DESIGN AND DEVELOPMENT OF DISC VALVE EXHAUST PORT FOR FOUR STROKE ENGINE

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MOHD NASHRIQ B. MOHD HANAFIAH

A report submitted in partial fulfillment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Automotive Engineering

Faculty of Mechanical Engineering
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NOVEMBER 2008

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this project and in our opinion this project is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive

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ID Number : MH05022

Date : 10 NOVEMBER 2008

Dedicated to my beloved parents, family, and friends..
Thank you for all your support, ideas, and cooperation..
All of you always in my heart forever..

ACKNOWLEDGEMENT

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Thank you for all.

ABSTRACT

This report presents the design and development of the disc valve exhaust port. Objectives of this project are to design and develop of disc valves exhaust port for MODENAS KRISS 110cc four stroke engine new cylinder head. In the original engine, a poppet valve is used in the exhaust port. A disc valve will replace the function of the existing poppet valve of controlling the exhaust port opening and closing. This report describe about the design and the working operational of the disc valve in the new cylinder head. The solid modeling of disc valve was designed using the computer-aided drawing software. The disc valve designed used the original valve timing and duration. As a conclusion, the disc valve duration and valve timing is fully controlled by the disc valve shape and design.

ABSTRAK

Laporan ini mempersembahkan mengenai rekaan dan pembinaan injap cakera untuk salur ekzos. Objektif projek adalah untuk mereka dan membina injap cakera salur ekzos untuk rekaan baru kepala silinder enjin empat lejang Modenas Kriss 110. Pada enjin asal, injap ‘poppet’ digunakan pada salur ekzos. Injap cakera akan menggantikan fungsi injap ‘poppet’ di dalam mengawal pembukaan dan penutupan salur ekzos. Permodelan struktur pejal bagi injap cakera direka dengan menggunakan perisian lukisan bantuan komputer. Rekaan injap cakera ini menggunakan pemasa injap dan tempoh enjin asal. Kesimpulannya, injap pemasa dan tempoh injap untuk injap cakera adalah dipengaruhi sepenuhnya oleh reka bentuk injap cakera itu sendiri.

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LIST OF SYMBOLS

a	Crank radius
B	Bore
D	Diameter
l	Connecting rod length
N	Crankshaft rotational speed
P	Power
r_c	Compression ratio
R	Connecting rod length/crank radius
s	Crank axis to piston pin distance
T	Torque
V	Cylinder volume
V_c	Clearance volume
V_d	Displaced cylinder volume
θ	Crank angle

LIST OF ABBREVIATIONS

TDC	Top dead center
BDC	Bottom dead center

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

There are many research has been done on the internal combustion engine especially for the four stroke and two stroke engine. Main objectives of the research are to improve the efficiency of the engine and increased the power produce by the engine. Four stroke and two stroke engines have their own advantages and disadvantages.

Advantages of two stroke engine are the engine design is simple compare to the four stroke engine. This type of engine does not have the valve train system that make the engine is less weight compare to another type of engine. Disadvantages of the four stroke engine are the noise produce from the exhaust is noisy. The engine also needs special lubricant to decrease the friction between the wall in the combustion chamber and the piston.

Advantages of four stroke engine are the emission produce is not dangerous to the environment compare to the two stroke engine. The noise produces by the exhaust also more silent than two stroke engine. Disadvantages of this engine are the design is complicated because it uses valve train system. That make the engine has more components and it is difficult to service this type of engine.

There are research has been done to combine the four stroke and two stroke single cylinder engine. The combination is done by removing the original valve train system for four stroke engine and replaced it by the new cylinder head that use the two stroke engine system. These combination engines will use dual piston where the main piston is in the engine while the second piston is used in the head.

1.2 PROBLEM STATEMENT

There are two general type of single cylinder engine in the market. It is two stroke engine and four stroke engine. Both of the engines have their own advantages and disadvantages. The advantages of the two stroke engine is the design of the engine, it use simple component. Two stroke engines is more efficient than four stroke engine in term of power but in exhaust emission four stroke engine have more advantages. These two types of engine can be combined into one engine system. The combination of this two engine will improved the internal combustion system.

The combination of this engine can be done by removing the head of the four stroke engine system that contain valve, rocker arm and camshaft and replaced the head existing system with the two stroke engine system. The new head design contains piston controlled and all the basic components that have in the two stroke engine. The exhaust system is important to make sure the engine can eliminate the exhaust gaseous smoothly and make the engine run efficiently. The important part in the exhaust port system is the valve. The new design head engine will eliminate the usage of the popper valve and replace by the disc valve. Advantages of using the disc valve compare to the popper valve are it can increase the volumetric efficiency since there is no valve in the way of the exhaust gaseous flow. Usage of the disc valve also can improve mechanical efficiency because there is no power working against the compression.

It’s important to design the disc valve to make sure the disc valve is working properly and can eliminate the exhaust gaseous smoothly. This project is to design and develop of the disc valve exhaust that can work properly on the new head engine design.

The disc valve must be open and closed the exhaust port in correct timing to make sure the flow of the exhaust gas can move smoothly.

1.3 OBJECTIVES

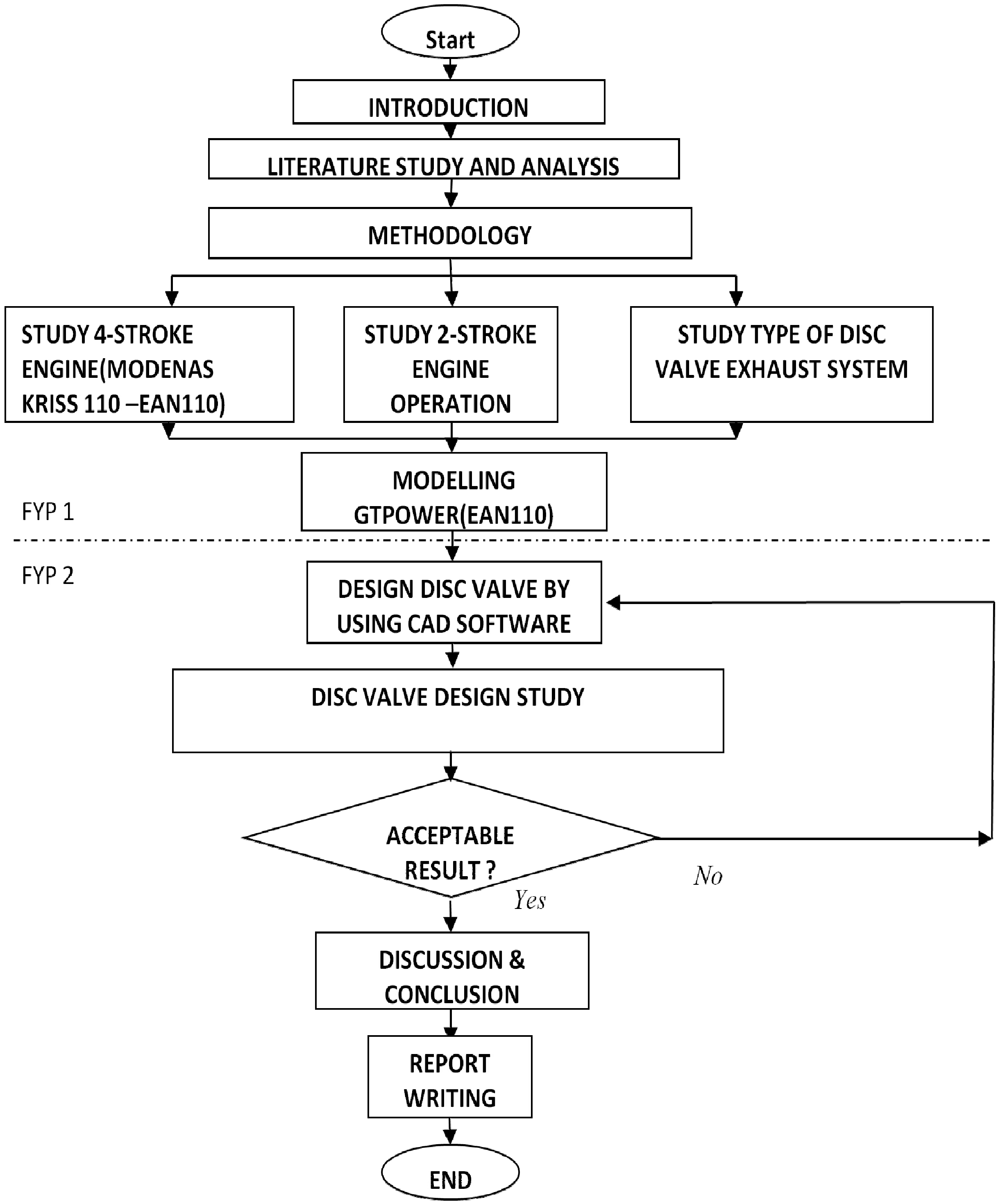
Objectives of this project are to design and develop a Disc valves exhaust port for the new cylinder head MODENAS KRISS 110cc four stroke engine.

1.4 SCOPE

Scopes of this project are:

1. Engine dissembled and cylinder head system component measurements.
2. GTPOWER modeling for the original engine valve train system (EAN 110)
3. Literature review on the BEARE HEAD engine.
4. Design on disc valves exhaust that used in the new head engine.
5. Animation of the disc valve exhaust port

1.5 FLOWCHART



CHAPTER 2

LITERATURE STUDY

2.1 FOUR STROKE ENGINE

Four stroke engines need to do four rotations to complete one cycle. First rotation is intake stroke. As the piston starts going down, the inlet valve is opened (mechanically opened by the turning of the crank-shaft). A mixture of air and gas is going in. As it reaches the bottom, the valve closes. Second rotation is compression stroke. The piston starts going up, caused by the force of the turning crankshaft. When it reaches the top, the air/gas mixture reaches a certain compression which is highly explosive.

Third rotation is power stroke. At this point, the electric circuit connected to the spark plug is turned on (driven mechanically by the position of the crank shaft). The spark plug causes a spark in the dense mixture of air and gas. The spark starts the explosion in the cylinder on top of the piston. This expansion caused by the explosion pushes the piston down. This force turns the crank-shaft around. The last rotation is exhaust stroke. As the piston goes up again, the outlet valve opens (being driven mechanically). The used air (smoke) from the explosion escapes through the outlet valve. As the piston reaches the top, the outlet valve closes.

The cycle is then repeated. Four stroke engines have the valve train system at the head of the engine to control the intake and exhaust valve.

The advantages of four stroke engine are:

- Last longer life than two stroke engines
- More efficient use of gas
- Less polluting. Four stroke engine does not release as much gas and oil mixture and in the exhaust along with an unpleasant odor
- Shown better gas mileage than the two-stroke engine and avoids the high decibel whine associated with the two-stroke engine.

2.1.1 Valvetrain system in the four stroke engine.

The valves are typically operated by a camshaft, with a series of cams along its length, each designed to open a valve appropriately for the execution of intake or exhaust strokes while rotating at half crankshaft speed. A tappet between valve and cam furnishes a contact surface on which the cam slides to open the valve. The location of the camshaft varies, as does the quantity.

Most engines use overhead cams, or even dual overhead cams, as in the illustration, in which cams directly actuate valves through a flat tappet. This design is typically capable of higher engine speeds because it gives the most direct and shortest inelastic path between cam and valve. In other engine designs, the cam shaft is placed in the crankcase and its motion transmitted by a push rod, rocker arms, and valve stems. Figure 2.1 shows the structure of four stroke engine

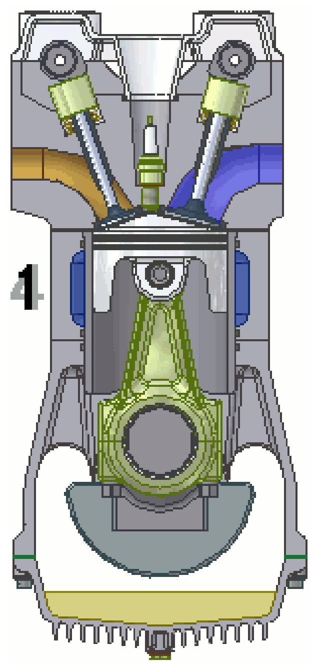


Figure 2.1: Four stroke engine structure

2.2 TWO STROKE ENGINE

Two strokes engine only need to do two rotations two complete one cycle. First rotation is intake and power stroke. The compressed fuel-air mixture ignites and thereby the piston is pressed down. At the same time the intake port is covered by the piston. Now the new mixture in the crankcase becomes recompressed. Shortly before the piston approaches the lower dead centre, the exhaust port and the overflow conduit are uncovered.

Being pressurized in the crankcase the mixture rushes into the cylinder displacing the consumed mixture (exhaust now). Second rotation is compression and exhaust stroke. The piston is moving up. The overflow conduit and the exhaust port are covered; the mixture in the cylinder is compressed. At the same time new fuel-air mixture is sucked into the crankcase. The basic structure we can see on the figure 2.2.

Advantages of two strokes engine:

- Has more get-up-and-go because it fires once every revolution, giving it twice the power of a four stroke, which only fires once every other revolution.
- Can be operated in any orientation because it lacks the oil sump of a four stroke engine, which has limited orientation if oil is to be retained in the sump
- The engine fires - spark plug ignites - once every revolution of the crankshaft.
- They produce twice the power than four stroke engines.
- The work required to overcome the friction of the exhaust and suction strokes is saved.
- As there is a working stroke in every revolution, a more uniform turning moment is obtained on the crankshaft and therefore, a lighter flywheel is required.
- Two-stroke engines are lighter than four-stroke engines for the same power output and speed.
- For the same, output, two-stroke engines occupy lesser space.
- They are much simpler than four stroke engines.
- Two stroke engines are simpler than four stroke engine. The construction of a two-stroke cycle engine is simple because it has ports instead of valves. This reduces the maintenance problems considerably.

Disadvantages of the two stroke engine

- Faster wear and shorter engine life than a four stroke due to the lack of a dedicated lubricating system.
- Heavily pollutes because of the simpler design and the gas/oil mixture that is released prior to, and in the exhaust (also creates an unpleasant smell).
- Has a high-decibel whine that may exceed legal noise limits in some areas, depending on the product and local applicable laws.
- They last less. Lubrication is not as efficient as in a four stroke engine with heavy oil.

- Do not use gas efficiently.
- Pollute more.
- High speed two-stroke engines are less efficient owing to the reduced volumetric efficiency.
- Part of the piston stroke is lost with the provision of the ports thus the effective compression is less in case of two-stroke engines.
- Two-stroke engines are liable to cause a heavier consumption of lubricating oil.

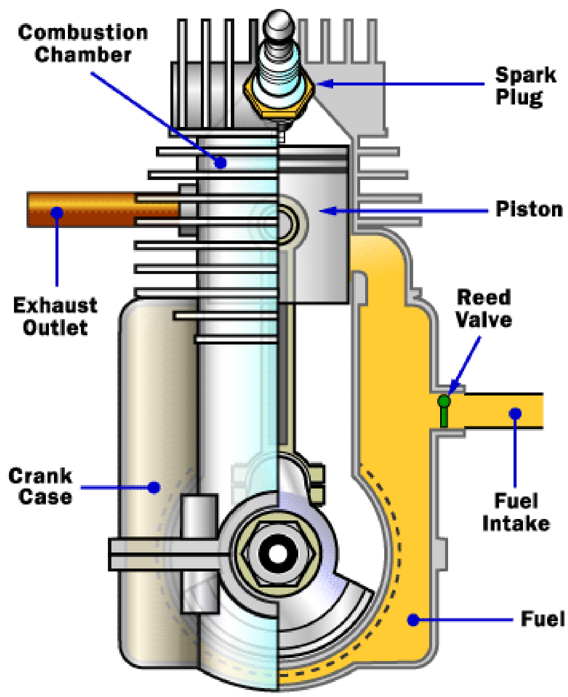


Figure 2.2: Basic structure of two stroke engine

2.3 SIX STROKE ENGINE

This engine is design by the Malcolm. J. Beare and was patented on 3rd February 1998 in the United State Patent. Another command name of this engine is Beare Head Engine. The engine is modified only on the head engine system while the bottom part of the engine is in the original condition.

Figure 2.3 shows the picture of the design of Beare Head Engine in the US Patent. The engine used two pistons; the first piston is the main piston while the second piston is in the head engine. The second piston function same as an intake valve in the original head engine system. This head engine eliminates all the usage of the popper valve that used in original head engine.

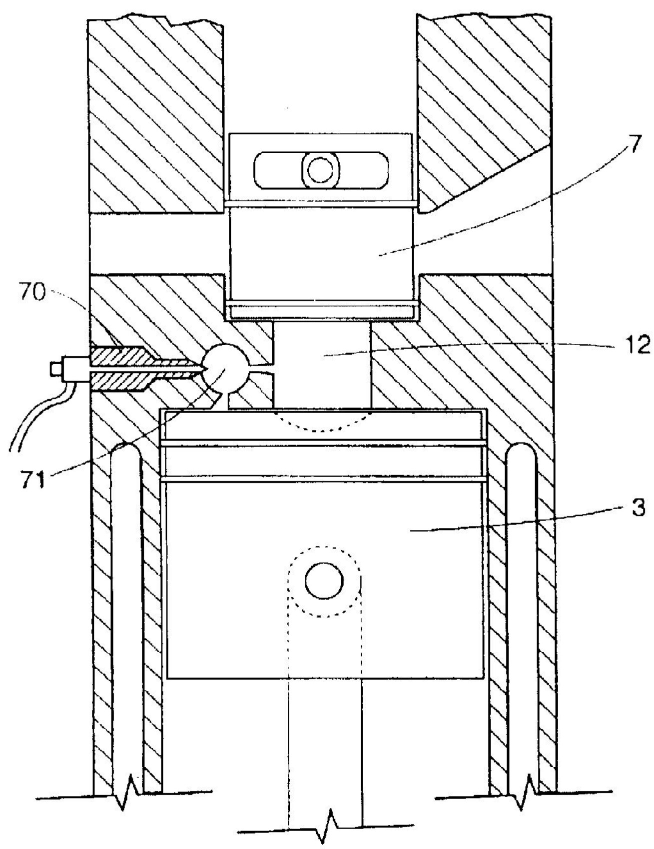


Figure 2.3: Basic picture of the Beare Head engine

Advantages of using this type of engine

- Power/torque increases of 35% (conservative)
- Simpler and less expensive manufacturing and tooling
- Reduction of cylinder head reciprocating parts
- Lower maintenance costs due to less wearing parts (Beare cylinder head)
- Longer service intervals possible due to lower operating temperatures recorded
- Increased economy due to the Beare Head's ability to operate and produce full operating power of much higher AIR to FUEL ratios
- Reduction of exhaust emissions due to less fuel being consumed and the real prospect of meeting EURO-4 emissions standards, doing away with the catalytic convertor
- Possible one piece engine block and head casting, saving more manufacturing costs
- Usable torque at as low as idle means suitability for lower RPM operation and adaptation to CVT (Constantly Variable Transmission)

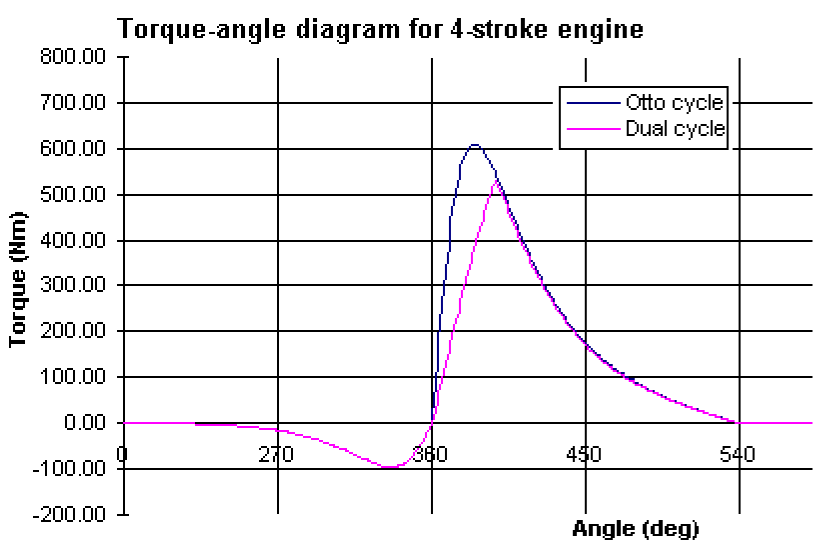


Figure 2.4: Graph torque vs angle diagram for original four stroke engine

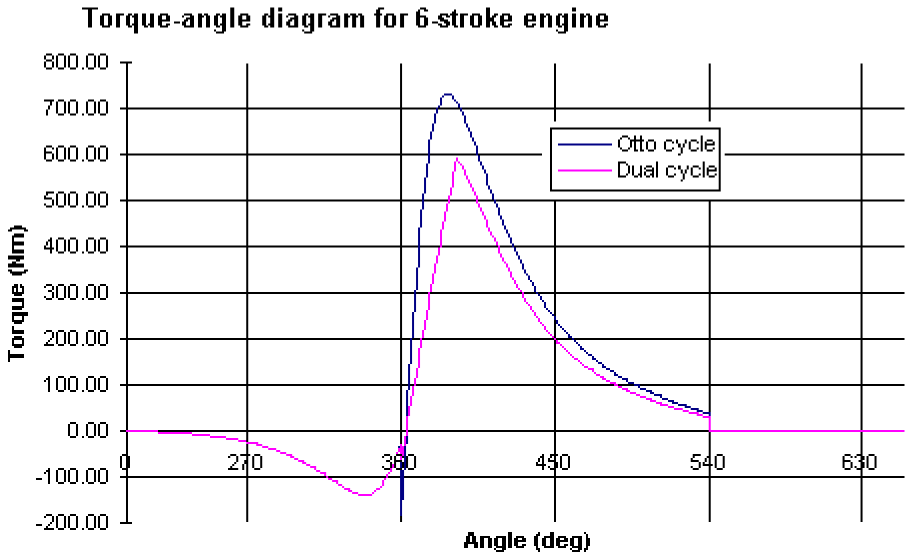


Figure2.5: Graph torque angle diagram for Beare Head engine

	Based on Otto Cycle		Total Torque	Based on Dual Cycle		Total Torque
4 stroke			49.82			39.36
	Main	*Top*		*Main*	*Top*	
6 stroke	56.78	4.61	61.38	38.66	4.21	42.87
Increase in torque			23.20%			8.93%

Figure 2.6: Comparison between four stroke and six stroke engine

Graph in figure 2.4 shows the torque vs angle diagram for the original engine that used as a prototype in the Beare Head engine, while the graph in figure 2.5 is shown the torque vs angle for the modified head engine system. From both of the graph it shows that the highest torque for the four stroke engine is about 600Nm while for the six stroke engine the highest torque produce is about 750Nm for the Otto cycle. For the dual cycle, the highest torque produce by the original four stroke engine is about 500Nm while for the six strokes engine is 600Nm. It can conclude that the six stroke engine can increased the torque.

Figure 2.6 shows the comparison between the original four stroke engine and the six stroke engine. Based on the Otto cycle it shows that the torque is increased about the 23.20%. The total torque for four stroke engines is 49.82Nm while for the six stroke engine the total torque is 61.38Nm. Based on the dual cycle process, the total torque for four stroke engine is39.36Nm while for the six stroke engine, the total torque is 42.87Nm. The torque is increased about 8.93%.

2.4 IMPORTANT ENGINE CHARACTERISTIC

There are some basic geometrical relationships and the parameters commonly used to characterized engine operation are developed.

2.4.1 Geometrical properties of reciprocating engine

Compression ratio, r_c:

r_c = maximum cylinder volume/minimum cylinder volume

$$r_c = (V_d + V_c) / V_c \tag{2.1}$$

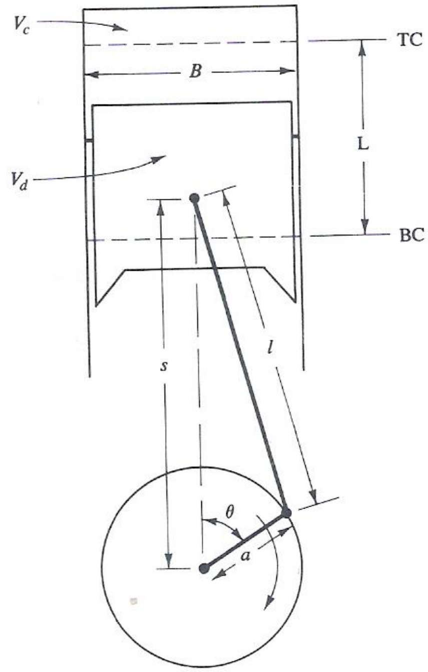


Figure 2.7: Basic geometry of reciprocating engine

Where V_d is the displaced or swept volume and V_c is the clearance volume.
Ratio of cylinder bore to piston stroke

$$R_{bs} = B/L \tag{2.2}$$

Ratio of connecting rod length to crank radius:

$$R = l/a \tag{2.3}$$

In addition, the stroke and crank radius are related by

$$L = 2a \tag{2.4}$$

Typical values of these parameters are r_c=8 to 12 for SI engines and r_c = 12 to 24 for CI engines; B/L = 0.8 to 1.2 for small and medium size engine, decreasing to about

0.5 for large low speed CI engine and R = 3 to 4 for small and medium size engine and it is increasing to 5 to 9 for large slow speed CI engines [2].

The cylinder volume V at any Crank position θ is

$$V = V_c + [(\pi B2/4)(l + a - s)] \qquad (2.5)$$

2.4.2 Brake torque and power

Engine torque is normally measured with a dynamometer. The engine is clamped on a test bed and shaft is connected to the dynamometer rotor.

Torque is equal to force multiplied by the length. The power delivered by the engine and absorbed by the dynamometer is the product of torque and angular speed:

$$P = 2\pi NT. \qquad (2.6)$$

Note that torque is a measure of an engine ability to do work. Power is the rate at which work is done. The value of engine power measured as described above is called brake power P_b. This power is usable power delivered by the engine to the load in this case a break. [2]

2.5 POPPET VALVE

Poppet valves are used in most piston engines to open and close the intake and exhaust ports in the cylinder head. The valve is usually a flat disk of metal with a long rod known as the valve stem out one end. The stem is used to push down on the valve and open it, with a spring generally used to close it when the stem is not being pushed on.

For certain applications the valve stem and disk are made of different steel alloys, or the valve stems may be hollow and filled with sodium to improve heat transport and transfer.

The engine normally operates the valves by pushing on the stems with cams and cam followers. The shape and position of the cam determines the valve lift and when and how quickly (or slowly) the valve is opened. The cams are normally placed on a fixed camshaft which is then geared to the crankshaft, running at half crankshaft speed in a four-stroke engine. On high performance engines (e.g., Ferrari cars), the camshaft is movable and the cams have a varying height, so by axially moving the camshaft in relation with the engine RPM, also the valve lift varies.

Although better heat conductors, aluminum cylinder heads require steel valve seat inserts while cast iron cylinder heads often used integral valve seats in the past. Because the valve stem extends into lubrication in the cam chamber it must be sealed against blow-by to prevent cylinder gases from escaping into the crankcase.

A rubber lip-type seal ensures that excessive amounts of oil are not drawn in from the crankcase on the induction stroke and that exhaust gas does not enter the crankcase on the exhaust stroke.

Figure 2.8: Poppet valve in the internal combustion engine

2.6 DISC VALVE

Malcolm Beare is an Australian engineer, he spent time pondering the possibilities of using rotary valves in a four-stroke engine, quiet, compact and inexpensive, but difficult to lubricate and keep cool, thus leaving the poppet valve the favorites for most current non-two stroke units.

Discounting of existing rotary valves, Malcolm came up with a new type, of his own design, but utilizing existing components, and allied it to a design that managed to take the load (combustion pressure), off the valve during the periods when temperatures and pressures peak.

The rotary valve used now is fourth in the development programmed, the first two being tested on boxer twins, and then on a 125cc, Honda farm-bike. The current slave unit is an XT500 Yamaha.

Positioned at the other end of the top crankshaft is a disc valve that regulates the exhaust timing, the only function being to prevent exhaust gases returning into the cylinder during the intake stroke, under light load and without any lubrication difficulties. The figure 2.9 shows the picture of the disc valve in the Malcolm J. Beare design and the location of the valve in the head engine.

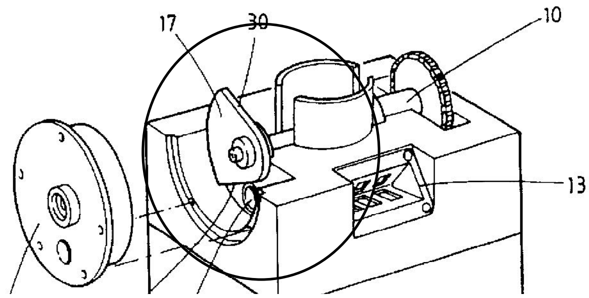


Figure 2.9: Location of the disc valve in the Malcolm J. Beare head engine.

CHAPTER 3

METHODOLOGY

3.1 TEST ENGINE SPECIFICATION

The test engine is four stroke single cylinder engines. The modification is on the head engine system. The engine used is Modenas Kriss 110cc, and the overall engine specification in the table 3.1.

Table 3.1: Modenas Kriss 110cc engine specification

Titles	**Descriptions**
Type	4-Stroke/Air cooled
No. of Cylinder	1 Cylinder
Displacement	111.6cc
Bore X Stroke	53.0 X 50.6
Compression Ratio	9.3:1
Maximum Power Output	6.6kw (8.2ps) /8500rpm
Maximum Torque	9.3N.m (0.95kgf) /4000rpm
Starting System	Electric/Kick
Lubrication System	Force lub.Wet
Engine Oil Capacity	1.1 Liter
Carburetor	KEIHIN PB18
Ignition System	DC-CDI
Engine Dry Mass	N/A
Maximum Speed	105 km/h
S.S. 200m	12.8 sec.

3.2 ENGINE DISASSEMBLY

Engine disassembly process is to analyze the component that have in the engine especially the head engine component. The entire component needs to be analyzing to get the accurate data about the engine system and how the engine operates. The original head engine system is used rocker arm to move the valve. All the head engine system also known as valve train system. Figure 3.1 is the engine and head engine component.

Figure 3.1: Modenas Kriss 110cc engine component

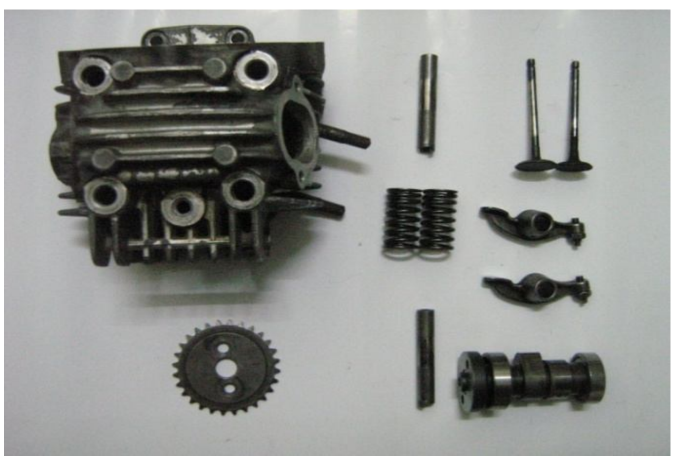


Figure 3.2: Original head engine component

3.3 COMPONENT MEASUREMENT

The component measurement is done on the engine system to get the benchmarking before the design can be done. It is important because, the benchmarking is the guidance for the design and modification. The measurement also important during the modeling the valves train in the GT Power.

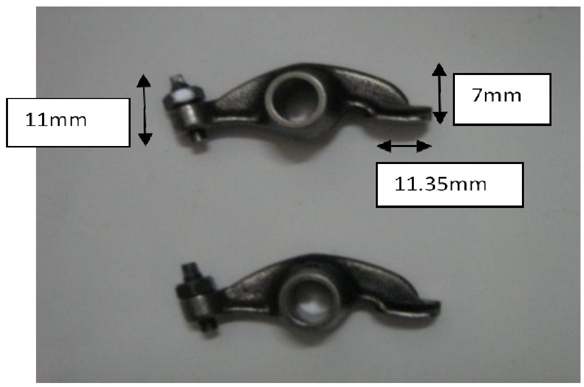


Figure 3.3: Rocker arm

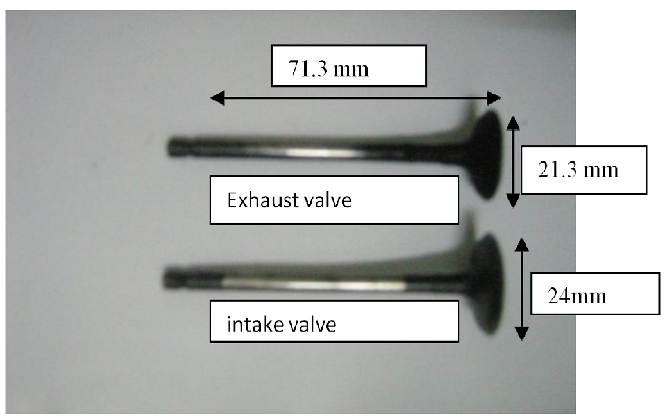


Figure3.4: Intake and exhaust poppet valve

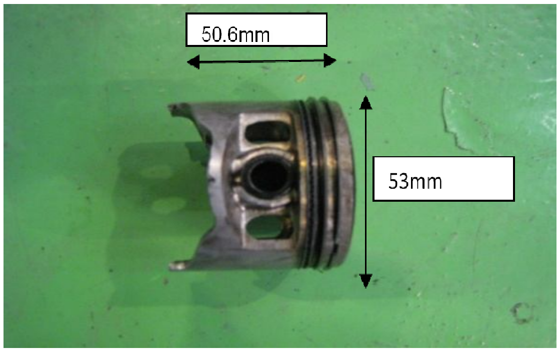


Figure 3.5: Engine piston

3.4 EXHAUST CAM PROFILE

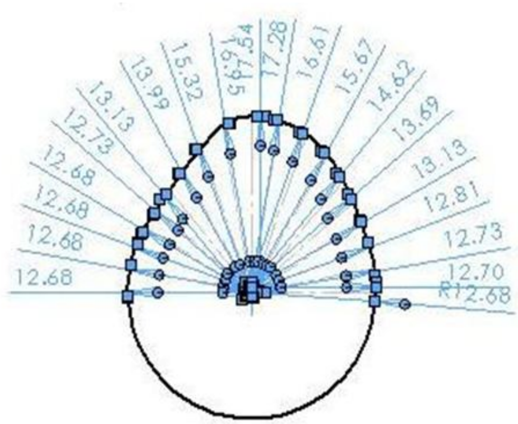


Figure 3.6: Exhaust camshaft profile

Cam profile is determined from the cam shaft. Cam shaft is used to control the valve open, valve closed and the duration of the valve. The exhaust cam profile is control the valve timing of the exhaust port while intake cam profiles control the intake port. The exhaust cam profile is measured by using the coordinate measuring machine (CMM). The measuring machine will transfer the data into the computer and the data will transfer into the Solidwork software to get the accurate value.

3.5 ORIGINAL VALVE TIMING.

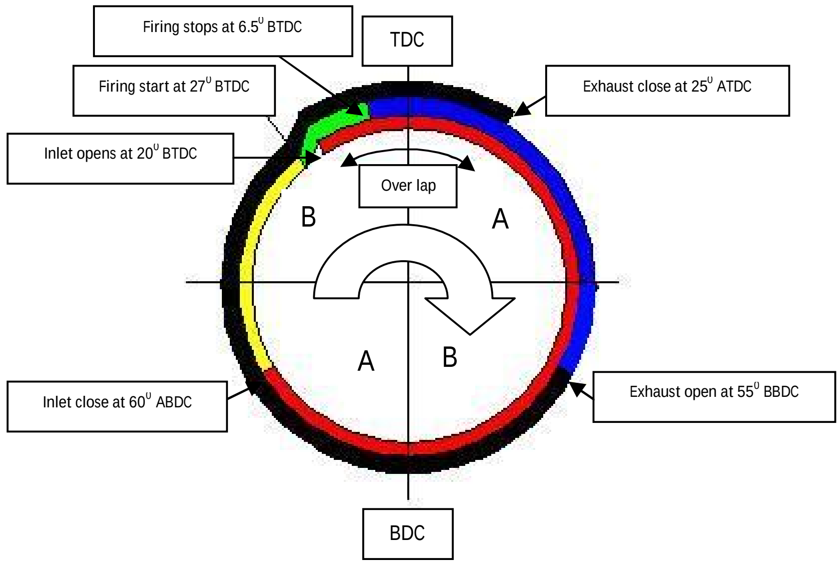


Figure 3.7: Original valve timing

Figure 3.7 shows the Modenas Kriss 110cc original valve timing. In the figure above, the inlet valve open is at 20^0 before top dead center (BTDC). During this period, it is intake stroke where in the combustion chamber is at low pressure and mixture of air and fuel is going into the chamber.

The valve closed is at 55^0 after bottom dead center (ABDC). The duration for intake valve open is 260^0. Exhaust valve open is at 55^0 before bottom dead center (BBDC). At the 25^0 after top dead center (ATDC), the exhaust valve is closed. During this period, in the combustion process it call exhaust strokes. During this process, the piston will push the exhaust emission to the exhaust port, and the exhaust emission will go to the air through the exhaust port.

3.5 HEAD ENGINE MODELING(GT POWER SOFTWARE)

GT Suite is the CAE(computer aided engineering) tools for design and analysis the engine, power train and vehicles. The unique feature of these tools is it contains single application for every cases study. GT Suite has six components which are:

GT-POWER -Engine simulation for performance and acoustics analysis, with full control capabilities

GT-DRIVE -Vehicle performance and cycle analysis for fuel economy and emissions, and driveline component dynamics

GT-VTRAIN -Valve train kinematics, quasi dynamics analysis, and multibody dynamics

GT-FUEL -Injection system pressure and flow dynamics, hydraulic system analysis

GT-COOL -Engine heat management and cooling system analysis

GT-CRANK -rigid and elastic dynamic analysis of crankshafts.

Head engine analysis for this project is used the GT Power software to make an analysis and modeling. All the measurement is transfer into the engine modeling in the GT Power to get the value for the valve lift vs. crank angle graph.

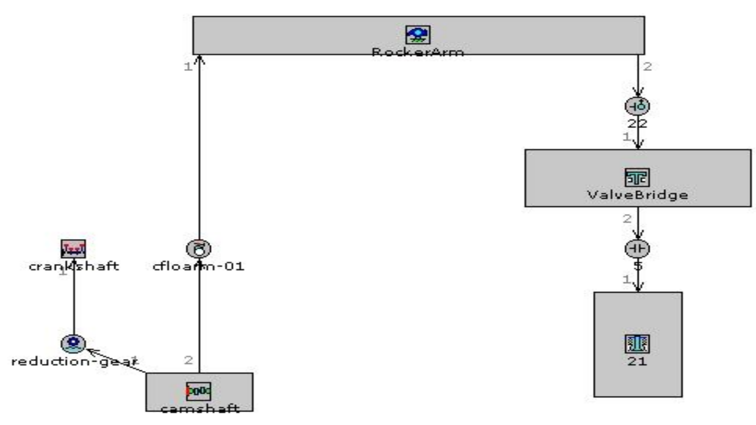


Figure 3.8: Head engine modeling in the GT Power

After transfer all the data into the head engine modeling such as the valve size, cam profile, rocker arm lift and any constraint, the data will be plot in the graph. Accuracy of the data depends on the accuracy of the constraint. Figure 3.9 shows the data from the head engine modeling.

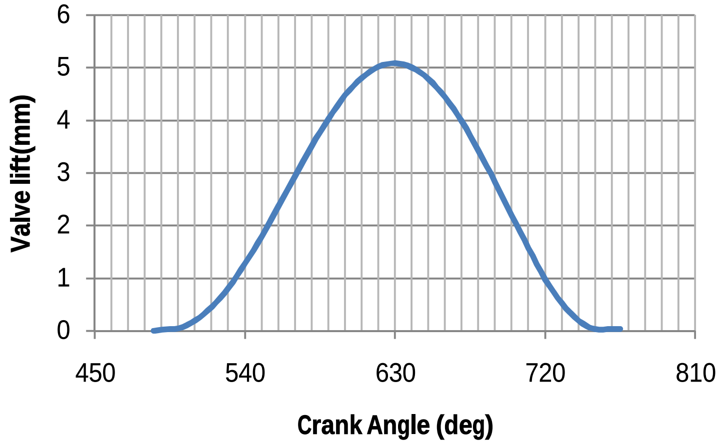


Figure 3.9: Graph exhaust valve lift vs crank angle

Graph 3.9 shown the exhaust valve lift vs crank angle. The exhaust valves open at the 483.75^o crank angle. Maximum valve lift is 5.2mm occur at the 630^o crank angle and it start to close during that time. The exhaust valve fully closed at the 765^o crank angle.

3.6 DATA ANALYSIS

Original engine data analysis are important to get the performance of the engine before the modification. In this case, the analysis is to get the swept volume data for the original Modenas Kriss 110cc engine. The graph swept volume vs crank angle can be get from the original sinusoidal equation below:

$$Y(t) = A\sin(\omega t+\theta) \tag{3.1}$$

From the equation, some alteration has been done to generate the graph and the equation become:

$$y(t) = 55\sin(\omega t-180)+55 \tag{3.2}$$

where;

ωt = crankshaft angle(in radians)

The graph swept volume vs crank angle generate by using Microsoft Excell and the graph is shown in figure 3.10. The data table is on appendix B.

At the 0^o crankshaft angle, the piston is at the top dead end centre (TDC), and the swept volume is zero. At the 180^o crankshaft angle, the piston is at the bottom dead center (BDC) and the swept volume is at the maximum point which is 110cc. at the 360^o crankshaft angle, the piston at the TDC and the swept volume is zero.

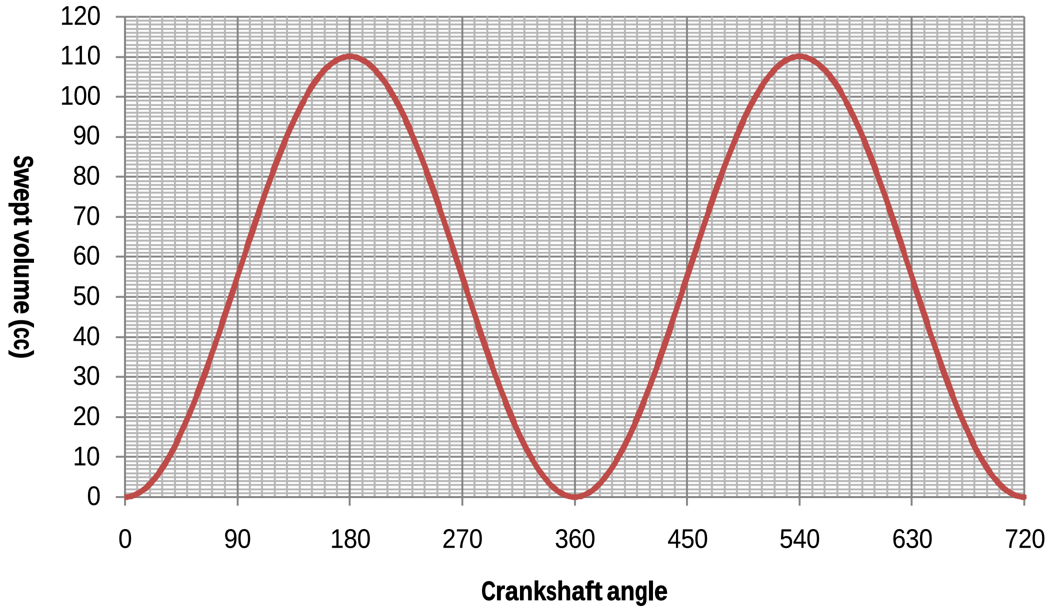


Figure 3.10: swept volume vs crankshaft angle

Crankshaft angle at the 540^o, the piston is at BDC and the swept volume is 110cc. at the 720^o crankshaft angle the piston at the TDC and the swept volume is come to zero back. At the 0^o until 180^o, it is intake stroke. at the 180^o until 360^o it is compression stroke. At 360^o until 540^o it is power stroke and at the 540^o until 720^o it is exhaust stroke.

CHAPTER 4

RESULT AND DISCUSSION

4.1 DESIGN LIMITATION

Design limitation is one of the important parameters during the design process. All the design must follow the limitations as guidelines. It is important because the limitations are frequently based on the safety precautions, space limit and regulations of the manufacturer. The disc valve design limitation is based on the original Modenas Kriss head engine dimension, original exhaust port size, and the original valve timing.

4.1.1 Original Modenas Kriss head engine dimension.

Figure 4.1: Location of the original engine in the Modenas Kriss 110cc

The limitation is required because to make sure that the new head engine design is can be just bolt on to the original engine without any modification to the chassis of the

Modenas Kriss. Beside that, the entire original component can be used such as the exhaust system and the firing system. The engine location in the Modenas Kriss is shown in the figure 4.1.

4.1.2 Original exhaust port size.

The design is use the original exhaust port size diameter. It is to exactly following the original engine specification without any modification. It is to make sure that the new design is following the original exhaust flow.

4.1.3 Original exhaust valve timing.

The design is focusing on the concept of the disc valve and the new head engine design applied to the original head engine Modenas Kriss 110cc. so that, the original valve timing is used because to make sure that the new design is following the original head engine working concept. Some modification on the valve timing will affect the performance of the engine and all the modification will be done on the next analysis.

4.2 DISC VALVE DESIGN.

The disc valve will used in the exhaust port for the new head engine design. The basic design is follow the original design in the Beare Head engine design. The disc valve basic working principle is the rotational motion and disc valve rotating by the shaft, gearing system and the chain system. In the new head engine, the disc valve is used to close and opened the exhaust port during the combustion process.

4.2.1 First design.

Figure 4.2 shows the basic design of the disc valve exhaust. The radius for the disc valve is 40 millimeter and the duration of the valve closed is 1000. All the dimension and valve duration is following the design limitation. The fully dimension is in the appendix E. This design is very basic design and it just a concept of the disc valve. The weakness of this design is the area of the exhaust port open is small if the valve is half open. The design is based on the Beare Head engine.

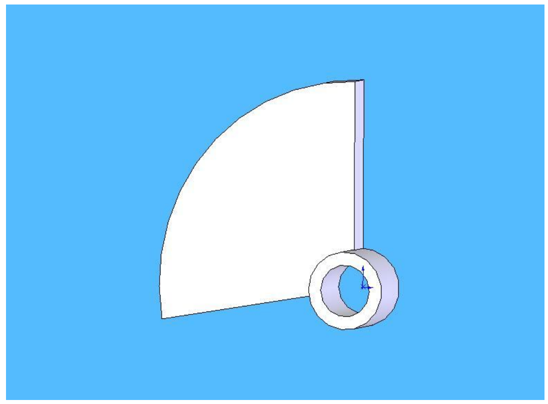


Figure 4.2: Basic design of the disc valve

4.2.2 Second design

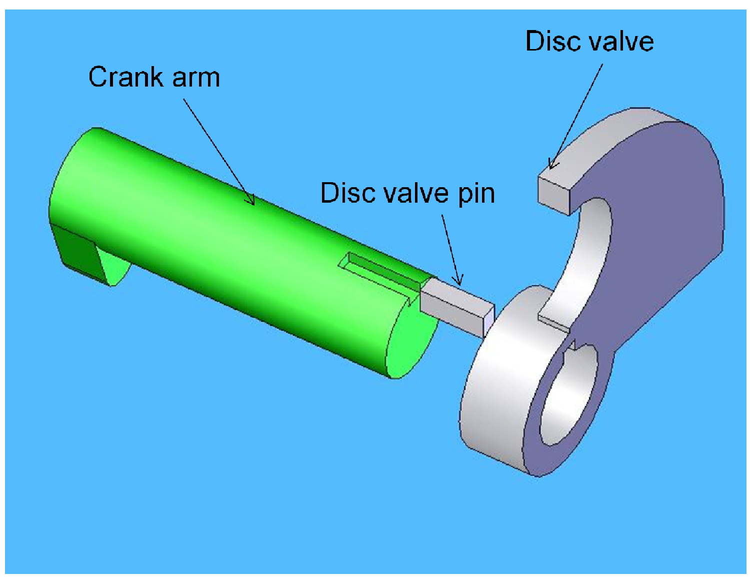


Figure 4.3: Second design of the disc valve

Figure 4.3 shows the improvement on the disc valve design and the way the disc valve connected to the crank arm. The component is disc valve, disc valve pin and the crank arm. The crank arm is connected to the disc valve by the disc valve pin. On the disc valve design, there are some modifications on the design. The modification is on the shape of the blade. The modification is on the figure 4.4. The half circle shape is adding to the design because it can increase the area open for the exhaust valve compared to the straight edge. The entire dimension is on the appendix F.

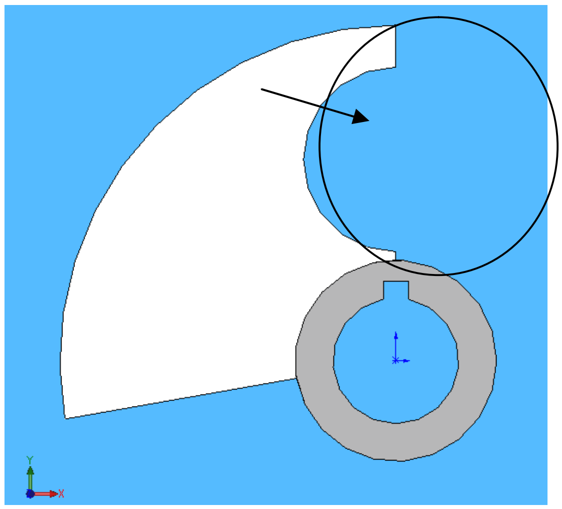


Figure 4.4: Half circle on the disc valve design

A disadvantage of this design is the valve timing is fixing. It is difficult to adjust the timing and it is important the timing can be adjustable. It is because the exhaust valve timing will affect the performance of the engine. If the timing is not suitable, the back pressure will happen during the combustion process. Another disadvantage is the connection between the disc valve and the crank arm is easy to defect. The reason is because the connection is only on the disc valve pin. All the force applied is on the disc valve pin.

4.2.3 Final design

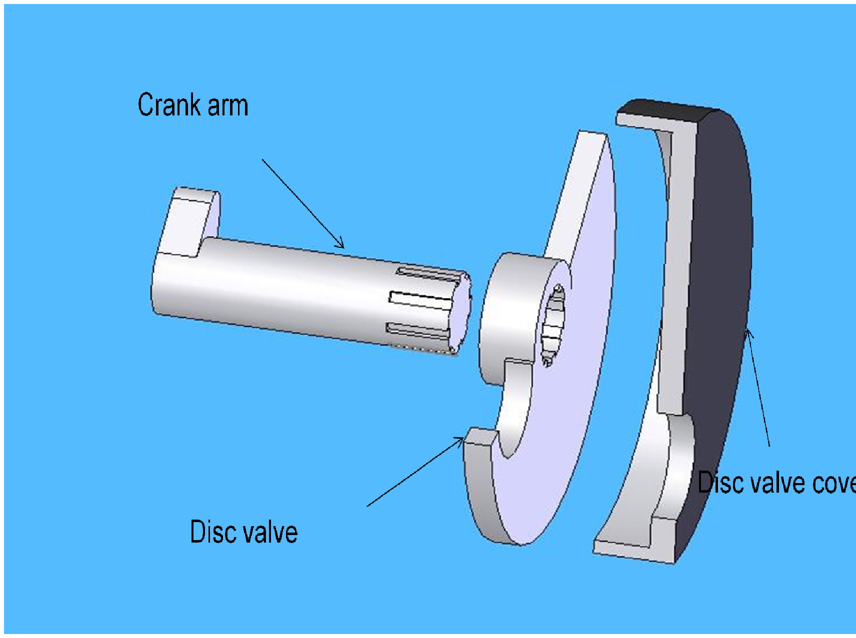


Figure 4.5: Final design of the disc valve

Figure 4.5 shows the final design of the disc valve. The design modification is including crank arm and the disc valve. The disc valve pin that has been design is removed and replace by the spline design concept.

The spline is on the crank arm and the disc valve. The dimension for the disc valve and crank arm spline is in the appendix G. The disc valve shape is slightly different from the previous design.

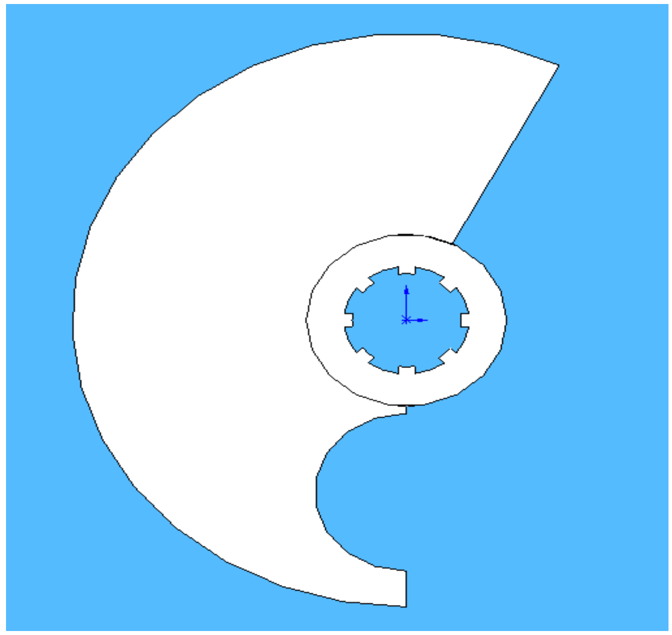


Figure 4.6: Disc valve exhaust port

Advantages of the new design are the valve timing is adjustable. Beside that, the force applied is not in the one point, but it separate to many points because the surface area contact is larger than before.

4.3 DISC VALVE ASSEMBLY IN THE NEW HEAD ENGINE SYSTEM.

The final design of the disc valve exhaust port finally will be assemble into the new head engine design. The disc valve is just bolt on into the head engine system. The structure of the disc valve assemblies in the new head engine design is shown in figure 4.7.

In the figure 4.7, that is some of the component for the new head engine component. The disc valve is fully controlled by the crank arm. It used the simple movement that is rotational movement. The exhaust port open and closed is controlled by the upper piston and the disc valve.

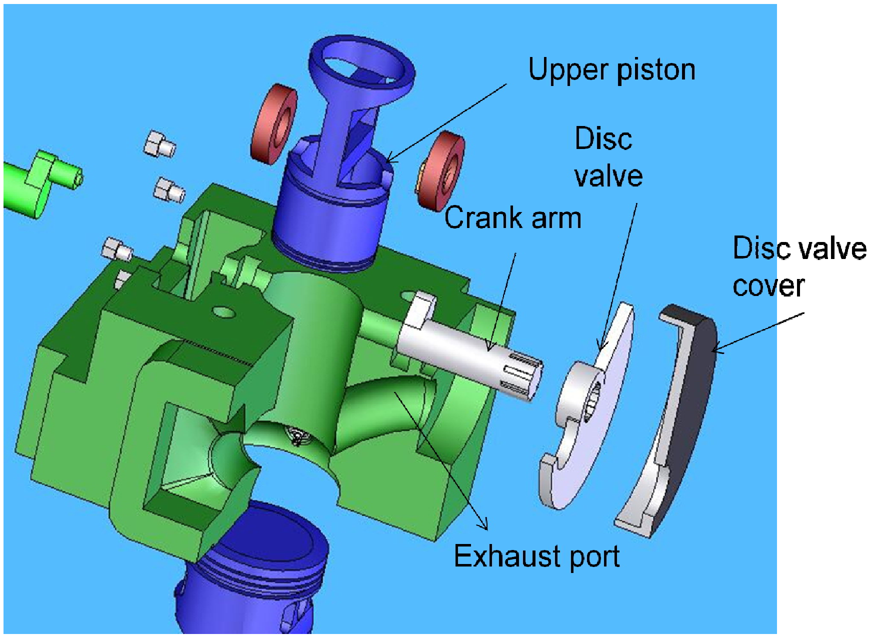


Figure 4.7: Picture of the disc valve design in the new cylinder head engine

The location of the new head engine exhaust port is same as the original location of the original head engine exhaust port to make sure that this new head engine system can use the original exhaust pipe. Main component for the disc valve exhaust port is crank arm, the disc valve, exhaust port, and the disc valve cover. The exhaust port diameter size is 22mm which is equally to the original exhaust port. The cover used to eliminate dirt from environment going into the combustion chamber that will make the combustion process inefficiency. Beside that, the disc valve covers also the joining between the exhaust port and the exhaust pipe. The lubrication system and the modification on the location and the valve timing need further study in the future.

4.4 DISC VALVE WORKING OPERATION

Disc valve working operational is based on the rotational movement. The disc valve is rotating by the crank arm and the gearing system. The disc valve operational is fully based on the movement of the upper piston and the crank arm. To describe the disc valve rotational, it will related to the new head engine working concept which is will be divided into the four process which is intake, compression, power and lastly exhaust stroke.

4.4.1 Intake stroke.

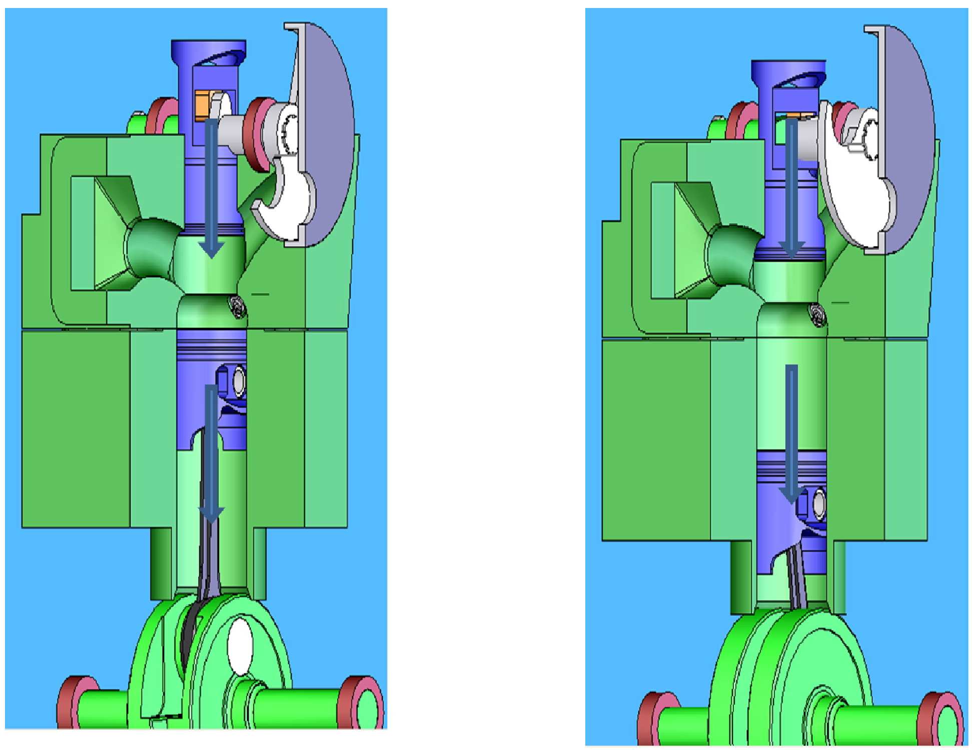


Figure 4.8: The movement of the disc valve during the intake stroke

During this process, the mixture of fuel and air is going into the combustion chamber. In the intake stroke, the main piston firstly is at the top dead center (TDC) while the upper second piston is at the bottom dead center (BDC). As the main piston is start descends, it will increase the volume, and at the same time upper piston is descend reducing the volume.

The pressure in the volume chamber is lower than the atmospheric pressure, that will make the mixture of the fuel and air is going through into the combustion chamber. The function of disc valve is during this process is to closed the exhaust port to make sure that there is no back pressure. At the 0^0 of crankshaft angle (main piston at the TDC), the disc valve is also at the 0^0.

During the main piston is at the bottom dead center (BDC), the second piston is descend at half of its bore, and the disc valve also rotate of the half of its valve timing. The rotational of the disc valve is depends on the crank arm and the crankshaft. The crankshaft angle at the 180^0(the main piston is at the BDC), the disc valve is rotate about 90^0. During this process, the upper piston is starting to close the exhaust port due to the location of the exhaust port in the new head engine system.

The movement of upper second piston is synchronized at half the main piston rotational speed. The movement is achieved by the design of the crank arm for the upper second piston. The process during the intake stroke is simplified in the figure 4.8.

4.4.2 Compression stroke

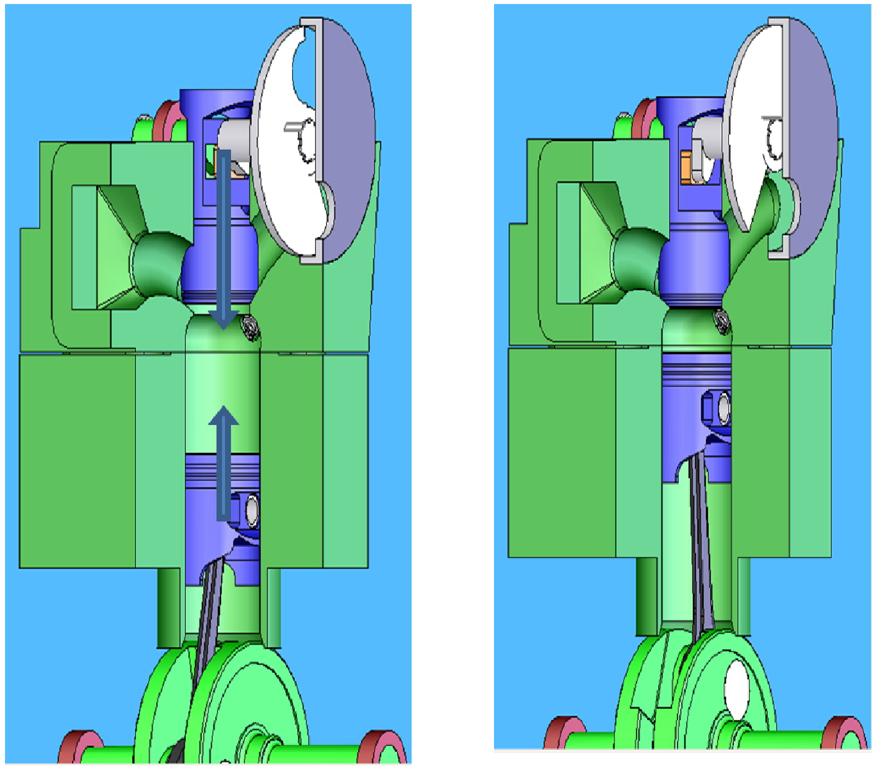


Figure 4.9: The movement of the disc valve during the compression stroke

In the compression stroke, the pressure in the combustion chamber is high. The compression stroke is compressing the mixture of fuel and air in the combustion chamber. The higher pressure during this process can be achieved to the 2000kPa for the original four stroke engine. For this engine, during the compression stroke, the main piston is ascending while the upper second piston is continues descending. Both pistons are reducing the volume in the combustion chamber.

At the end process, the main piston at the top dead center (TDC), while the second upper piston is at the top dead center (TDC). The crankshaft angle is at the 360^0 while the disc valve is rotate about 180^0. During this process, the upper second piston is slowly closed the exhaust port while the disc valve is rotate slowly open the exhaust port. When the upper second piston at the TDC, the exhaust port is fully closed by the piston and the disc valve is start to open the exhaust port due the rotational motion of the valve and the location of the exhaust port. Figure 4.9 shows how the disc valve rotate during the compression stroke

4.4.3 Power (Expansion) stroke

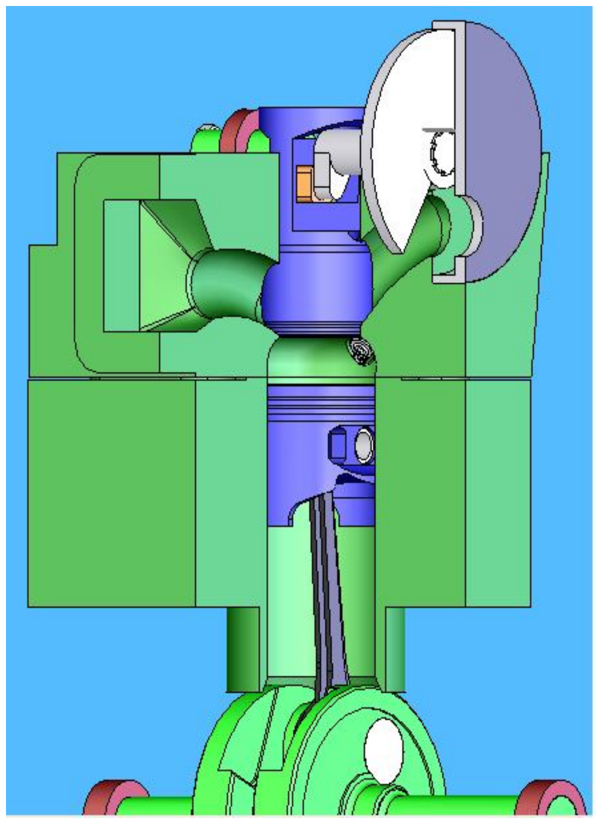


Figure 4.10: Movement of the disc valve during the power(expansion) stroke.

In the expansion stroke, the compress mixture of fuel and air is burning and it ignites by the firing from the motorcycle plug. During the process, the mixture is at the highest pressure. The temperature at the combustion chamber is also high. The mixture is easy to burn.

In the expansion stroke, the main piston and the upper second piston is at the top dead center (TDC). The exhaust port is only closing by the upper second piston. The disc valve is starting open the exhaust port. After the ignition process, the main piston is start descending while the upper second piston is starting ascending. During the second piston is ascending, automatically the exhaust port is start to open and the disc valve is fully open the exhaust port due to the rotation of the crank arm. The process is in the figure 4.10.

4.4.4 Exhaust stroke.

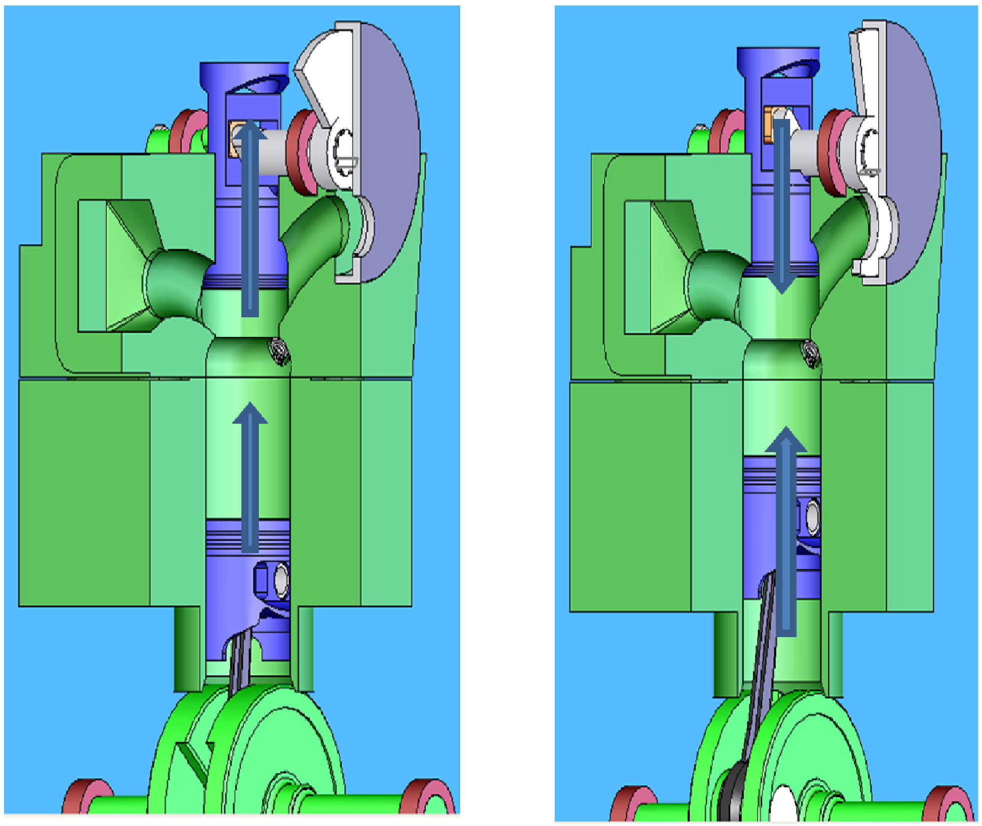


Figure 4.11: movement of the disc valve during the exhaust stroke

Exhaust stroke is the last stroke for every internal combustion engine. During this stroke, the emission is going out from the combustion chamber. The exhaust emission will going through the exhaust port, and going through the exhaust piping.

In the new head engine, during the exhaust stroke, the main piston will ascending from bottom dead center (BDC) to the top dead center reducing the volume of the combustion chamber while the upper second piston is continuous ascending to the bottom dead center (BDC). During this process, the upper second piston is automatically open the exhaust port and the disc valve has already open the exhaust port. When the crankshaft angle is 720^0, the disc valve is start closing the exhaust port. The exhaust port fully open is during the main piston is ascending. Figure 4.11 shows the disc valve during the exhaust stroke.

4.5 COMPONENT COMPARISON.

In this subchapter, the component comparison is between the original exhaust valve trains with the new disc valve exhaust port. The comparison is only on the working concept and the number of component.

4.5.1 Original exhaust valve train.

Figure 4.12: The original exhaust component valve train popper valve, valve spring, cam shaft, rocker arm.

In the original exhaust valve train system, the components are the popper valve, valve spring, cam shaft and the rocker arm. In the original valve train system, the exhaust valve is controlled by the cam shaft and the cam profile. The crankshaft will rotate the camshaft and it is connected by the chain and the gearing system.

The camshaft will connected to the rocker arm and the rocker arm will push the popper valve to open the exhaust port. The valve lift is depending on the rocker arm and the exhaust cam profile. The spring is used to push back the popper valve to close back the exhaust port. This system working is complicated and it is difficult to modified or adjust the valve timing.

4.5.2 Disc valve exhaust port.

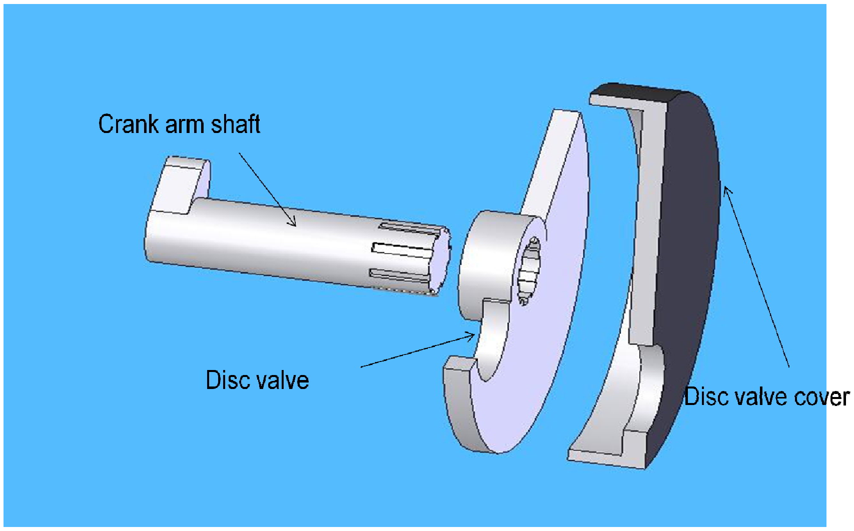


Figure 4.13: The disc valve exhaust port component.

Figure 4.13 shows the component for the disc valve exhaust port. The components are the disc valve, the crank arm shaft and the disc valve cover. The working principle for the disc valve is only rotational motion. The crank shaft will connected to the crank arm by the chain and gearing system. The crankshaft will rotate the crank arm. The disc valve is connected to the crank arm and automatically the disc valve will follow the rotation of the crank arm.

The valve timing for the disc valve is fully controlled by the design of the disc valve. The duration for the disc valve open is also controlled by the disc valve. The number of component is also less than the original component and it is easy to assemble in the head engine.

4.6 SWEPT VOLUME FOR THE NEW HEAD ENGINE SYSTEM.

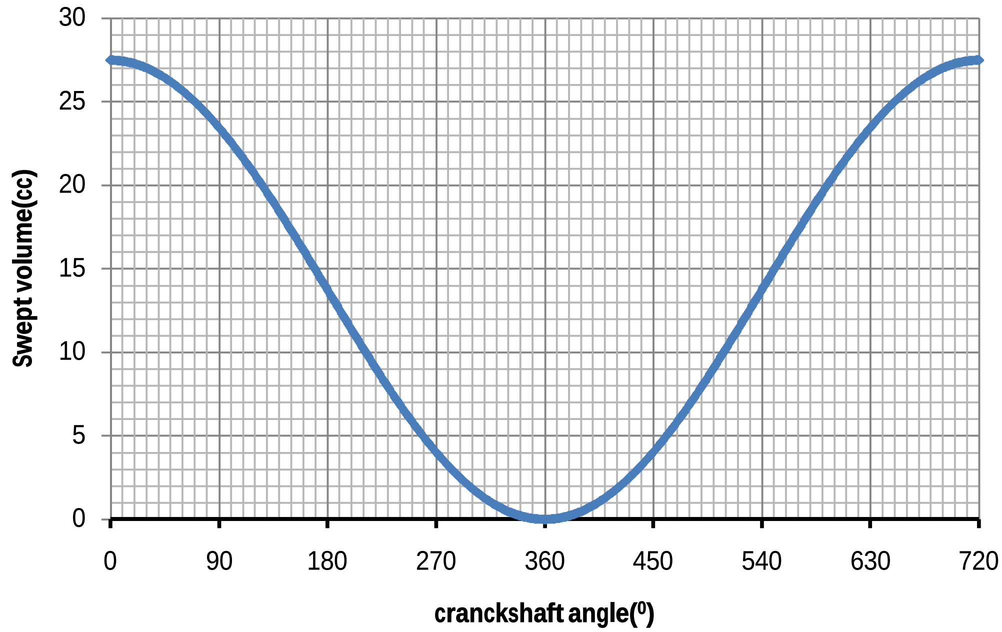


Figure 4.14: Graph of swept volume for upper second piston vs crankshaft angle.

Figure 4.14 shows swept volume for the upper second piston vs the crankshaft angle. The graph plotting is based on the data that have on the appendix C. The graph is based on the sinusoidal graph that is:

$$y(t)=13.75\cos(wt/2)+13.75 \tag{4.1}$$

At the 0^0 crankshaft angle, the main piston is at the top dead center while the upper second piston is at the bottom dead center. The swept volume for the second upper piston at the 00 crankshaft angle is 27.5 centimeter cubic. At the 180^0 crankshaft angle, the swept volume for the upper piston is decreasing to the half of the original swept volume. Crankshaft angle at 360^0, the upper piston swept volume is zero centimeter cubic. During this time, the upper piston is at the top dead center. When the crankshaft angle is at the 540^0, the upper piston is at the half of the combustion chamber and the swept volume is half of the full swept volume. At the crankshaft angle is 720^0, the swept volume is 27.5 centimeter cubic which is at this angle, and the upper piston is at the bottom dead center.

The second upper piston swept volume is the ratio of the Beare Head engine to the Modenas Kriss head engine. From the Beare Head engine, the ratio of the swept volume main piston to the upper second piston is equal to four. By using the same ratio as Beare Head engine, the second upper piston swept volume for Modenas Kriss 110cc engine is equal to 27.5 centimeter cubic. The calculation is on the appendix xx. For the combustion chamber, the ratio for the Beare Head engine is 10. The combustion chamber for the Modenas Kriss 110cc is 11centimeter cubic. The full calculation is on the appendix D.

After using the new head engine, the swept volume is increasing compared using the original head engine. It is because in the new head engine design, the upper second piston has own swept volume during the combustion process.

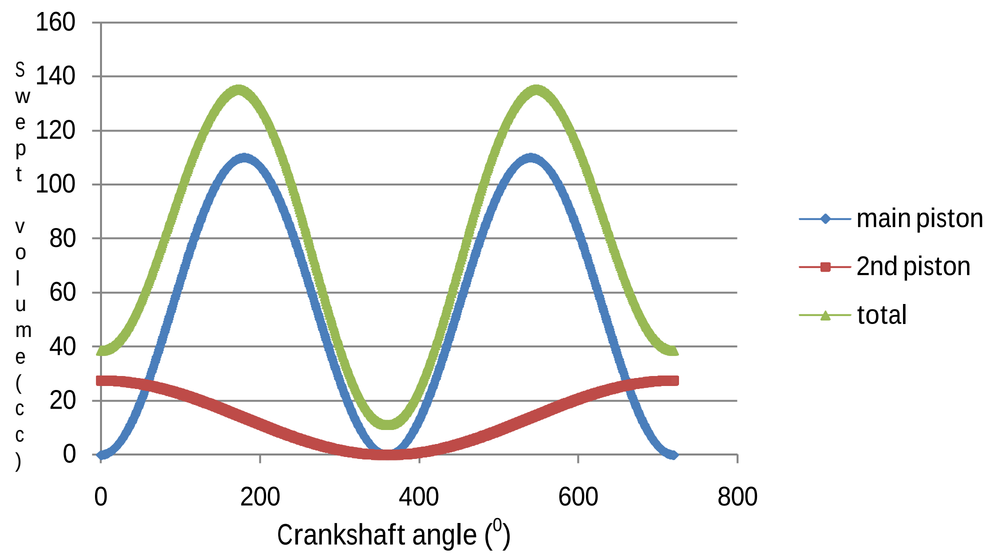


Figure 4.15: Combination graph of the swept volume vs crankshaft angle

Figure 4.15 is the combination of the original swept volume and the upper second piston swept volume. From the graph, it shows that the total swept volume for the new head engine is increased. The total swept volume for the new head engine is about 137.5 centimeter cubic. All the data for the combination graph are in the appendix C. The graph is generate by using Microsoft excel.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSIONS

Disc valve exhaust port is some of the design that can replace the usage of popper valve in the internal combustion engine. The simple working concept and simple component is the advantages of using the disc valve exhaust port system.

In the new cylinder head, the disc valve is assembling with the crank arm. The disc valve rotational is based on the crank arm rotational. The crankshaft is connected to the crank arm by the gearing and chain system. The crank arm will connected to the upper second piston and the disc valve. The upper second piston movement is synchronized at half of the main piston rotational speed that means the upper piston movement is half of the main piston movement.

The exhaust port open is controlled by the upper second piston and the disc valve. The exhaust valve timing and exhaust valve duration is fully based on the design of the disc valve. The different disc valve will affect the valve timing. The valve timing will affect the performance and engine efficiency of the engine.

The spline design in the disc valve is used to control the valve timing. The disc valve design is to control the valve duration. Both of the components are important to make sure that the disc valve is following the original valve timing.

5.2 RECOMMENDATIONS

In this project, there are several analyses and work can be done to improve the disc valve design. It is important to make sure that the project can operate in the internal combustion engine with the fewer defects.

5.2.1 Analysis on the disc valve component and the suitable material.

The analysis is important to make sure that the component is fewer defects with the suitable materials. The working temperature for the exhaust port can reach about 1000 degrees centigrade. It is important to make sure that this disc valve component can work at this range of temperature. The suggestions for the material are ceramic coated plastic, aluminum or titanium.

5.2.2 Study on exhaust valve timing.

The valve timing will affect the engine performance. The study is on the different type of the valve timing.

5.2.3 Design the lubrication system

The disc valve component is rotational motion. The friction is between the disc valve and the head engine wall. The lubrication is important to make sure that the friction can be reduced.

5.2.4 Component fabrication.

The disc valve concept can be operate in the Solidwork animation, to make sure that the component can be operate, it is important to fabricate and analysis on the design.

5.2.4 Study on location and design of the exhaust port.

The location and the design of the exhaust port will affect the exhaust gaseous flow. The different location also will affect the exhaust valve timing. The analysis can be done by using CFD flow analysis.

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   (Sunday, 10 February 2008)

10. http://www.isdm.co.uk/aspin/AspinEssay/essay.htm

    (Thursday, 14 February 2008)

APPENDIX A

Gantt chart for final year project 1 and 2.

a) Gantt chart for final year project 1

Week / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project briefing by supervisor																
literature review																
schedule management																
submission of project planning																
study on the original engine system-4 stroke engine(EAN 110)																
study about 2-stroke engine																
study on disc valve																
study about GT POWER software																
modelling the crankshaft on GT POWER																
get the data from the software																
Submit proposal																
Presentation																

b) Gantt chart for final year project 2

. Week / Activity	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Project briefing by supervisor																
schedule management																
submission of project planning																
Study the concept of six stroke engine																
Design the disc valve																
Study the result																
modification on the design																
Draft report																
presentation																
Report typing																

APPENDIX B

Table swept volume vs crank angle for original Modenas Kriss 110

cranck shaft angle(degree)	radians	main piston swept volume(cc)
0	0	0
1	0.017453	0.008376766
2	0.034907	0.033504514
3	0.05236	0.075375588
4	0.069813	0.133977236
5	0.087266	0.209291605
6	0.10472	0.301295755
7	0.122173	0.40996166
8	0.139626	0.535256219
9	0.15708	0.677141267
10	0.174533	0.835573584
11	0.191986	1.01050491
12	0.20944	1.20188196
13	0.226893	1.409646437
14	0.244346	1.633735055
15	0.261799	1.874079554
16	0.279253	2.130606723
17	0.296706	2.403238422
18	0.314159	2.691891604
19	0.331613	2.996478342
20	0.349066	3.316905857
21	0.366519	3.653076543
22	0.383972	4.004887999
23	0.401426	4.37223306
24	0.418879	4.75499983
25	0.436332	5.153071713
26	0.453786	5.566327454
27	0.471239	5.99464117
28	0.488692	6.437882393
29	0.506145	6.895916107
30	0.523599	7.368602792
31	0.541052	7.855798461
32	0.558505	8.357354711
33	0.575959	8.873118763
34	0.593412	9.402933509
35	0.610865	9.946637564
36	0.628319	10.50406531

37	0.645772	11.07504695
38	0.663225	11.65940855
39	0.680678	12.25697212
40	0.698132	12.86755563
41	0.715585	13.49097309
42	0.733038	14.1270346
43	0.750492	14.77554641
44	0.767945	15.43631098
45	0.785398	16.10912703
46	0.802851	16.79378962
47	0.820305	17.4900902
48	0.837758	18.19781665
49	0.855211	18.91675341
50	0.872665	19.64668147
51	0.890118	20.38737849
52	0.907571	21.13861886
53	0.925025	21.90017373
54	0.942478	22.67181112
55	0.959931	23.453296
56	0.977384	24.24439031
57	0.994838	25.04485307
58	1.012291	25.85444047
59	1.029744	26.67290588
60	1.047198	27.5
61	1.064651	28.33547089
62	1.082104	29.17906405
63	1.099557	30.03052251
64	1.117011	30.88958693
65	1.134464	31.7559956
66	1.151917	32.62948463
67	1.169371	33.50978793
68	1.186824	34.39663736
69	1.204277	35.28976278
70	1.22173	36.18889212
71	1.239184	37.0937515
72	1.256637	38.00406531
73	1.27409	38.91955624
74	1.291544	39.83994543
75	1.308997	40.76495252
76	1.32645	41.69429574
77	1.343904	42.62769201

78	1.361357	43.56485701
79	1.37881	44.50550525
80	1.396263	45.44935023
81	1.413717	46.39610442
82	1.43117	47.34547945
83	1.448623	48.29718611
84	1.466077	49.25093452
85	1.48353	50.20643415
86	1.500983	51.16339394
87	1.518436	52.12152241
88	1.53589	53.08052768
89	1.553343	54.04011765
90	1.570796	55
91	1.58825	55.95988235
92	1.605703	56.91947232
93	1.623156	57.87847759
94	1.640609	58.83660606
95	1.658063	59.79356585
96	1.675516	60.74906548
97	1.692969	61.70281389
98	1.710423	62.65452055
99	1.727876	63.60389558
100	1.745329	64.55064977
101	1.762783	65.49449475
102	1.780236	66.43514299
103	1.797689	67.37230799
104	1.815142	68.30570426
105	1.832596	69.23504748
106	1.850049	70.16005457
107	1.867502	71.08044376
108	1.884956	71.99593469
109	1.902409	72.9062485
110	1.919862	73.81110788
111	1.937315	74.71023722
112	1.954769	75.60336264
113	1.972222	76.49021207
114	1.989675	77.37051537
115	2.007129	78.2440044
116	2.024582	79.11041307
117	2.042035	79.96947749
118	2.059489	80.82093595

119	2.076942	81.66452911
120	2.094395	82.5
121	2.111848	83.32709412
122	2.129302	84.14555953
123	2.146755	84.95514693
124	2.164208	85.75560969
125	2.181662	86.546704
126	2.199115	87.32818888
127	2.216568	88.09982627
128	2.234021	88.86138114
129	2.251475	89.61262151
130	2.268928	90.35331853
131	2.286381	91.08324659
132	2.303835	91.80218335
133	2.321288	92.5099098
134	2.338741	93.20621038
135	2.356194	93.89087297
136	2.373648	94.56368902
137	2.391101	95.22445359
138	2.408554	95.8729654
139	2.426008	96.50902691
140	2.443461	97.13244437
141	2.460914	97.74302788
142	2.478368	98.34059145
143	2.495821	98.92495305
144	2.513274	99.49593469
145	2.530727	100.0533624
146	2.548181	100.5970665
147	2.565634	101.1268812
148	2.583087	101.6426453
149	2.600541	102.1442015
150	2.617994	102.6313972
151	2.635447	103.1040839
152	2.6529	103.5621176
153	2.670354	104.0053588
154	2.687807	104.4336725
155	2.70526	104.8469283
156	2.722714	105.2450002
157	2.740167	105.6277669
158	2.75762	105.995112
159	2.775074	106.3469235

160	2.792527	106.6830941
161	2.80998	107.0035217
162	2.827433	107.3081084
163	2.844887	107.5967616
164	2.86234	107.8693933
165	2.879793	108.1259204
166	2.897247	108.3662649
167	2.9147	108.5903536
168	2.932153	108.798118
169	2.949606	108.9894951
170	2.96706	109.1644264
171	2.984513	109.3228587
172	3.001966	109.4647438
173	3.01942	109.5900383
174	3.036873	109.6987042
175	3.054326	109.7907084
176	3.071779	109.8660228
177	3.089233	109.9246244
178	3.106686	109.9664955
179	3.124139	109.9916232
180	3.141593	110
181	3.159046	109.9916232
182	3.176499	109.9664955
183	3.193953	109.9246244
184	3.211406	109.8660228
185	3.228859	109.7907084
186	3.246312	109.6987042
187	3.263766	109.5900383
188	3.281219	109.4647438
189	3.298672	109.3228587
190	3.316126	109.1644264
191	3.333579	108.9894951
192	3.351032	108.798118
193	3.368485	108.5903536
194	3.385939	108.3662649
195	3.403392	108.1259204
196	3.420845	107.8693933
197	3.438299	107.5967616
198	3.455752	107.3081084
199	3.473205	107.0035217
200	3.490659	106.6830941
201	3.508112	106.3469235
202	3.525565	105.995112
203	3.543018	105.6277669
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207	3.612832	104.0053588
208	3.630285	103.5621176
209	3.647738	103.1040839
210	3.665191	102.6313972
211	3.682645	102.1442015
212	3.700098	101.6426453
213	3.717551	101.1268812
214	3.735005	100.5970665
215	3.752458	100.0533624
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217	3.787364	98.92495305
218	3.804818	98.34059145
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220	3.839724	97.13244437
221	3.857178	96.50902691
222	3.874631	95.8729654
223	3.892084	95.22445359
224	3.909538	94.56368902
225	3.926991	93.89087297
226	3.944444	93.20621038
227	3.961897	92.5099098
228	3.979351	91.80218335
229	3.996804	91.08324659
230	4.014257	90.35331853
231	4.031711	89.61262151
232	4.049164	88.86138114
233	4.066617	88.09982627
234	4.08407	87.32818888
235	4.101524	86.546704
236	4.118977	85.75560969
237	4.13643	84.95514693
238	4.153884	84.14555953
239	4.171337	83.32709412
240	4.18879	82.5
241	4.206243	81.66452911

242	4.223697	80.82093595
243	4.24115	79.96947749
244	4.258603	79.11041307
245	4.276057	78.2440044
246	4.29351	77.37051537
247	4.310963	76.49021207
248	4.328417	75.60336264
249	4.34587	74.71023722
250	4.363323	73.81110788
251	4.380776	72.9062485
252	4.39823	71.99593469
253	4.415683	71.08044376
254	4.433136	70.16005457
255	4.45059	69.23504748
256	4.468043	68.30570426
257	4.485496	67.37230799
258	4.502949	66.43514299
259	4.520403	65.49449475
260	4.537856	64.55064977
261	4.555309	63.60389558
262	4.572763	62.65452055
263	4.590216	61.70281389
264	4.607669	60.74906548
265	4.625123	59.79356585
266	4.642576	58.83660606
267	4.660029	57.87847759
268	4.677482	56.91947232
269	4.694936	55.95988235
270	4.712389	55
271	4.729842	54.04011765
272	4.747296	53.08052768
273	4.764749	52.12152241
274	4.782202	51.16339394
275	4.799655	50.20643415
276	4.817109	49.25093452
277	4.834562	48.29718611
278	4.852015	47.34547945
279	4.869469	46.39610442
280	4.886922	45.44935023
281	4.904375	44.50550525
282	4.921828	43.56485701

283	4.939282	42.62769201
284	4.956735	41.69429574
285	4.974188	40.76495252
286	4.991642	39.83994543
287	5.009095	38.91955624
288	5.026548	38.00406531
289	5.044002	37.0937515
290	5.061455	36.18889212
291	5.078908	35.28976278
292	5.096361	34.39663736
293	5.113815	33.50978793
294	5.131268	32.62948463
295	5.148721	31.7559956
296	5.166175	30.88958693
297	5.183628	30.03052251
298	5.201081	29.17906405
299	5.218534	28.33547089
300	5.235988	27.5
301	5.253441	26.67290588
302	5.270894	25.85444047
303	5.288348	25.04485307
304	5.305801	24.24439031
305	5.323254	23.453296
306	5.340708	22.67181112
307	5.358161	21.90017373
308	5.375614	21.13861886
309	5.393067	20.38737849
310	5.410521	19.64668147
311	5.427974	18.91675341
312	5.445427	18.19781665
313	5.462881	17.4900902
314	5.480334	16.79378962
315	5.497787	16.10912703
316	5.51524	15.43631098
317	5.532694	14.77554641
318	5.550147	14.1270346
319	5.5676	13.49097309
320	5.585054	12.86755563
321	5.602507	12.25697212
322	5.61996	11.65940855
323	5.637413	11.07504695

324	5.654867	10.50406531
325	5.67232	9.946637564
326	5.689773	9.402933509
327	5.707227	8.873118763
328	5.72468	8.357354711
329	5.742133	7.855798461
330	5.759587	7.368602792
331	5.77704	6.895916107
332	5.794493	6.437882393
333	5.811946	5.99464117
334	5.8294	5.566327454
336	5.864306	4.75499983
337	5.88176	4.37223306
338	5.899213	4.004887999
339	5.916666	3.653076543
340	5.934119	3.316905857
341	5.951573	2.996478342
342	5.969026	2.691891604
343	5.986479	2.403238422
344	6.003933	2.130606723
345	6.021386	1.874079554
346	6.038839	1.633735055
347	6.056293	1.409646437
348	6.073746	1.20188196
349	6.091199	1.01050491
350	6.108652	0.835573584
351	6.126106	0.677141267
352	6.143559	0.535256219
353	6.161012	0.40996166
354	6.178466	0.301295755
355	6.195919	0.209291605
356	6.213372	0.133977236
357	6.230825	0.075375588
358	6.248279	0.033504514
359	6.265732	0.008376766
360	6.283185	0
361	6.300639	0.008376766
362	6.318092	0.033504514
363	6.335545	0.075375588
364	6.352998	0.133977236
365	6.370452	0.209291605

366	6.387905	0.301295755
367	6.405358	0.40996166
368	6.422812	0.535256219
369	6.440265	0.677141267
370	6.457718	0.835573584
371	6.475172	1.01050491
372	6.492625	1.20188196
373	6.510078	1.409646437
374	6.527531	1.633735055
375	6.544985	1.874079554
376	6.562438	2.130606723
377	6.579891	2.403238422
378	6.597345	2.691891604
379	6.614798	2.996478342
380	6.632251	3.316905857
381	6.649704	3.653076543
382	6.667158	4.004887999
383	6.684611	4.37223306
384	6.702064	4.75499983
385	6.719518	5.153071713
386	6.736971	5.566327454
387	6.754424	5.99464117
388	6.771877	6.437882393
389	6.789331	6.895916107
390	6.806784	7.368602792
391	6.824237	7.855798461
392	6.841691	8.357354711
393	6.859144	8.873118763
394	6.876597	9.402933509
395	6.894051	9.946637564
396	6.911504	10.50406531
397	6.928957	11.07504695
398	6.94641	11.65940855
399	6.963864	12.25697212
400	6.981317	12.86755563
401	6.99877	13.49097309
402	7.016224	14.1270346
403	7.033677	14.77554641
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405	7.068583	16.10912703
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407	7.10349	17.4900902
408	7.120943	18.19781665
409	7.138397	18.91675341
410	7.15585	19.64668147
411	7.173303	20.38737849
412	7.190757	21.13861886
413	7.20821	21.90017373
414	7.225663	22.67181112
415	7.243116	23.453296
416	7.26057	24.24439031
417	7.278023	25.04485307
418	7.295476	25.85444047
419	7.31293	26.67290588
420	7.330383	27.5
421	7.347836	28.33547089
422	7.365289	29.17906405
423	7.382743	30.03052251
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425	7.417649	31.7559956
426	7.435103	32.62948463
427	7.452556	33.50978793
428	7.470009	34.39663736
429	7.487462	35.28976278
430	7.504916	36.18889212
431	7.522369	37.0937515
432	7.539822	38.00406531
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434	7.574729	39.83994543
435	7.592182	40.76495252
436	7.609636	41.69429574
437	7.627089	42.62769201
438	7.644542	43.56485701
439	7.661995	44.50550525
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441	7.696902	46.39610442
442	7.714355	47.34547945
443	7.731809	48.29718611
444	7.749262	49.25093452
445	7.766715	50.20643415
446	7.784168	51.16339394
447	7.801622	52.12152241

448	7.819075	53.08052768
449	7.836528	54.04011765
450	7.853982	55
451	7.871435	55.95988235
452	7.888888	56.91947232
453	7.906342	57.87847759
454	7.923795	58.83660606
455	7.941248	59.79356585
456	7.958701	60.74906548
457	7.976155	61.70281389
458	7.993608	62.65452055
459	8.011061	63.60389558
460	8.028515	64.55064977
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466	8.133234	70.16005457
467	8.150688	71.08044376
468	8.168141	71.99593469
469	8.185594	72.9062485
470	8.203047	73.81110788
471	8.220501	74.71023722
472	8.237954	75.60336264
473	8.255407	76.49021207
474	8.272861	77.37051537
475	8.290314	78.2440044
476	8.307767	79.11041307
477	8.325221	79.96947749
478	8.342674	80.82093595
479	8.360127	81.66452911
480	8.37758	82.5
481	8.395034	83.32709412
482	8.412487	84.14555953
483	8.42994	84.95514693
484	8.447394	85.75560969
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486	8.4823	87.32818888
487	8.499753	88.09982627
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493	8.604473	92.5099098
494	8.621927	93.20621038
495	8.63938	93.89087297
496	8.656833	94.56368902
497	8.674286	95.22445359
498	8.69174	95.8729654
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558	9.738937	107.3081084
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563	9.826204	105.6277669
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577	10.07055	98.92495305
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580	10.12291	97.13244437
581	10.14036	96.50902691
582	10.15782	95.8729654
583	10.17527	95.22445359
584	10.19272	94.56368902
585	10.21018	93.89087297
586	10.22763	93.20621038
587	10.24508	92.5099098
588	10.26254	91.80218335
589	10.27999	91.08324659
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591	10.3149	89.61262151
592	10.33235	88.86138114
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595	10.38471	86.546704
596	10.40216	85.75560969
597	10.41962	84.95514693
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599	10.45452	83.32709412
600	10.47198	82.5
601	10.48943	81.66452911
602	10.50688	80.82093595
603	10.52434	79.96947749
604	10.54179	79.11041307
605	10.55924	78.2440044
606	10.5767	77.37051537
607	10.59415	76.49021207
608	10.6116	75.60336264
609	10.62906	74.71023722
610	10.64651	73.81110788
611	10.66396	72.9062485
612	10.68142	71.99593469

613	10.69887	71.08044376
614	10.71632	70.16005457
615	10.73377	69.23504748
616	10.75123	68.30570426
617	10.76868	67.37230799
618	10.78613	66.43514299
619	10.80359	65.49449475
620	10.82104	64.55064977
621	10.83849	63.60389558
622	10.85595	62.65452055
623	10.8734	61.70281389
624	10.89085	60.74906548
625	10.90831	59.79356585
626	10.92576	58.83660606
627	10.94321	57.87847759
628	10.96067	56.91947232
629	10.97812	55.95988235
630	10.99557	55
631	11.01303	54.04011765
632	11.03048	53.08052768
633	11.04793	52.12152241
634	11.06539	51.16339394
635	11.08284	50.20643415
636	11.10029	49.25093452
637	11.11775	48.29718611
638	11.1352	47.34547945
639	11.15265	46.39610442
640	11.17011	45.44935023
641	11.18756	44.50550525
642	11.20501	43.56485701
643	11.22247	42.62769201
644	11.23992	41.69429574
645	11.25737	40.76495252
647	11.29228	38.91955624
648	11.30973	38.00406531
649	11.32719	37.0937515
650	11.34464	36.18889212
651	11.36209	35.28976278
652	11.37955	34.39663736
653	11.397	33.50978793
654	11.41445	32.62948463

655	11.43191	31.7559956
656	11.44936	30.88958693
657	11.46681	30.03052251
658	11.48427	29.17906405
659	11.50172	28.33547089
660	11.51917	27.5
661	11.53663	26.67290588
662	11.55408	25.85444047
663	11.57153	25.04485307
664	11.58899	24.24439031
665	11.60644	23.453296
666	11.62389	22.67181112
667	11.64135	21.90017373
668	11.6588	21.13861886
669	11.67625	20.38737849
670	11.69371	19.64668147
671	11.71116	18.91675341
672	11.72861	18.19781665
673	11.74607	17.4900902
674	11.76352	16.79378962
675	11.78097	16.10912703
676	11.79843	15.43631098
677	11.81588	14.77554641
678	11.83333	14.1270346
679	11.85079	13.49097309
680	11.86824	12.86755563
681	11.88569	12.25697212
682	11.90315	11.65940855
683	11.9206	11.07504695
684	11.93805	10.50406531
685	11.95551	9.946637564
686	11.97296	9.402933509
687	11.99041	8.873118763
688	12.00787	8.357354711
689	12.02532	7.855798461
690	12.04277	7.368602792
691	12.06023	6.895916107
692	12.07768	6.437882393
693	12.09513	5.99464117
694	12.11259	5.566327454
695	12.13004	5.153071713
696	12.14749	4.75499983
697	12.16494	4.37223306
698	12.1824	4.004887999
699	12.19985	3.653076543
700	12.2173	3.316905857
701	12.23476	2.996478342
702	12.25221	2.691891604
703	12.26966	2.403238422
704	12.28712	2.130606723
705	12.30457	1.874079554
706	12.32202	1.633735055
707	12.33948	1.409646437
708	12.35693	1.20188196
709	12.37438	1.01050491
710	12.39184	0.835573584
711	12.40929	0.677141267
712	12.42674	0.535256219
713	12.4442	0.40996166
714	12.46165	0.301295755
715	12.4791	0.209291605
716	12.49656	0.133977236
717	12.51401	0.075375588
718	12.53146	0.033504514
719	12.54892	0.008376766
720	12.56637	0

APPENDIX C

Table of swept volume for second piston, total swept volume vs crank angle.

Cranck shaft angle (degree)	radians	2nd piston swept volume(cc)	total swept volume
0	0	27.5	38.5
1	0.017453	27.49947644	38.50785321
2	0.034907	27.49790581	38.53141032
3	0.05236	27.49528822	38.57066381
4	0.069813	27.49162387	38.62560111
5	0.087266	27.48691305	38.69620465
6	0.10472	27.4811561	38.78245186
7	0.122173	27.47435348	38.88431514
8	0.139626	27.46650569	39.00176191
9	0.15708	27.45761334	39.13475461
10	0.174533	27.4476771	39.28325068
11	0.191986	27.43669773	39.44720264
12	0.20944	27.42467606	39.62655802
13	0.226893	27.41161302	39.82125945
14	0.244346	27.39750959	40.03124464
15	0.261799	27.38236684	40.2564464
16	0.279253	27.36618595	40.49679267
17	0.296706	27.34896812	40.75220654
18	0.314159	27.33071468	41.02260629
19	0.331613	27.31142702	41.30790536
20	0.349066	27.2911066	41.60801246
21	0.366519	27.26975498	41.92283152
22	0.383972	27.24737377	42.25226177
23	0.401426	27.22396469	42.59619775
24	0.418879	27.19952951	42.95452934
25	0.436332	27.1740701	43.32714181
26	0.453786	27.14758839	43.71391584
27	0.471239	27.12008641	44.11472758
28	0.488692	27.09156624	44.52944863
29	0.506145	27.06203006	44.95794616
30	0.523599	27.03148011	45.4000829
31	0.541052	26.99991873	45.85571719
32	0.558505	26.96734832	46.32470303
33	0.575959	26.93377135	46.80689012
34	0.593412	26.89919039	47.3021239
35	0.610865	26.86360807	47.81024564
36	0.628319	26.8270271	48.33109241
37	0.645772	26.78945026	48.86449721
38	0.663225	26.75088041	49.41028897
39	0.680678	26.7113205	49.96829262
40	0.698132	26.67077354	50.53832916
41	0.715585	26.6292426	51.12021569
42	0.733038	26.58673086	51.71376546
43	0.750492	26.54324156	52.31878797
44	0.767945	26.498778	52.93508898
45	0.785398	26.45334357	53.56247061
46	0.802851	26.40694173	54.20073136
47	0.820305	26.35957602	54.84966622
48	0.837758	26.31125004	55.50906669
49	0.855211	26.26196747	56.17872088
50	0.872665	26.21173207	56.85841354
51	0.890118	26.16054766	57.54792615
52	0.907571	26.10841814	58.24703699
53	0.925025	26.05534747	58.9555212
54	0.942478	26.00133971	59.67315083
55	0.959931	25.94639896	60.39969496
56	0.977384	25.8905294	61.13491971
57	0.994838	25.8337353	61.87858837
58	1.012291	25.77602097	62.63046144
59	1.029744	25.71739082	63.3902967
60	1.047198	25.6578493	64.1578493
61	1.064651	25.59740096	64.93287184
62	1.082104	25.53605038	65.71511443
63	1.099557	25.47380226	66.50432477
64	1.117011	25.41066132	67.30024825
65	1.134464	25.34663238	68.10262798
66	1.151917	25.28172031	68.91120494
67	1.169371	25.21593005	69.72571799
68	1.186824	25.14926662	70.54590398
69	1.204277	25.08173509	71.37149787
70	1.22173	25.01334061	72.20223273
71	1.239184	24.94408838	73.03783988
72	1.256637	24.87398367	73.87804898
73	1.27409	24.80303183	74.72258807
74	1.291544	24.73123826	75.57118369
75	1.308997	24.65860843	76.42356095
76	1.32645	24.58514786	77.2794436
77	1.343904	24.51086216	78.13855417

78	1.361357	24.43575697	79.00061398
79	1.37881	24.35983802	79.86534328
80	1.396263	24.28311109	80.73246132
81	1.413717	24.20558203	81.60168645
82	1.43117	24.12725673	82.47273618
83	1.448623	24.04814116	83.34532727
84	1.466077	23.96824135	84.21917587
85	1.48353	23.88756338	85.09399753
86	1.500983	23.8061134	85.96950734
87	1.518436	23.7238976	86.84542001
88	1.53589	23.64092225	87.72144994
89	1.553343	23.55719368	88.59731132
90	1.570796	23.47271824	89.47271824
91	1.58825	23.38750238	90.34738474
92	1.605703	23.30155259	91.22102491
93	1.623156	23.21487542	92.09335301
94	1.640609	23.12747745	92.96408351
95	1.658063	23.03936535	93.83293121
96	1.675516	22.95054584	94.69961132
97	1.692969	22.86102566	95.56383955
98	1.710423	22.77081165	96.4253322
99	1.727876	22.67991066	97.28380624
100	1.745329	22.58832963	98.1389794
101	1.762783	22.49607553	98.99057027
102	1.780236	22.40315538	99.83829837
103	1.797689	22.30957625	100.6818842
104	1.815142	22.21534529	101.5210495
105	1.832596	22.12046965	102.3555171
106	1.850049	22.02495657	103.1850111
107	1.867502	21.92881332	104.0092571
108	1.884956	21.83204722	104.8279819
109	1.902409	21.73466564	105.6409141
110	1.919862	21.636676	106.4477839
111	1.937315	21.53808576	107.248323
112	1.954769	21.43890242	108.0422651
113	1.972222	21.33913355	108.8293456
114	1.989675	21.23878673	109.6093021
115	2.007129	21.13786961	110.381874
116	2.024582	21.03638988	111.146803
117	2.042035	20.93435526	111.9038328

118	2.059489	20.83177353	112.6527095
119	2.076942	20.72865249	113.3931816
120	2.094395	20.625	114.125
121	2.111848	20.52082395	114.8479181
122	2.129302	20.41613228	115.5616918
123	2.146755	20.31093295	116.2660799
124	2.164208	20.20523399	116.9608437
125	2.181662	20.09904343	117.6457474
126	2.199115	19.99236937	118.3205582
127	2.216568	19.88521993	118.9850462
128	2.234021	19.77760327	119.6389844
129	2.251475	19.66952758	120.2821491
130	2.268928	19.5610011	120.9143196
131	2.286381	19.45203209	121.5352787
132	2.303835	19.34262884	122.1448122
133	2.321288	19.2327997	122.7427095
134	2.338741	19.12255302	123.3287634
135	2.356194	19.0118972	123.9027702
136	2.373648	18.90084066	124.4645297
137	2.391101	18.78939187	125.0138455
138	2.408554	18.67755931	125.5505247
139	2.426008	18.56535149	126.0743784
140	2.443461	18.45277697	126.5852213
141	2.460914	18.33984431	127.0828722
142	2.478368	18.22656212	127.5671536
143	2.495821	18.11293903	128.0378921
144	2.513274	17.99898367	128.4949184
145	2.530727	17.88470474	128.9380672
146	2.548181	17.77011094	129.3671774
147	2.565634	17.65521099	129.7820922
148	2.583087	17.54001364	130.1826589
149	2.600541	17.42452767	130.5687292
150	2.617994	17.30876187	130.9401591
151	2.635447	17.19272506	131.2968089
152	2.6529	17.07642606	131.6385437
153	2.670354	16.95987375	131.9652326
154	2.687807	16.843077	132.2767495
155	2.70526	16.72604469	132.572973
156	2.722714	16.60878575	132.8537859
157	2.740167	16.4913091	133.119076

158	2.75762	16.37362369	133.3687357	198	3.455752	11.59902611	129.9071345
159	2.775074	16.25573848	133.6026619	199	3.473205	11.48059542	129.4841171
160	2.792527	16.13766244	133.8207566	200	3.490659	11.36233756	129.0454317
161	2.80998	16.01940458	134.0229262	201	3.508112	11.24426152	128.591185
162	2.827433	15.90097389	134.2090823	202	3.525565	11.12637631	128.1214883
163	2.844887	15.7823794	134.379141	203	3.543018	11.0086909	127.6364578
164	2.86234	15.66363014	134.5330234	204	3.560472	10.89121425	127.1362144
165	2.879793	15.54473514	134.6706556	205	3.577925	10.77395531	126.6208836
166	2.897247	15.42570347	134.7919684	206	3.595378	10.656923	126.0905955
167	2.9147	15.30654419	134.8968978	207	3.612832	10.54012625	125.5454851
168	2.932153	15.18726637	134.9853844	208	3.630285	10.42357394	124.9856915
169	2.949606	15.0678791	135.0573742	209	3.647738	10.30727494	124.4113588
170	2.96706	14.94839146	135.1128179	210	3.665191	10.19123813	123.8226353
171	2.984513	14.82881257	135.1516713	211	3.682645	10.07547233	123.2196739
172	3.001966	14.70915151	135.1738953	212	3.700098	9.959986358	122.6026316
173	3.01942	14.58941742	135.1794558	213	3.717551	9.84478901	121.9716702
174	3.036873	14.4696194	135.1683236	214	3.735005	9.72988906	121.3269556
175	3.054326	14.34976658	135.140475	215	3.752458	9.615295257	120.6686577
176	3.071779	14.22986808	135.0958908	216	3.769911	9.501016327	119.996951
177	3.089233	14.10993304	135.0345575	217	3.787364	9.387060974	119.312014
178	3.106686	13.98997059	134.9564661	218	3.804818	9.273437876	118.6140293
179	3.124139	13.86998986	134.8616131	219	3.822271	9.160155686	117.9031836
180	3.141593	13.75	134.75	220	3.839724	9.047223029	117.1796674
181	3.159046	13.63001014	134.6216334	221	3.857178	8.934648508	116.4436754
182	3.176499	13.51002941	134.4765249	222	3.874631	8.822440694	115.6954061
183	3.193953	13.39006696	134.3146914	223	3.892084	8.710608133	114.9350617
184	3.211406	13.27013192	134.1361547	224	3.909538	8.599159341	114.1628484
185	3.228859	13.15023342	133.9409418	225	3.926991	8.488102805	113.3789758
186	3.246312	13.0303806	133.7290848	226	3.944444	8.377446983	112.5836574
187	3.263766	12.91058258	133.5006209	227	3.961897	8.267200302	111.7771101
188	3.281219	12.79084849	133.2555923	228	3.979351	8.157371158	110.9595545
189	3.298672	12.67118743	132.9940462	229	3.996804	8.047967913	110.1312145
190	3.316126	12.55160854	132.716035	230	4.014257	7.938998901	109.2923174
191	3.333579	12.4321209	132.421616	231	4.031711	7.830472419	108.4430939
192	3.351032	12.31273363	132.1108517	232	4.049164	7.722396732	107.5837779
193	3.368485	12.19345581	131.7838094	233	4.066617	7.61478007	106.7146063
194	3.385939	12.07429653	131.4405615	234	4.08407	7.507630629	105.8358195
195	3.403392	11.95526486	131.0811853	235	4.101524	7.400956568	104.9476606
196	3.420845	11.83636986	130.7057631	236	4.118977	7.294766012	104.0503757
197	3.438299	11.7176206	130.3143822	237	4.13643	7.189067046	103.144214

238	4.153884	7.083867722	102.2294273
239	4.171337	6.979176049	101.3062702
240	4.18879	6.875	100.375
241	4.206243	6.771347509	99.43587662
242	4.223697	6.66822647	98.48916242
243	4.24115	6.565644735	97.53512222
244	4.258603	6.463610117	96.57402319
245	4.276057	6.362130385	95.60613478
246	4.29351	6.261213269	94.63172864
247	4.310963	6.160866452	93.65107852
248	4.328417	6.061097577	92.66446022
249	4.34587	5.961914242	91.67215147
250	4.363323	5.863324	90.67443188
251	4.380776	5.765334359	89.67158285
252	4.39823	5.667952781	88.66388747
253	4.415683	5.571186682	87.65163044
254	4.433136	5.475043432	86.635098
255	4.45059	5.379530351	85.61457783
256	4.468043	5.284654714	84.59035897
257	4.485496	5.190423746	83.56273174
258	4.502949	5.096844623	82.53198762
259	4.520403	5.003924471	81.49841922
260	4.537856	4.911670367	80.46232014
261	4.555309	4.820089335	79.42398491
262	4.572763	4.729188351	78.3837089
263	4.590216	4.638974337	77.34178822
264	4.607669	4.549454163	76.29851964
265	4.625123	4.460634645	75.2542005
266	4.642576	4.372522549	74.20912861
267	4.660029	4.285124584	73.16360218
268	4.677482	4.198447406	72.11791972
269	4.694936	4.112497616	71.07237997
270	4.712389	4.027281759	70.02728176
271	4.729842	3.942806324	68.98292397
272	4.747296	3.859077745	67.93960543
273	4.764749	3.776102399	66.89762481
274	4.782202	3.693886603	65.85728055
275	4.799655	3.612436619	64.81887077
276	4.817109	3.53175865	63.78269317
277	4.834562	3.451858839	62.74904495

278	4.852015	3.372743272	61.71822272
279	4.869469	3.294417973	60.6905224
280	4.886922	3.216888907	59.66623914
281	4.904375	3.140161978	58.64566723
282	4.921828	3.06424303	57.62910003
283	4.939282	2.989137843	56.61682985
284	4.956735	2.914852138	55.60914788
285	4.974188	2.841391571	54.60634409
286	4.991642	2.768761737	53.60870717
287	5.009095	2.696968167	52.61652441
288	5.026548	2.626016327	51.63008164
289	5.044002	2.555911623	50.64966313
290	5.061455	2.486659391	49.67555151
291	5.078908	2.418264906	48.70802768
292	5.096361	2.350733377	47.74737074
293	5.113815	2.284069947	46.79385788
294	5.131268	2.218279691	45.84776432
295	5.148721	2.15336762	44.90936322
296	5.166175	2.089338678	43.9789256
297	5.183628	2.02619774	43.05672025
298	5.201081	1.963949615	42.14301366
299	5.218534	1.902599044	41.23806993
300	5.235988	1.842150698	40.3421507
301	5.253441	1.782609181	39.45551506
302	5.270894	1.723979027	38.57841949
303	5.288348	1.666264701	37.71111778
304	5.305801	1.609470598	36.85386091
305	5.323254	1.553601044	36.00689704
306	5.340708	1.498660292	35.17047142
307	5.358161	1.444652528	34.34482625
308	5.375614	1.391581863	33.53020072
309	5.393067	1.33945234	32.72683083
310	5.410521	1.288267928	31.9349494
311	5.427974	1.238032525	31.15478593
312	5.445427	1.188749957	30.38656661
313	5.462881	1.140423977	29.63051417
314	5.480334	1.093058265	28.88684789
315	5.497787	1.046656428	28.15578346
316	5.51524	1.001222	27.43753298
317	5.532694	0.95675844	26.73230485

318	5.550147	0.913269136	26.04030373
319	5.5676	0.870757398	25.36173049
320	5.585054	0.829226464	24.69678209
321	5.602507	0.788679497	24.04565162
322	5.61996	0.749119586	23.40852814
323	5.637413	0.710549741	22.78559669
324	5.654867	0.672972901	22.17703821
325	5.67232	0.636391927	21.58302949
326	5.689773	0.600809606	21.00374311
327	5.707227	0.566228646	20.43934741
328	5.72468	0.532651681	19.89000639
329	5.742133	0.500081268	19.35587973
330	5.759587	0.468519889	18.83712268
331	5.77704	0.437969945	18.33388605
332	5.794493	0.408433764	17.84631616
333	5.811946	0.379913595	17.37455476
334	5.8294	0.352411609	16.91873906
335	5.846853	0.325929902	16.47900162
336	5.864306	0.30047049	16.05547032
337	5.88176	0.276035311	15.64826837
338	5.899213	0.252626228	15.25751423
339	5.916666	0.230245021	14.88332156
340	5.934119	0.208893396	14.52579925
341	5.951573	0.188572979	14.18505132
342	5.969026	0.169285317	13.86117692
343	5.986479	0.151031879	13.5542703
344	6.003933	0.133814055	13.26442078
345	6.021386	0.117633156	12.99171271
346	6.038839	0.102490415	12.73622547
347	6.056293	0.088386984	12.49803342
348	6.073746	0.075323939	12.2772059
349	6.091199	0.063302272	12.07380718
350	6.108652	0.052322901	11.88789649
351	6.126106	0.042386661	11.71952793
352	6.143559	0.033494309	11.56875053
353	6.161012	0.025646522	11.43560818
354	6.178466	0.018843897	11.32013965
355	6.195919	0.013086953	11.22237856
356	6.213372	0.008376128	11.14235336
357	6.230825	0.004711782	11.08008737

358	6.248279	0.002094192	11.03559871
359	6.265732	0.000523558	11.00890032
360	6.283185	0	11
361	6.300639	0.000523558	11.00890032
362	6.318092	0.002094192	11.03559871
363	6.335545	0.004711782	11.08008737
364	6.352998	0.008376128	11.14235336
365	6.370452	0.013086953	11.22237856
366	6.387905	0.018843897	11.32013965
367	6.405358	0.025646522	11.43560818
368	6.422812	0.033494309	11.56875053
369	6.440265	0.042386661	11.71952793
370	6.457718	0.052322901	11.88789649
371	6.475172	0.063302272	12.07380718
372	6.492625	0.075323939	12.2772059
373	6.510078	0.088386984	12.49803342
374	6.527531	0.102490415	12.73622547
375	6.544985	0.117633156	12.99171271
376	6.562438	0.133814055	13.26442078
377	6.579891	0.151031879	13.5542703
378	6.597345	0.169285317	13.86117692
379	6.614798	0.188572979	14.18505132
380	6.632251	0.208893396	14.52579925
381	6.649704	0.230245021	14.88332156
382	6.667158	0.252626228	15.25751423
383	6.684611	0.276035311	15.64826837
384	6.702064	0.30047049	16.05547032
385	6.719518	0.325929902	16.47900162
386	6.736971	0.352411609	16.91873906
387	6.754424	0.379913595	17.37455476
388	6.771877	0.408433764	17.84631616
389	6.789331	0.437969945	18.33388605
390	6.806784	0.468519889	18.83712268
391	6.824237	0.500081268	19.35587973
392	6.841691	0.532651681	19.89000639
393	6.859144	0.566228646	20.43934741
394	6.876597	0.600809606	21.00374311
395	6.894051	0.636391927	21.58302949
396	6.911504	0.672972901	22.17703821
397	6.928957	0.710549741	22.78559669

398	6.94641	0.749119586	23.40852814
399	6.963864	0.788679497	24.04565162
400	6.981317	0.829226464	24.69678209
401	6.99877	0.870757398	25.36173049
402	7.016224	0.913269136	26.04030373
403	7.033677	0.95675844	26.73230485
404	7.05113	1.001222	27.43753298
405	7.068583	1.046656428	28.15578346
406	7.086037	1.093058265	28.88684789
407	7.10349	1.140423977	29.63051417
408	7.120943	1.188749957	30.38656661
409	7.138397	1.238032525	31.15478593
410	7.15585	1.288267928	31.9349494
411	7.173303	1.33945234	32.72683083
412	7.190757	1.391581863	33.53020072
413	7.20821	1.444652528	34.34482625
414	7.225663	1.498660292	35.17047142
415	7.243116	1.553601044	36.00689704
416	7.26057	1.609470598	36.85386091
417	7.278023	1.666264701	37.71111778
418	7.295476	1.723979027	38.57841949
419	7.31293	1.782609181	39.45551506
420	7.330383	1.842150698	40.3421507
421	7.347836	1.902599044	41.23806993
422	7.365289	1.963949615	42.14301366
423	7.382743	2.02619774	43.05672025
424	7.400196	2.089338678	43.9789256
425	7.417649	2.15336762	44.90936322
426	7.435103	2.218279691	45.84776432
427	7.452556	2.284069947	46.79385788
428	7.470009	2.350733377	47.74737074
429	7.487462	2.418264906	48.70802768
430	7.504916	2.486659391	49.67555151
431	7.522369	2.555911623	50.64966313
432	7.539822	2.626016327	51.63008164
433	7.557276	2.696968167	52.61652441
434	7.574729	2.768761737	53.60870717
435	7.592182	2.841391571	54.60634409
436	7.609636	2.914852138	55.60914788
437	7.627089	2.989137843	56.61682985

438	7.644542	3.06424303	57.62910003
439	7.661995	3.140161978	58.64566723
440	7.679449	3.216888907	59.66623914
441	7.696902	3.294417973	60.6905224
442	7.714355	3.372743272	61.71822272
443	7.731809	3.451858839	62.74904495
444	7.749262	3.53175865	63.78269317
445	7.766715	3.612436619	64.81887077
446	7.784168	3.693886603	65.85728055
447	7.801622	3.776102399	66.89762481
448	7.819075	3.859077745	67.93960543
449	7.836528	3.942806324	68.98292397
450	7.853982	4.027281759	70.02728176
451	7.871435	4.112497616	71.07237997
452	7.888888	4.198447406	72.11791972
453	7.906342	4.285124584	73.16360218
454	7.923795	4.372522549	74.20912861
455	7.941248	4.460634645	75.2542005
456	7.958701	4.549454163	76.29851964
457	7.976155	4.638974337	77.34178822
458	7.993608	4.729188351	78.3837089
459	8.011061	4.820089335	79.42398491
460	8.028515	4.911670367	80.46232014
461	8.045968	5.003924471	81.49841922
462	8.063421	5.096844623	82.53198762
463	8.080874	5.190423746	83.56273174
464	8.098328	5.284654714	84.59035897
465	8.115781	5.379530351	85.61457783
466	8.133234	5.475043432	86.635098
467	8.150688	5.571186682	87.65163044
468	8.168141	5.667952781	88.66388747
469	8.185594	5.765334359	89.67158285
470	8.203047	5.863324	90.67443188
471	8.220501	5.961914242	91.67215147
472	8.237954	6.061097577	92.66446022
473	8.255407	6.160866452	93.65107852
474	8.272861	6.261213269	94.63172864
475	8.290314	6.362130385	95.60613478
476	8.307767	6.463610117	96.57402319
477	8.325221	6.565644735	97.53512222

478	8.342674	6.66822647	98.48916242
479	8.360127	6.771347509	99.43587662
480	8.37758	6.875	100.375
481	8.395034	6.979176049	101.3062702
482	8.412487	7.083867722	102.2294273
483	8.42994	7.189067046	103.144214
484	8.447394	7.294766012	104.0503757
485	8.464847	7.400956568	104.9476606
486	8.4823	7.507630629	105.8358195
487	8.499753	7.61478007	106.7146063
488	8.517207	7.722396732	107.5837779
489	8.53466	7.830472419	108.4430939
490	8.552113	7.938998901	109.2923174
491	8.569567	8.047967913	110.1312145
492	8.58702	8.157371158	110.9595545
493	8.604473	8.267200302	111.7771101
494	8.621927	8.377446983	112.5836574
495	8.63938	8.488102805	113.3789758
496	8.656833	8.599159341	114.1628484
497	8.674286	8.710608133	114.9350617
498	8.69174	8.822440694	115.6954061
499	8.709193	8.934648508	116.4436754
500	8.726646	9.047223029	117.1796674
501	8.7441	9.160155686	117.9031836
502	8.761553	9.273437876	118.6140293
503	8.779006	9.387060974	119.312014
504	8.796459	9.501016327	119.996951
505	8.813913	9.615295257	120.6686577
506	8.831366	9.72988906	121.3269556
507	8.848819	9.84478901	121.9716702
508	8.866273	9.959986358	122.6026316
509	8.883726	10.07547233	123.2196739
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511	8.918632	10.30727494	124.4113588
512	8.936086	10.42357394	124.9856915
513	8.953539	10.54012625	125.5454851
514	8.970992	10.656923	126.0905955
515	8.988446	10.77395531	126.6208836
516	9.005899	10.89121425	127.1362144
517	9.023352	11.0086909	127.6364578
518	9.040806	11.12637631	128.1214883
519	9.058259	11.24426152	128.591185
520	9.075712	11.36233756	129.0454317
521	9.093165	11.48059542	129.4841171
522	9.110619	11.59902611	129.9071345
523	9.128072	11.7176206	130.3143822
524	9.145525	11.83636986	130.7057631
525	9.162979	11.95526486	131.0811853
526	9.180432	12.07429653	131.4405615
527	9.197885	12.19345581	131.7838094
528	9.215338	12.31273363	132.1108517
529	9.232792	12.4321209	132.421616
530	9.250245	12.55160854	132.716035
531	9.267698	12.67118743	132.9940462
532	9.285152	12.79084849	133.2555923
533	9.302605	12.91058258	133.5006209
534	9.320058	13.0303806	133.7290848
535	9.337511	13.15023342	133.9409418
536	9.354965	13.27013192	134.1361547
537	9.372418	13.39006696	134.3146914
538	9.389871	13.51002941	134.4765249
539	9.407325	13.63001014	134.6216334
540	9.424778	13.75	134.75
541	9.442231	13.86998986	134.8616131
542	9.459685	13.98997059	134.9564661
543	9.477138	14.10993304	135.0345575
544	9.494591	14.22986808	135.0958908
545	9.512044	14.34976658	135.140475
546	9.529498	14.4696194	135.1683236
547	9.546951	14.58941742	135.1794558
548	9.564404	14.70915151	135.1738953
549	9.581858	14.82881257	135.1516713
550	9.599311	14.94839146	135.1128179
551	9.616764	15.0678791	135.0573742
552	9.634217	15.18726637	134.9853844
553	9.651671	15.30654419	134.8968978
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555	9.686577	15.54473514	134.6706556
556	9.704031	15.66363014	134.5330234
557	9.721484	15.7823794	134.379141

558	9.738937	15.90097389	134.2090823
559	9.756391	16.01940458	134.0229262
560	9.773844	16.13766244	133.8207566
561	9.791297	16.25573848	133.6026619
562	9.80875	16.37362369	133.3687357
563	9.826204	16.4913091	133.119076
564	9.843657	16.60878575	132.8537859
565	9.86111	16.72604469	132.572973
567	9.896017	16.95987375	131.9652326
568	9.91347	17.07642606	131.6385437
569	9.930923	17.19272506	131.2968089
570	9.948377	17.30876187	130.9401591
571	9.96583	17.42452767	130.5687292
572	9.983283	17.54001364	130.1826589
573	10.00074	17.65521099	129.7820922
574	10.01819	17.77011094	129.3671774
575	10.03564	17.88470474	128.9380672
576	10.0531	17.99898367	128.4949184
577	10.07055	18.11293903	128.0378921
578	10.088	18.22656212	127.5671536
579	10.10546	18.33984431	127.0828722
580	10.12291	18.45277697	126.5852213
581	10.14036	18.56535149	126.0743784
582	10.15782	18.67755931	125.5505247
583	10.17527	18.78939187	125.0138455
584	10.19272	18.90084066	124.4645297
585	10.21018	19.0118972	123.9027702
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587	10.24508	19.2327997	122.7427095
588	10.26254	19.34262884	122.1448122
589	10.27999	19.45203209	121.5352787
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591	10.3149	19.66952758	120.2821491
592	10.33235	19.77760327	119.6389844
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594	10.36726	19.99236937	118.3205582
595	10.38471	20.09904343	117.6457474
596	10.40216	20.20523399	116.9608437
597	10.41962	20.31093295	116.2660799
598	10.43707	20.41613228	115.5616918

599	10.45452	20.52082395	114.8479181
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601	10.48943	20.72865249	113.3931816
602	10.50688	20.83177353	112.6527095
603	10.52434	20.93435526	111.9038328
604	10.54179	21.03638988	111.146803
605	10.55924	21.13786961	110.381874
606	10.5767	21.23878673	109.6093021
607	10.59415	21.33913355	108.8293456
608	10.6116	21.43890242	108.0422651
609	10.62906	21.53808576	107.248323
610	10.64651	21.636676	106.4477839
611	10.66396	21.73466564	105.6409141
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615	10.73377	22.12046965	102.3555171
616	10.75123	22.21534529	101.5210495
617	10.76868	22.30957625	100.6818842
619	10.80359	22.49607553	98.99057027
620	10.82104	22.58832963	98.1389794
621	10.83849	22.67991066	97.28380624
622	10.85595	22.77081165	96.4253322
623	10.8734	22.86102566	95.56383955
624	10.89085	22.95054584	94.69961132
626	10.92576	23.12747745	92.96408351
627	10.94321	23.21487542	92.09335301
628	10.96067	23.30155259	91.22102491
629	10.97812	23.38750238	90.34738474
630	10.99557	23.47271824	89.47271824
631	11.01303	23.55719368	88.59731132
632	11.03048	23.64092225	87.72144994
633	11.04793	23.7238976	86.84542001
634	11.06539	23.8061134	85.96950734
635	11.08284	23.88756338	85.09399753
636	11.10029	23.96824135	84.21917587
637	11.11775	24.04814116	83.34532727
638	11.1352	24.12725673	82.47273618
639	11.15265	24.20558203	81.60168645
640	11.17011	24.28311109	80.73246132

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642	11.20501	24.43575697	79.00061398
643	11.22247	24.51086216	78.13855417
644	11.23992	24.58514786	77.2794436
645	11.25737	24.65860843	76.42356095
646	11.27483	24.73123826	75.57118369
647	11.29228	24.80303183	74.72258807
648	11.30973	24.87398367	73.87804898
649	11.32719	24.94408838	73.03783988
650	11.34464	25.01334061	72.20223273
651	11.36209	25.08173509	71.37149787
652	11.37955	25.14926662	70.54590398
653	11.397	25.21593005	69.72571799
654	11.41445	25.28172031	68.91120494
655	11.43191	25.34663238	68.10262798
656	11.44936	25.41066132	67.30024825
657	11.46681	25.47380226	66.50432477
658	11.48427	25.53605038	65.71511443
659	11.50172	25.59740096	64.93287184
660	11.51917	25.6578493	64.1578493
661	11.53663	25.71739082	63.3902967
662	11.55408	25.77602097	62.63046144
663	11.57153	25.8337353	61.87858837
665	11.60644	25.94639896	60.39969496
666	11.62389	26.00133971	59.67315083
667	11.64135	26.05534747	58.9555212
668	11.6588	26.10841814	58.24703699
669	11.67625	26.16054766	57.54792615
670	11.69371	26.21173207	56.85841354
671	11.71116	26.26196747	56.17872088
672	11.72861	26.31125004	55.50906669
673	11.74607	26.35957602	54.84966622
674	11.76352	26.40694173	54.20073136
675	11.78097	26.45334357	53.56247061
676	11.79843	26.498778	52.93508898
677	11.81588	26.54324156	52.31878797
678	11.83333	26.58673086	51.71376546
679	11.85079	26.6292426	51.12021569
680	11.86824	26.67077354	50.53832916
681	11.88569	26.7113205	49.96829262

682	11.90315	26.75088041	49.41028897
683	11.9206	26.78945026	48.86449721
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685	11.95551	26.86360807	47.81024564
686	11.97296	26.89919039	47.3021239
687	11.99041	26.93377135	46.80689012
688	12.00787	26.96734832	46.32470303
689	12.02532	26.99991873	45.85571719
690	12.04277	27.03148011	45.4000829
691	12.06023	27.06203006	44.95794616
692	12.07768	27.09156624	44.52944863
693	12.09513	27.12008641	44.11472758
694	12.11259	27.14758839	43.71391584
695	12.13004	27.1740701	43.32714181
696	12.14749	27.19952951	42.95452934
697	12.16494	27.22396469	42.59619775
698	12.1824	27.24737377	42.25226177
699	12.19985	27.26975498	41.92283152
700	12.2173	27.2911066	41.60801246
701	12.23476	27.31142702	41.30790536
702	12.25221	27.33071468	41.02260629
703	12.26966	27.34896812	40.75220654
704	12.28712	27.36618595	40.49679267
705	12.30457	27.38236684	40.2564464
706	12.32202	27.39750959	40.03124464
707	12.33948	27.41161302	39.82125945
708	12.35693	27.42467606	39.62655802
709	12.37438	27.43669773	39.44720264
710	12.39184	27.4476771	39.28325068
711	12.40929	27.45761334	39.13475461
712	12.42674	27.46650569	39.00176191
713	12.4442	27.47435348	38.88431514
714	12.46165	27.4811561	38.78245186
715	12.4791	27.48691305	38.69620465
716	12.49656	27.49162387	38.62560111
717	12.51401	27.49528822	38.57066381
718	12.53146	27.49790581	38.53141032
719	12.54892	27.49947644	38.50785321
720	12.56637	27.5	38.5

APPENDIX D

Calculation on second piston swept volume

Ratio of swept volume for BEARE HEAD engine

$$\frac{\text{Main piston}}{2^{nd}\text{ piston}} = \frac{1000}{250} = 4$$

For MODENAS KRISS engine

$$\frac{\text{Main piston}}{2^{nd}\text{ piston}} = 4$$

$$\frac{110}{2^{nd}\text{ piston}} = 4$$

2^{nd} piston swept volume prediction = 110 /4
= **27.5 cc**

Ratio of combustion chamber for beare head engine

$$\frac{\text{Swept volume}}{\text{Combustion chamber}} = \frac{1000}{100} = 10$$

For MODENAS KRISS

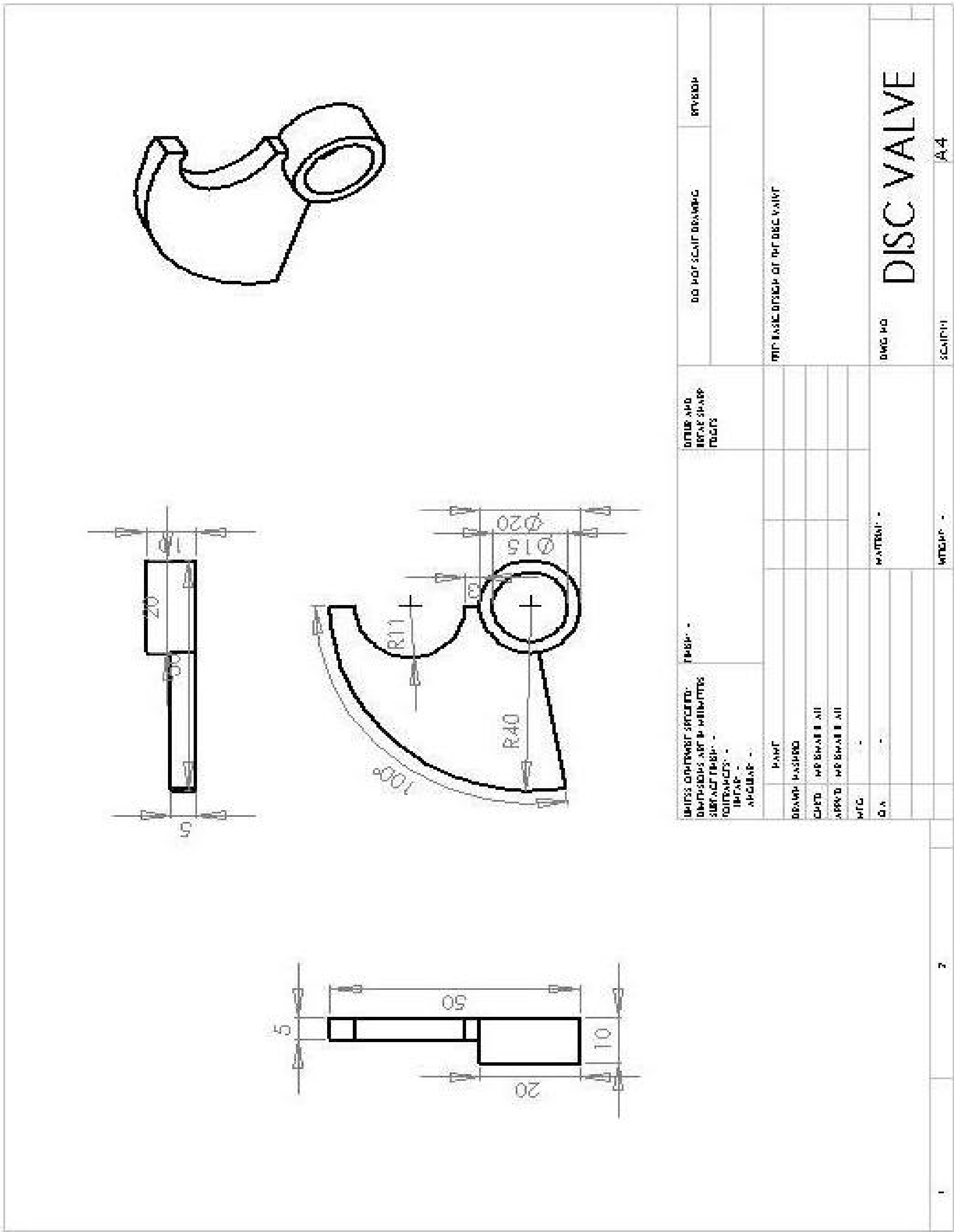
$$\frac{\text{Swept volume}}{\text{Combustion chamber}} = 10$$

$$\frac{110}{\text{Combustion chamber}} = 10$$

Combustion chamber prediction = 110/10 = **11**

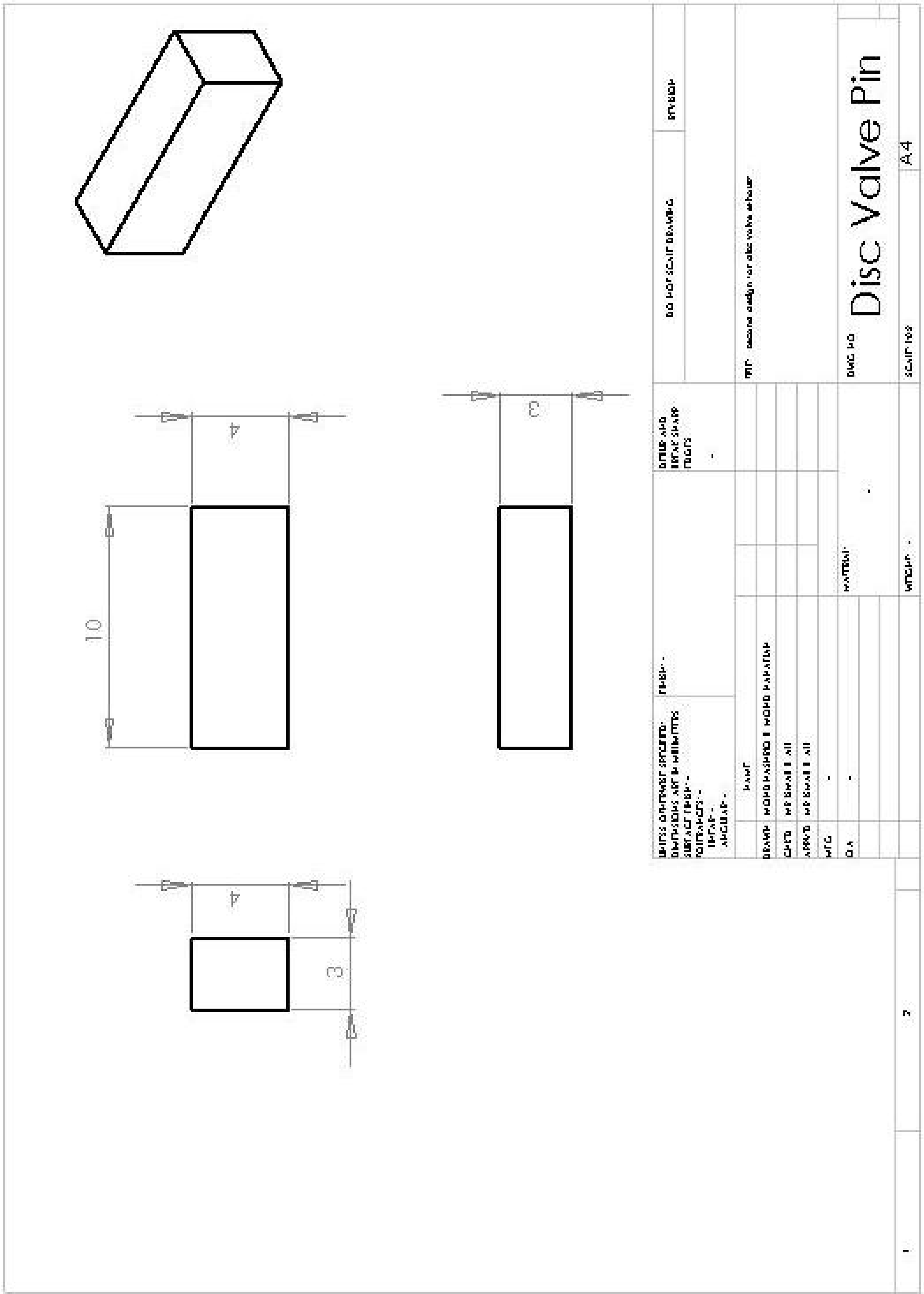
APPENDIX E

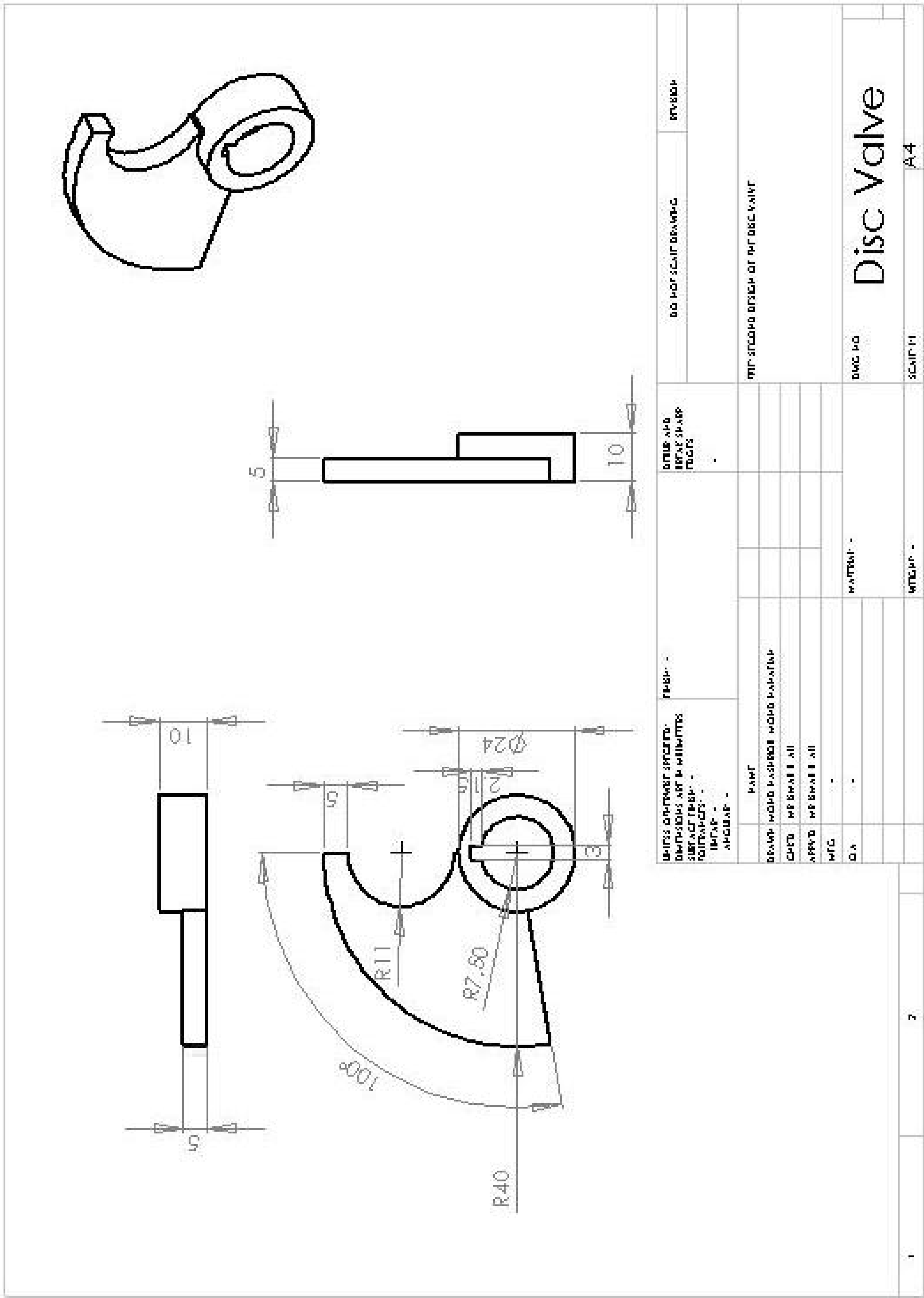
Dimension for basic design of the disc valve exhaust port


DISC VALVE
A4
R40
R11
100°
Ø20
Ø15
50
20
10
5

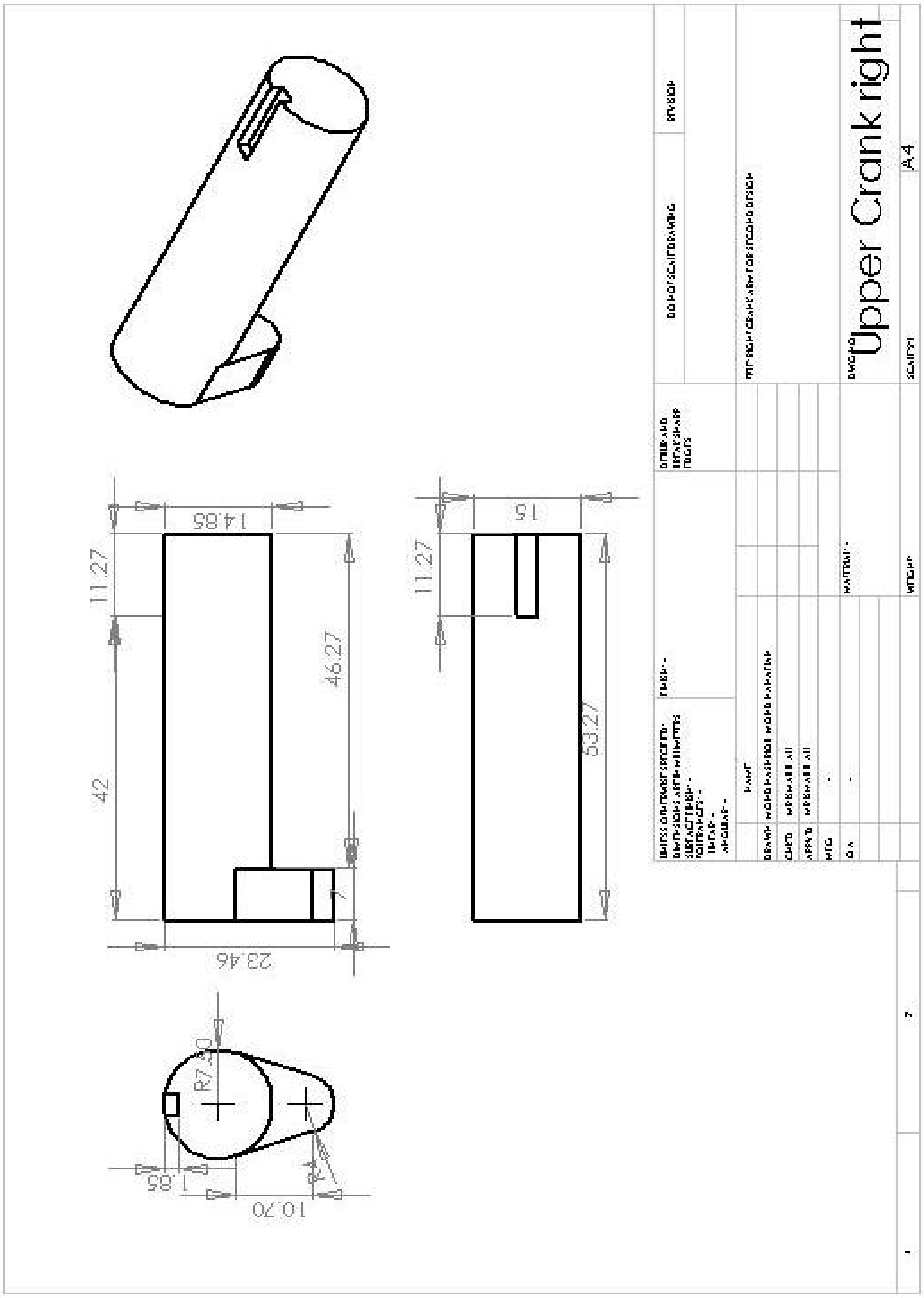
APPENDIX F

Dimension for second design of the disc valve exhaust port


10
4
3
4
3
DO NOT SCALE DRAWING
REVISION
Disc Valve Pin
A4

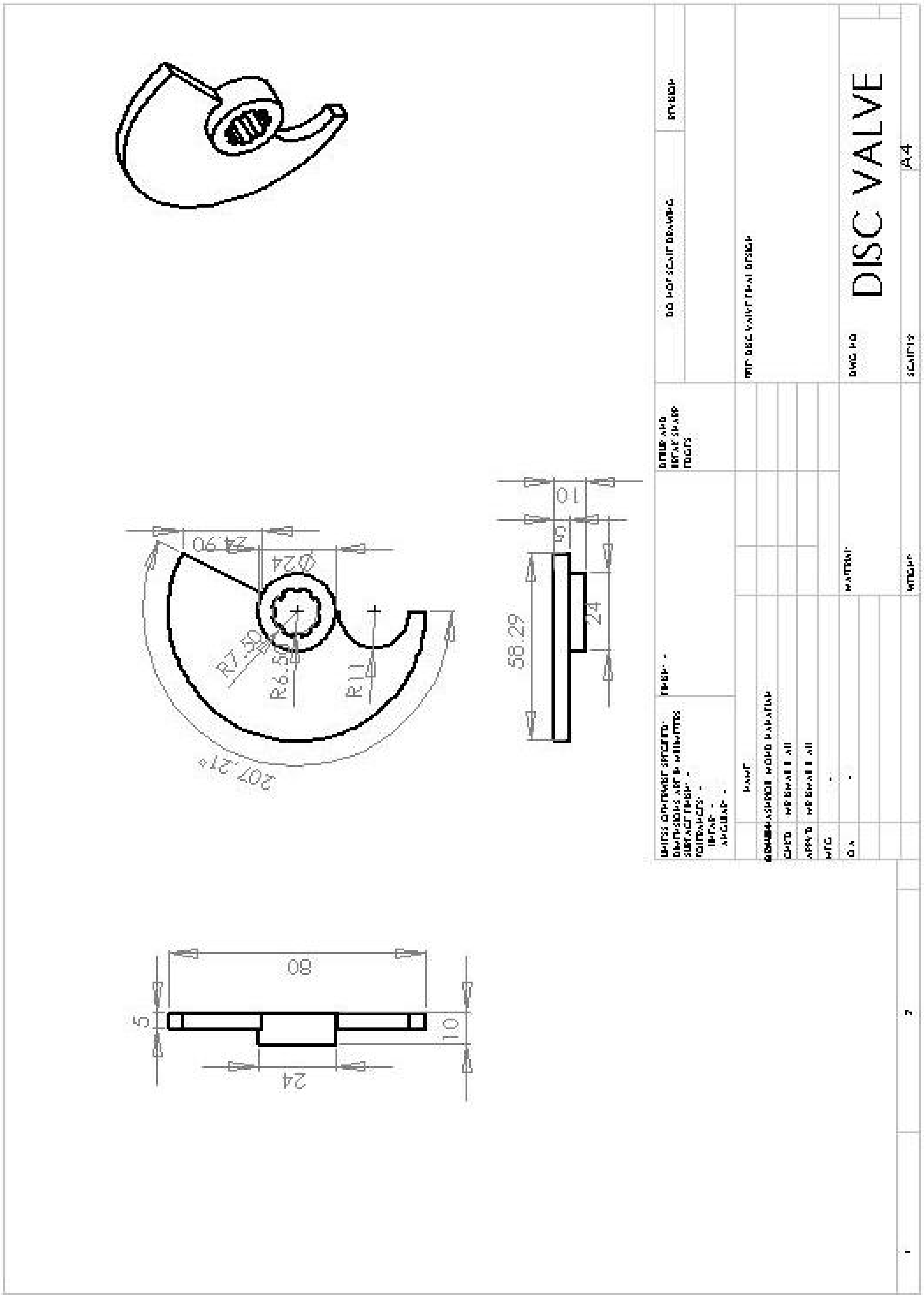


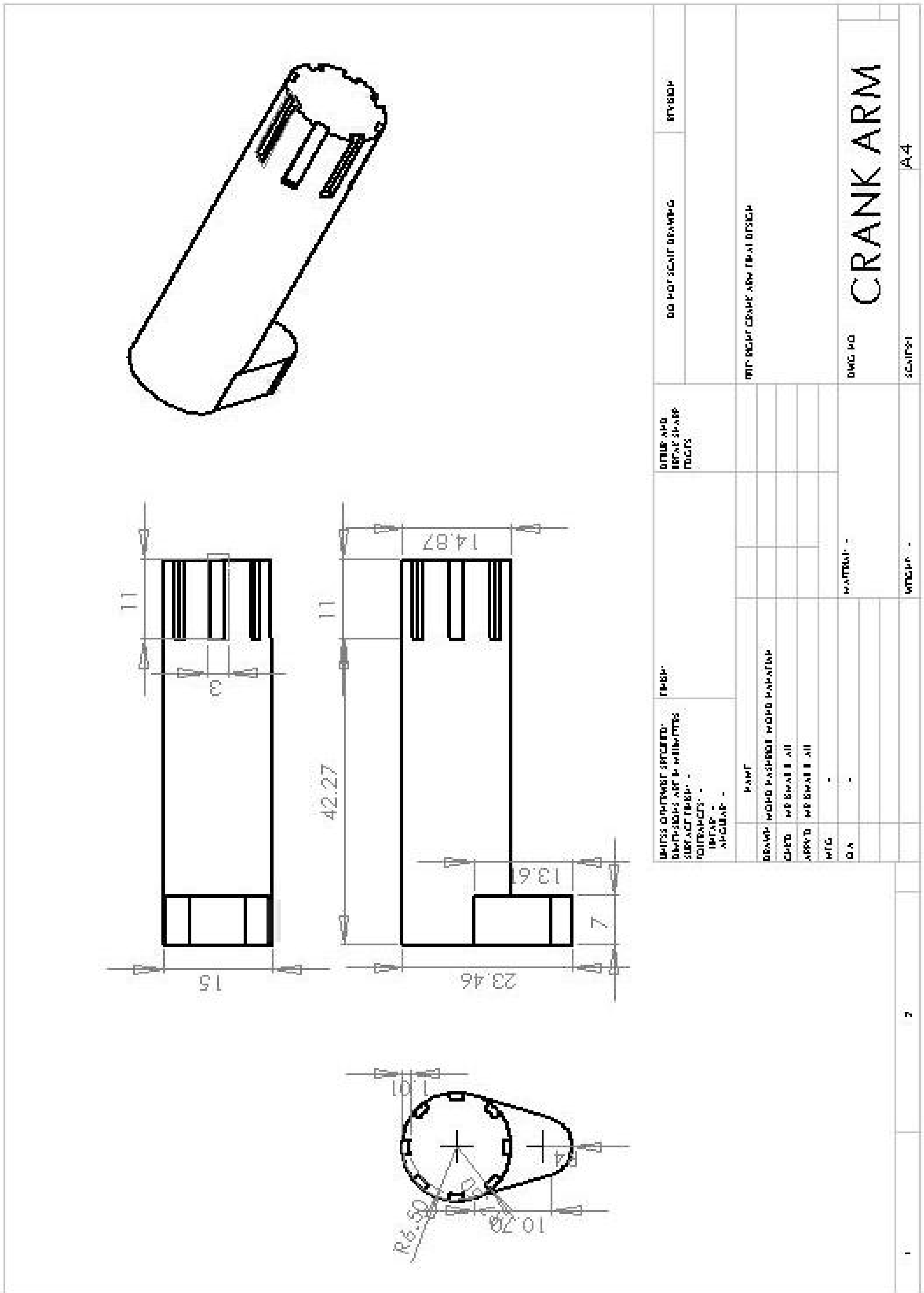
Disc Valve
A4
R40
R11
R7.50
Ø24
10
5
3


Upper Crank right
A4
14.85
11.27
42
46.27
7
23.46
15
11.27
53.27
R7.50
R4
1.85
10.70

APPENDIX G

Dimension for final design of the disc valve exhaust port


DISC VALVE
A4
80
24
5
10
58.29
R11
R7.50
R6.50
Ø24
24.90
207.21°


CRANK ARM
A4
14.87
11
3
42.27
13.61
7
15
23.46
1.01
R6.50
10.70
4