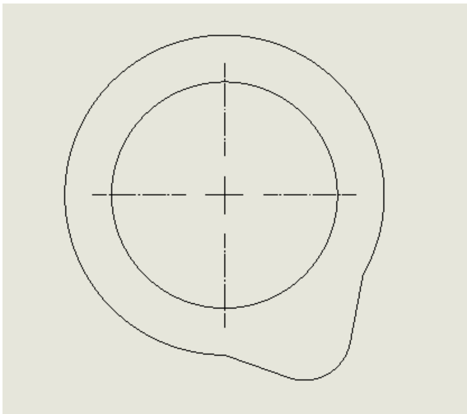


Figure 4.3: Water injection cam

4.2.1 Cam Fabrication

Cam fabrication started with 50mm x 50mm x 18mm flat bar steel. Based on drawing, the size of flat bar must be higher than the size of the cam. The thickness of the cam is 14mm but the thickness of the flat bar is 18mm. That's why the flat bar need to be grind on the surface to decrease the thickness thus get the smooth surface. For this process, milling machine is chose to help the work piece get right thickness.

4.2.2 Milling Machine

Before we can begin to start making chips on the milling machine, the work piece must somehow be securely fastened to the machine table. On most jobs that require milling, setting up the work piece is the most difficult part of the job. Setups require critical thinking because not only does that part have to be fastened to the table, but the part must be positioned so that the proper surfaces can be machine using the correct features of the work piece for positioning. If the setup is not properly planned and the accuracy is not insured in the setup, the part will probably end up as scrap.

For this process, work piece need to:

- Surface grinding (allow reduce thickness and get smooth surface)
- Four square (Important to the next process – clamped into CNC)

Figure 4.13 shows how milling machine work to grind the surface of the work piece. The RPM calculation of the milling machine is just similar with the lathe machine.

Figure 4.4: Milling machine work

Three unit of the flat bar which is used to get machining is the intake cam, exhaust cam and water injection cam.

4.2.3 EDM Wire Cut

Wire EDM machining (Electrical Discharge Machining) is an electro thermal production process in which a thin single-strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through work piece to get the shape of the cam. Before enter the wire cut, drawing of the cam converted from CAD into CAM. This is practically significant to EDM read the drawing.
Three type of flat bar which is two similar thicknesses and one is different:

i. Intake and exhaust cam (14mm thickness)
ii. Water Injection cam (10mm thickness)

Work piece clamped into the clamper. It is very important to make sure the work piece is four square due to the coding of EDM. The most important is the balancing of the work piece surface. The amount of clamping pressure required to hold small, thin and fragile parts is minimal, preventing damage or distortion to the work piece.

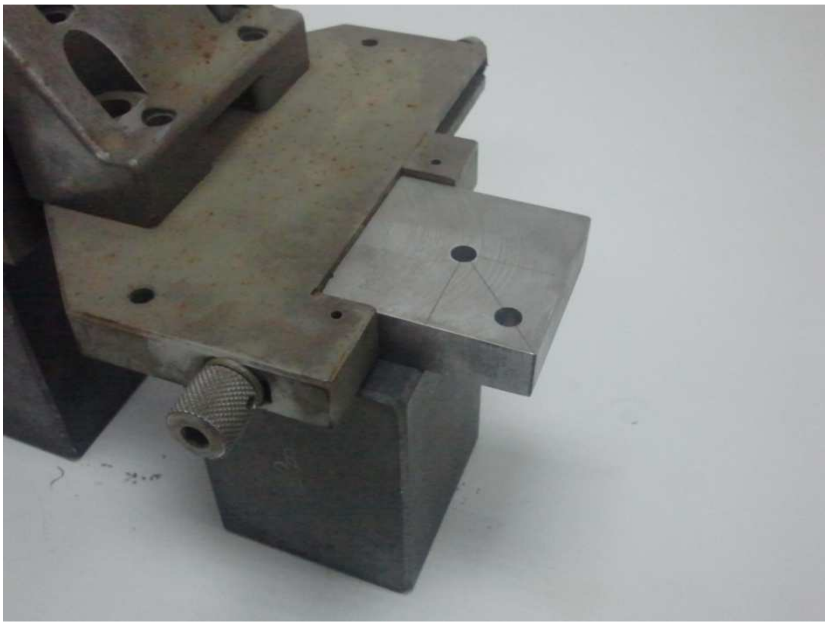
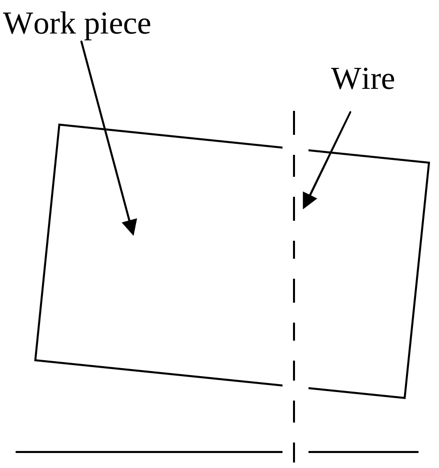


Figure 4.5: Work piece clamper



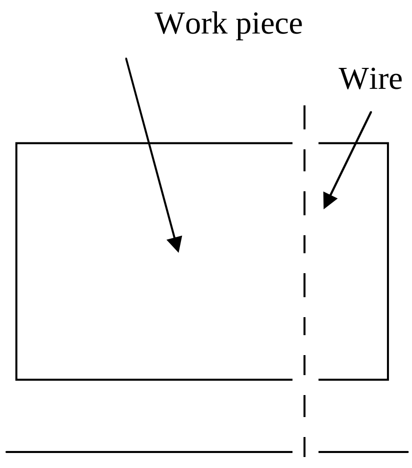


Figure 4.6: Non-straight condition **Figure 4.7:** Straight condition

Based on figure 4.17 and 4.18, there are two ways how the wire cutting the part. First is making a hole inside the part with started at the centre point. Another way is cut out on the outside of the part. But before the wire can cut the part, it is important to make two small holes at the part using 5mm diameter drilling. The main purpose is to justify the wire pass through into the hole before EDM programming itself to find the centre point of the small hole.

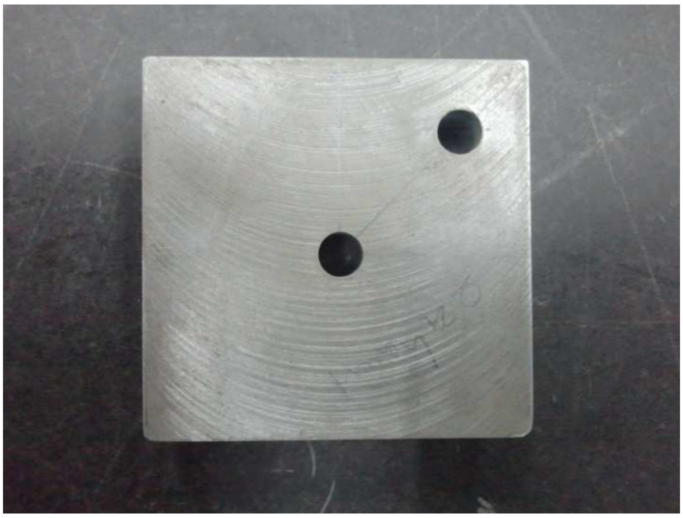


Figure 4.8: Two small holes

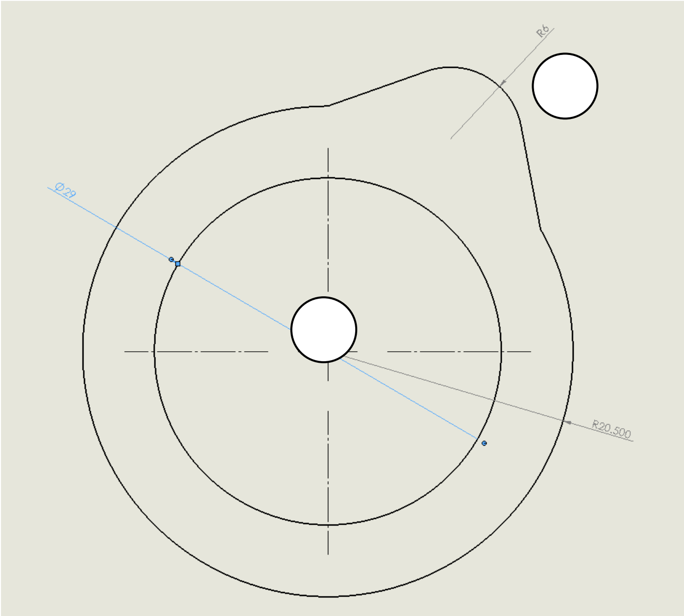


Figure 4.9: Two holes for inside and outside cam

4.3 SHAFT MACHINING

The lathe machine is the main role to develop the shaft. Diameter of the steel reduced little by little from the existing 55 mm until the maximum diameter of the shaft 50 mm followed by the design drawing. For the conventional machine, automatic mode was chose to make the smooth surface with constant speed.

There are rules and principles of cutting speeds and R.P.M. calculations that apply to all metal cutting operations. The operating speed for all metal cutting operations is based on the cutting tool material and the hardness of the material to be cut. The RPM setting depends on the cutting speed and the diameter of the part.

The RPM setting will change with the diameter of the part. As the diameter of the part gets smaller, the RPM must increase to maintain the recommended surface footage. A larger wheel (part) will need to turn fewer revolutions per minute to cover the same distance in the same amount of time than a smaller wheel (part). Therefore, to maintain the recommended cutting speed, larger diameter parts must be run at slower speeds than a smaller diameter part.

The lathe must be set so that the part will be operating at the proper surface speed. Spindle speed settings on the lathe are done in RPMs.

To calculate the proper RPM for the tool and the work piece, we must use the following formula:

$$\frac{\text{Cutting speed (CS)} \times 4}{\text{Diameter of part (D)}}$$

A cut is to be made with a high-speed steel (HSS) tool on a 2-inch diameter piece of 1018 steel with a brinnel hardness of 200. Calculate the RPM setting to perform this cut.

Cutting Speed = 100 (fpm)

Diameter of part = 2.0

$$\text{RPM} = \frac{\text{CS} \times 4}{\text{D}} = \frac{100 \times 4}{2} = \frac{400}{2} = 200\text{RPM}$$

4.4 FINAL PRODUCTS

Most work pieces come off the machine as a finished part, without the need for secondary operations. It's a one-step process. The edges of the finished cams will have virtually no burrs.

Figure 4.10: Exhaust cam

Figure 4.11: Intake cam

4.5 ASSEMBLY

Assemble mean the combination between cams and shaft together to get both parts fix to another. For the real manufacturing, there are no assemblies for camshaft development due to the machining that make a cams and shaft with one process (CNC machining). It is difference with this thesis that developed cams and shaft with difference machine.

Figure 4.12: Final product six-stroke engine camshaft

4.6 PROBLEM ANALYSIS

There have a problem in milling machine. It focused at the clamper. It is very difficult to clamp the work piece because some time the surface of the work piece is not balance. After doing the surface balancing, when we tight the clamper, clamper will give much pressure at the work piece until the height of one side work piece will be not same with another side. These can affect the height of work piece when doing machining. It shows that milling machine have problem at the clamper.

There also have some problems when doing machining at the EDM wire cut. Firstly at the most time the EDM cannot read the drawing after CAD converted to the CAM. The effect is the system can't show the coding and the programming stuck. After that, EDM wire cut known as slow rate of material removal. EDM's panel shows it progress to feed 1minute for 1mm work piece. Then, another issue is reproducing sharp corners on the work piece is difficult due to electrode wear.

4.7 STRESS ANALYSIS ON CAMSHAFT

4.7.1 Stress Von Mises

Figure 4.13 shows the result of Von Mises stress that has been analyzed by using the FEA Algor software. In this project, there have two different materials used which is Mild Steel (AISI 1080) and Stainless Steel (AISI 202). The von Mises stress is used to predict yielding of both materials under valve loading condition that exert the cams. In this case, a camshaft is said to start yielding when its von Mises stress reaches a critical value known as the yield strength. Loads that have been put on the cams are 101.3N for both intake and water injection cams and 390N for exhaust cam.

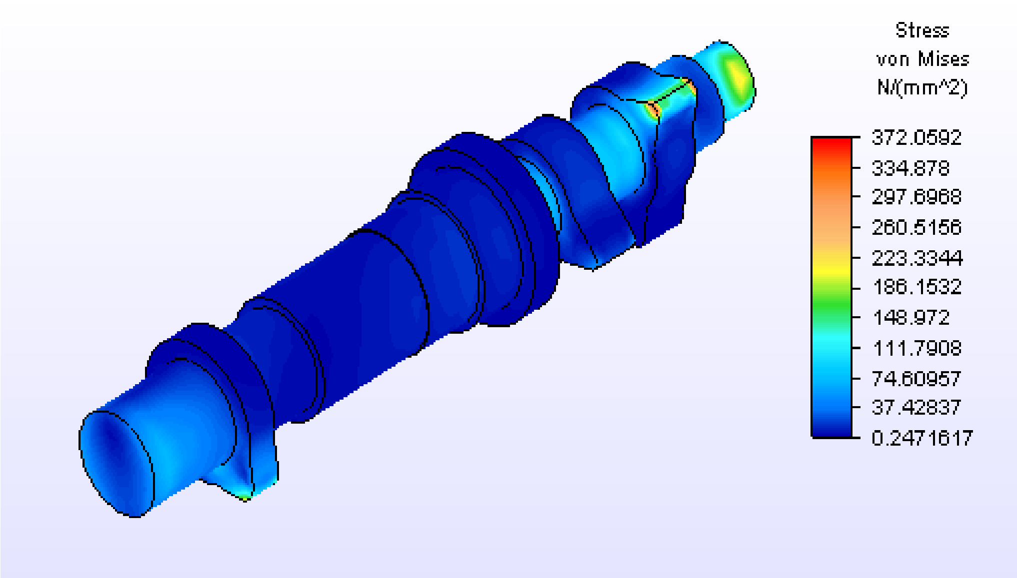


Figure 4.13: Stress Von Mises

Table 4.1 shows the value of von Mises stress for both Mild Steel (AISI 1080) and Stainless Steel (AISI 202). The table illustrate that the minimum stress value for AISI 1080 is 0.2462 N/mm^2 and the maximum stress value is 369.0072 N/mm^2 . For AISI 202, the material is said to be yield when the maximum stress value occurred which is 372.0592 N/mm^2 exerted to the cam. By the way, the minimum stress value is 0.2471 N/mm^2. It concluded that the AISI 202 have higher value for the maximum stress which mean the strength of the material is greater than AISI 1080. It also proved with the minimum value of the stress for the AISI 1080 is lower than AISI 202.

Table 4.1: Different Von Mises stress between AISI 1080 and AISI 202

Stress (N/mm^2)	
Mild Steel (AISI 1080)	Stainless Steel (AISI 202)
0.2462	0.2471
37.1223	37.4284
73.9984	74.6096
110.8745	111.7908
147.7506	148.972
184.6267	186.972
221.5028	223.3344
258.3789	260.5156
295.255	297.6968
332.1311	334.878
369.0072	372.0592

4.7.2 Stress Minimum Principal Direction

Figure 4.14 shows the result of Stress Minimum Principal Direction. According to the camshaft elasticity, an infinitesimal volume of material at an arbitrary point or inside the solid camshaft can rotate so that only normal stresses remain and all shear stresses are zero. In this case, principal direction stress is the direction of the normal vector when the normal vector of a camshaft surface and the stress vector acting on that surface are collinear.

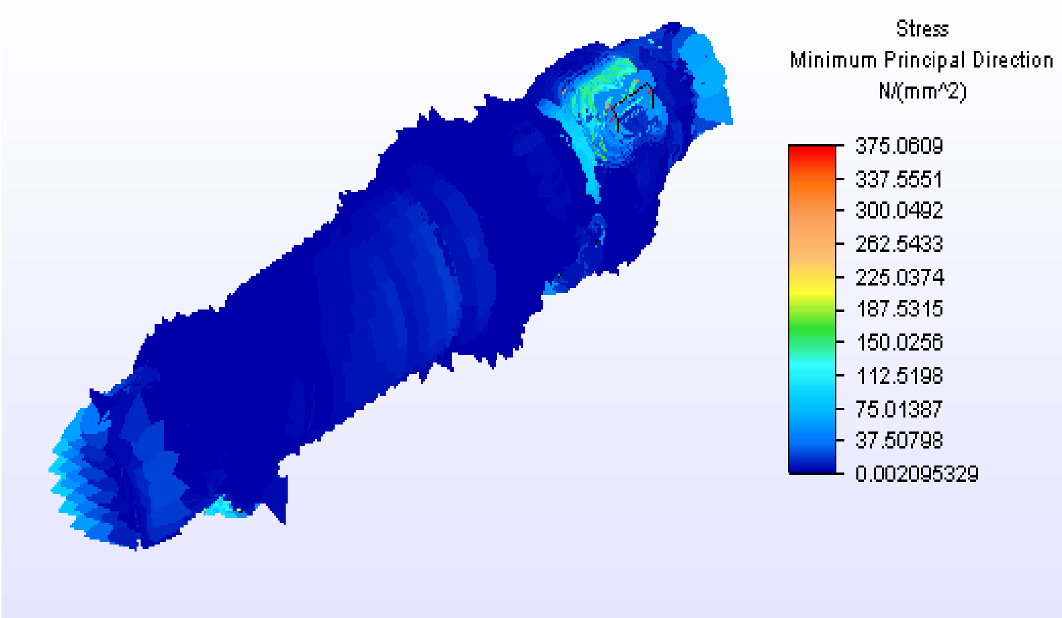


Figure 4.14: Stress Minimum Principal Direction

Table 4.2 illustrate the value of minimum principal direction stress is differ between mild steel (AISI 1080) and stainless steel (AISI 202). Normally, both of the data is increase abruptly with a rather similar value but there is a difference for minimum and maximum stress. Based on the data, the minimum stress value for AISI 1080 and AISI 202 is 0.0021 N/mm^2 and 0.0058 N/mm^2 respectively. It shows that there has difference for about 0.0037 N/mm^2 for both materials. Thus, the maximum stress for AISI 1080 which is 375.0609 N/mm^2 is lower than AISI 202 which is 380.6808 N/mm^2 .It can be concluded that for a principal direction stress, the AISI 202 material is still greater than AISI 1080 so that very compatible for camshaft manufacturing.

Table 4.2: Different Stress Minimum Principal Direction between AISI 1080 and AISI 202

Stress (N/mm^2)	
Mild Steel (AISI 1080)	Stainless Steel (AISI 202)
0.0021	0.0058
37.5079	38.0733
75.0138	76.1407
112.5198	114.2083
150.0256	152.2758
187.5315	190.3433
225.0374	228.4108
262.5433	266.4782
300.0492	304.5458
337.5551	432.6133
375.0609	380.6808

4.7.3 Stress Maximum Principal Direction

Figure 4.15 represent the Maximum Principal Direction Stress. The principal direction stresses have particular significance for camshaft engineering. The process of creating a new surface in a camshaft mass by excavation causes principal stresses to be locally oriented perpendicular and parallel to the free surface. The principal stress is exactly perpendicular to the free surface is zero. The maximum value is occurring in a direction parallel to the camshaft-free surface.

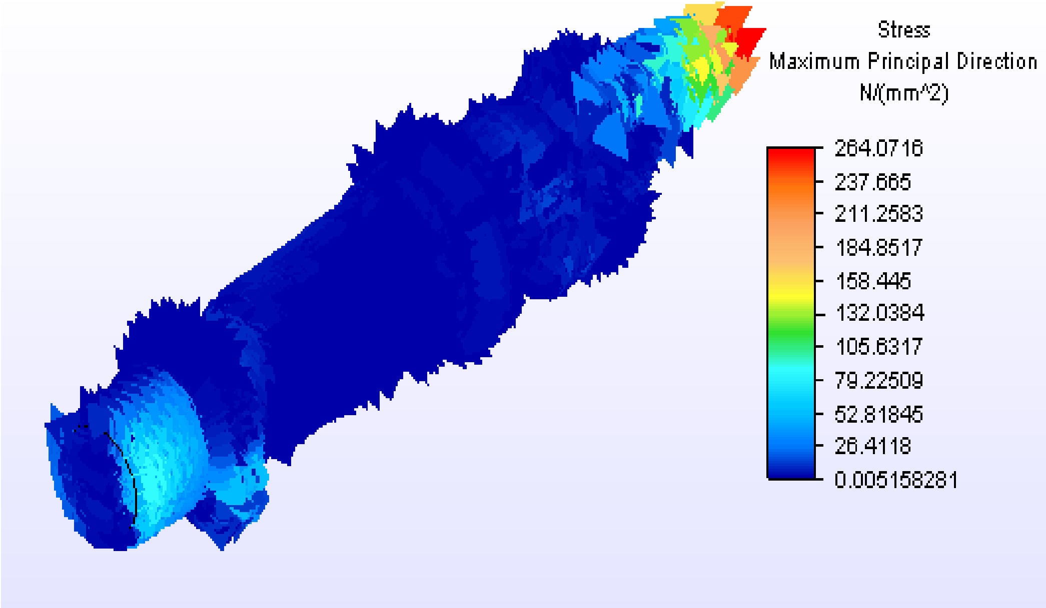


Figure 4.15: Stress Maximum Principal Direction

Table 4.3 brings out the result value for maximum principal direction stress that have been analyze to the camshaft by using the FEA Algor software. The stress test for both materials is complete. According to the data, the value of minimum stress for a mild steel (AISI 1080) is 0.0052 N/mm^2 and 0.0038 N/mm^2 for a stainless steel (AISI 202). The maximum stress value of` AISI 202 reach until 267.1239 N/mm^2 which is higher than AISI 1080 that only 264.0716 N/mm^2 . As a whole, the best value of stress test on a camshaft is small value at the minimum stress and high value for maximum stress. This situation appears to have on stainless steel (AISI 202).

Table 4.3: Different Stress Maximum Principal Direction between AISI 1080 and AISI 202

Stress (N/mm^2)	
Mild Steel (AISI 1080)	Stainless Steel (AISI 202)
0.0052	0.0038
26.4118	26.7158
52.8185	53.4278
79.2251	80.1398
105.6317	106.8518
132.0384	133.5639
158.445	160.2759
184.8517	186.9879
211.2583	213.6999
237.665	240.4119
264.0716	267.1239

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

For a conclusion, it is crucial to know six stroke engines helping in increasing of efficiency which have concept the first four strokes function as a conventional internal combustion engine. There have intake stroke, compression stroke, power stroke and exhaust stroke and further including additional strokes namely a vapour power stroke and a vapour exhaust stroke for generating additional power. One of important part that must be modified is camshaft. Its main function is to control the valve timing, thereby allowing the intake valve to open at the right time for feeding air and fuel mixture into the engine.

Compared to a four strokes engine, the camshafts of the six strokes engine have different shape at the exhaust cam and additional cam for a water injection. In exhaust cam, there have double lobe used for first and second exhaust stroke. Before camshaft fabrication, it is crucial to make complete design including size, parameter, material, etc. For a summary, this project material used low carbon steel since it is for display camshaft. Parameter, size and design have drawn in Solid Work as shown in chapter 3. There have three machining used which is lathe machine for a shaft fabrication, milling machine for a cam surface, and EDM wire cut to a cams fabrication.

5.2 RECOMMENDATION FOR FUTURE RESEARCH

There are several types of holding devices used on the engine lathe. The most common is the three-jaw chuck, and the second one is four-jaw chuck. There have a problem in three-jaw chuck. The main problem is the long process necessary to centre the work piece, requiring a high level of in the use of a dial indicator. It must be perfect by changing to the four-jaw chuck due to its advantage such as versatile, provides a secure hold o the work piece, large range of sizes, and has extremely accurate centring method.

For the most time EDM wire cut often does decrease burn times, this approach has caused many problems in the areas of automatic wire feeding, wire expense and ability to find replacement wire. Maybe the way to speed up in machine time on a wire EDM is using special wires.

Finding the material of the steel is very limited. The most common is aluminum and low carbon steel. It have several disadvantages using the low carbon steel. It has low hardness for camshaft manufacturing and expose to corrosion. It must be good if prepare another type of steel like alloy. Alloy can be as metal that increase hardness, malleability, electrical conductivity and melting point.

In addition, it is recommended to familiarize with the milling machine while performing the reduction metal thickness operation to avoid accidents that may lead to serious injuries. Follow the steps in the experiments procedure to collect the data and always be careful of the machine when it is in operation. Cases of injuries finger to the machine due to carelessness have occurred in the industry. On the other cases, the milling tool touched the clamper thus broke the tool.

REFERENCE

Bajulaz Six-Stroke Engine Accessed June 2007

"Camshaft definition by Merriam-Webster". Merriam-webster.com. 2010-08-13. http://www.merriam-webster.com/dictionary/camshaft. Retrieved 2010-11-07

Cengel, Yunus A; Michael A Boles, Yaling He (2009). *Thermodynamics An Engineering Approach. N.p.*. The McGraw Hill Companies.

Chen SL, Jen YW (2000) *Data fusion neural network for tool condition monitoring in CNC milling machining.*

Hardenberg, Horst O. (1999). *The Middle Ages of the Internal combustion Engine*. Society of Automotive Engineers (SAE)

Ipek R, Selcuk B (2005) *The dry wear profile of cam shaft*. J Mater Process Technol.

Johansson, T. & McCarthy, S. (1999*) Global warming post-Kyoto: continuing impasse or prospects for progress?* Energy Dev Rep Energy, 69–71.

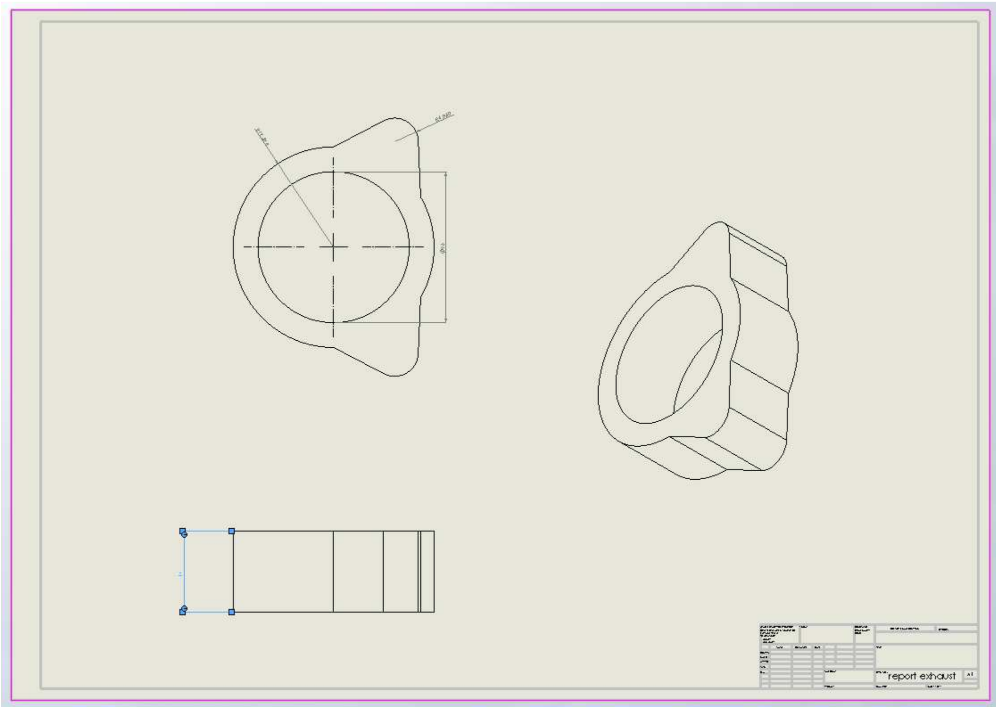
Lyons, Pete (February 23, 2006). "*Inside Bruce Crower's Six-Stroke Engine*". AutoWeek.

M.K.Paswan et al (2008) *New Concept of Bio-Diesel in Six Stroke Engines A Review ARISER* Vol. 4 No. 4 (2008) 227-231.

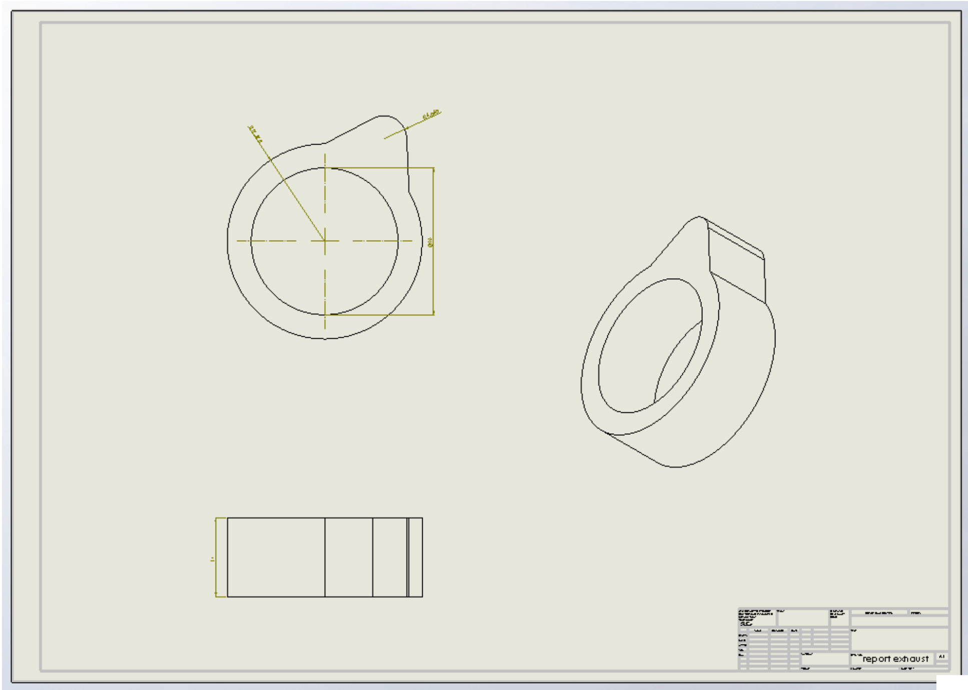
Wang G, Taylor D, Bouquin B, Ciepalowicz A (2000) *Predictionof fatigue failure in a camshaft using the crack modelling method*.

APPENDIX A

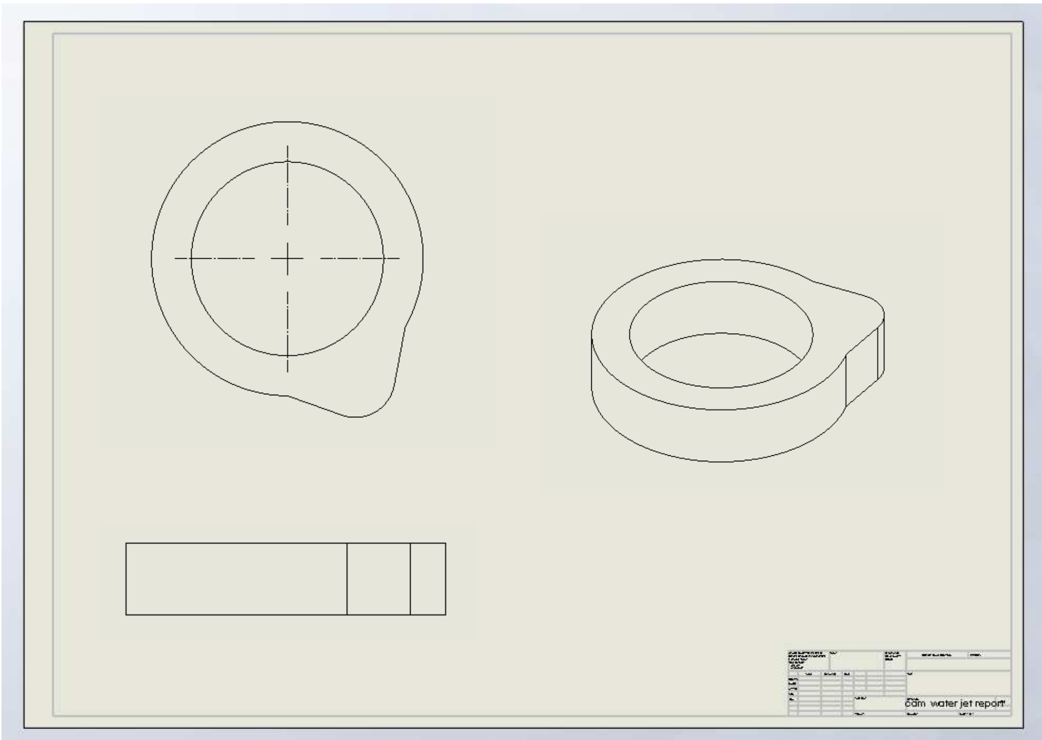
Drawing of the cams and shaft



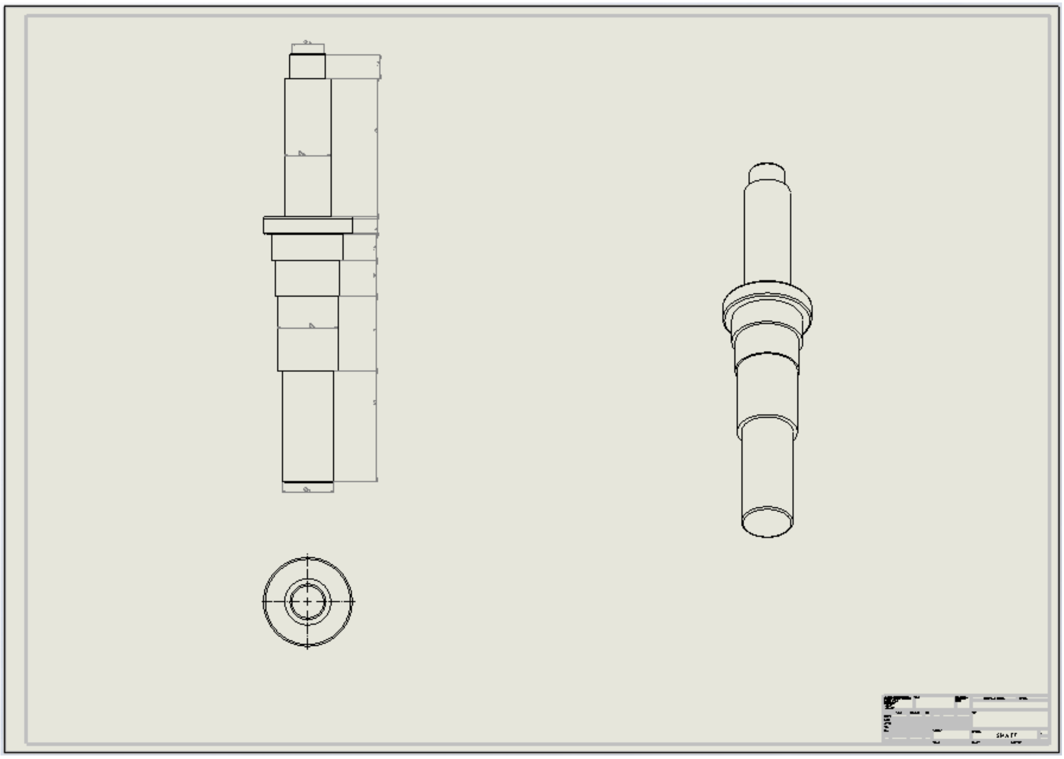
(a) Drawing of exhaust cam



(b) Drawing of intake cam



(c) Drawing of water injection cam



(d) Drawing of shaft.

APPENDIX B

Figure of machines in camshaft fabricating.

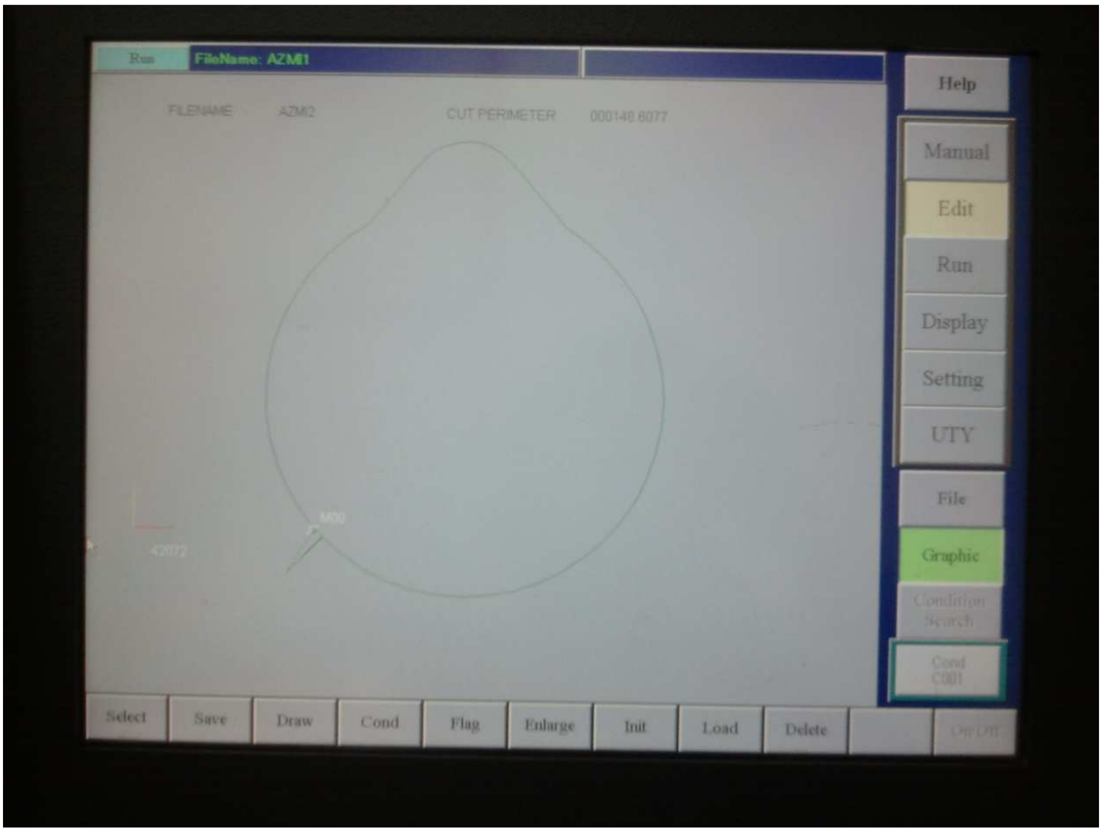
(a) Milling machine.

(b) Lathe machine.

(c) EDM wire cut

APPENDIX C

Drawing and coding of programming for EDM wire cut



(a) Design graphic

```
          ON  OFF  IP  HRP  MAO  SV  V  SF  C  PIK  CTRL  WK  WT  WS  WP
C000  =  008  016  2215  000  242  030  8  0020  0  000  0000  030  130  020  045;
C000  =  008  016  2215  000  242  028  8  0020  0  000  0000  030  130  020  040;
C000  =  002  023  2215  000  750  040  8  6060  0  000  0000  030  150  020  012;
H000  =  +000000.0100      ;
H001  =  +000000.2300      ;
H002  =  +000000.1600      ;
(FIG-1 1ST ALL CIRCUMFERENCE);
QAIC(2,1,0.1500,0.1950,0.0200,008.0,0030,0070,15,035);
G54;
G90;`
G92X0.0Y0.0Z0;
G29;
T94;
T84;
C000;
G42H000G01X4.301Y-2.5;
C001X12.9904Y-7.5;
H0001;
M98P0001;
T85;
```

```
G149G249;

( FIG-1 2ND RECIPROCATED) ;

C002;

G41H000G01X12.9904Y-7.5;

H002;



M98P0002;

M02;

;

N0001;

G02X-14.6533Y3.2062I-12.9904J7.5;

G01X-18.9835Y5.7062;

X-14.4335Y13.587;

X-10.1033Y11.087;

G02X13.23331Y-7.0629110.1033J-11.087;

M00;

X12.9904Y-7.51-13.2331J7.0629;

G40H000G01X0.0Y0.0;

M99;

;

N0002;
```

```
G03X13.2331Y-7.06291-12.9904J7.5;

X10.1033Y11.0871-13.2331J7.0629;

G01X-14.4335Y13.587;

X-18.9835Y5.7062;

X-14.6544Y3.2062;

G03X12.9904Y-7.5115.6577J-5.2062;

G40H000G01X0.0Y0.0;

M99;
```

(b) Coding of graphic

APPENDIX D

Bill of material for camshaft and machining specification

Work Material	Hardness, Bhn	Cutting Speed, fpm	
		High-Speed Steel	Carbide
Plain Carbon Steel, AISI 1010 to AISI 1030	to 150 150 to 200	110 100 to 140 100 80 to 120	600 400 to 900 450 300 to 700
AISI B1111, AISI B1112, AISI B1113, Steel	140 to 180	140 110 to 200	650 400 to 1200
Plain Carbon Steel, AISI 1040 to 1095	120 to 180 180 to 220 220 to 300	195 80 to 120 85 70 to 110 60 30 to 80	600 400 to 800 350 300 to 500 200 100 to 300

All Alloy Steels Having .3% or Less Carbon Content: AISI 1320, AISI 3120, AISI 4130, AISI 4020, AISI 5020, AISI 4118, AISI 9310, etc.	180 to 220 220 to 300 300 to 400	80 65 to 100 60 30 to 80 40 30 to 50	350 300 to 600 300 200 to 350 125 100 to 150
All Alloy Steels Having More Than .3% Carbon Content: AISI 1340, AISI 2340, AISI 4140, AISI 4150, AISI 4340, AISI 5140, AISI 5150, AISI 52100, AISI 8660, AISI 9260, etc.	180 to 220 220 to 300 300 to 400	80 60 to 100 55 30 to 80 30 20 to 50	325 275 to 450 250 180 to 300 100 80 to 130