EXHAUST PORT FLOW ON VARIOUS CYLINDER HEAD USING FLOWBENCH

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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
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

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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/Manufacturing*

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

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ACKNOWLEDGEMENT

I am grateful and would like to express my sincere appreciation to Mr. Mohd Fairusham Bin Ghazali and Mr. Ismail Bin Ali from the Department of Mechanical Engineering, Universiti Malaysia Pahang for providing tremendous technical guidance, advices, continuous encouragement, constructive criticisms, suggestions and glorious knowledge throughout this project and administrative support during this project.

I would like to express my sincere gratitude to my parents Hj. Che Pa Bin Hashim and Hjh. Noripah Binti Md. Shah for their love, dream and sacrifice throughout my life. Special thanks to my siblings for the supports and motivations. Finally, special thanks to my committee members BMA 2005/2006. I would like to acknowledge their comments and suggestions, which was crucial for the successful completion of this study.

ABSTRACT

This is a project about the study of exhaust port flow for Proton 4G92 and Toyota 4 AGE cylinder head. It is a testing using SF-1020 Air Flowbench machine that has been used to determine the air flow between the original exhaust port and modified exhaust port. In this study, an experiment approach has been performed to investigate the flow distribution of exhaust gases that will affect the performance of the engine by the design of exhaust port shape for cylinder head. The modification to the cylinder head such as eliminates the valve guide, porting and polishing has been done as a parameter during this experiment. Both cylinder heads are adapted with modification and it gives positive results of air flow increment for every modification applied. The highest air flow is in Proton 4G92 cylinder head and it improves the power and performance of the engine.

ABSTRAK

Projek ini adalah suatu penyelidikan tentang kebuk ekzos pada kepala silinder Proton 4G92 dan Toyota 4AGE. Ini adalah satu ujian menggunakan mesin SF-1020 Flowbench untuk mendapatkan maklumat mengenai aliran udara pada kebuk ekzos yang berkeadaan asal dan yang telah dimodifikasi. Dalam kajian ini, kaedah eksperimen telah digunakan untuk mengkaji aliran gas ekzos yang akan mempengaruhi potensi sesuatu enjin dengan reka bentuk kebuk ekzos pada kepala silinder. Pengubahsuaian pada kepala silinder seperti meratakan panduan injap, pembesaran kepala silinder dan meratakan permukaan kepala silinder adalah pembolehubah yang dimanipulasikan dalam eksperimen ini. Kedua-dua kepala silinder ini menunjukkan perkembangan positif terhadap peningkatan jumlah udara bagi setiap modifikasi yang dibuat. Pengaliran udara tertinggi adalah pada kepala silinder Proton 4G92 dan ia meningkatkan kuasa dan potensi enjin tersebut.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

hp	Horsepower
kW	kilowatt
l/s	Liters per second
cfm	Cubic feet per minute
In.H_2O	Inches of water
cm	centimeters
in	inches
mm	millimeters
kPa	Kilopascals per square cm
Ft/sec	Feet per second
m/s	Meters per second
Sq.in	Square inches
Cd	Coefficient of discharge

LIST OF ABBREVIATIONS

SF	SuperFlow
Cu	Copper
Al	Aluminium
rpm	Revolution per minutes

CHAPTER 1

INTRODUCTION

1.1 Project Background

This is a project about the study of exhaust port flow for Proton and Toyota cylinder head. It is a testing using SF-1020 Air Flowbench machine that used to determine the air flow between the original exhaust port and modified exhaust port. In this study, an experiment approach has been performed to investigate the flow distribution of exhaust gases that affected the performance of the engine by the design of exhaust port shape for cylinder head. The modifications to the cylinder head such as eliminate the valve guide, porting, and polishing has been done as a parameter during this experiment.

A cylinder head is bolted to the top of each bank of cylinders to seal the individual cylinders and contain the combustion process that takes place inside the cylinder. The cylinder head contains at least one intake valve and one exhaust valve for each cylinder. This allows the air-fuel mixture to enter the cylinder and the burned exhaust gas to exit the cylinder. Both Proton and Toyota engines have four valves in each cylinder, two for intake and two for exhaust.

Cylinder head porting refers to the process of modifying the intake and exhaust ports of and internal combustion engine to improve the quality and quantity of the gas flow. Cylinder head as manufactured are usually suboptimal due to the design and manufacturing constrains. Porting head provides the finely detailed attention required to bring the engine to the highest level of efficiency. More than any other single factor, the porting process is responsible for the high power output of modern engines. This process can be applied to a standard racing engine to optimize its power output for daily use or to alter its power output characteristic to suit a particular application. An engine running at high speed experiences a totally different substance.

1.2 Problem Statement

In the internal combustion engine, cylinder head is one of the options that have been modified by car enthusiast to increase their engines performance. One way of increasing engine performance is by increasing the amount of air flow that will be drawn into the engine. Normally, car enthusiast will modified their cylinder head rather than simply bolt on the latest racing cylinder head that are available in the market which require high in cost.

Main factor of this problem occur when the cylinder head of both engines are not same in size and shape. In Toyota engine, the valve and spring are designed smaller compared to the valve and spring build in Proton engine. Somehow, the different of this design will make the different in engine performance even though the same 1.6 L engines used.

Therefore, there are needs to study the effects of the modification methods such as eliminating the valve guide, porting and polishing on overall output performance of the Toyota 4AGE 1.6L and Proton 4G92 1.6L engine.

1.3 Objectives Of The Project

The objectives of the project are:-

i) To study on the air flow characteristics of the exhaust port in cylinder head.

ii) To investigate engine power and performance improvement by the amount of air drawn out of the engine.

iii) To compare the shape and design of 1.6L 4G92 Proton and 1.6L 4AGE Toyota exhaust port in cylinder head engines.

1.4 Scopes Of The Project

i) Studies the detailed of various exhaust port cylinder head engine design based on 1.6L 4G92 Proton and 1.6L 4AGE engines.

ii) Using SF-1020 Air Flowbench machine to investigate the air flow characteristics through exhaust port cylinder head.

iii) Investigate and study the air flow of original exhaust port for both engines.

iv) Investigate and study the air flow of modified exhaust port which is eliminating the valve guide, porting and polishing.

1.5 Flow Chart

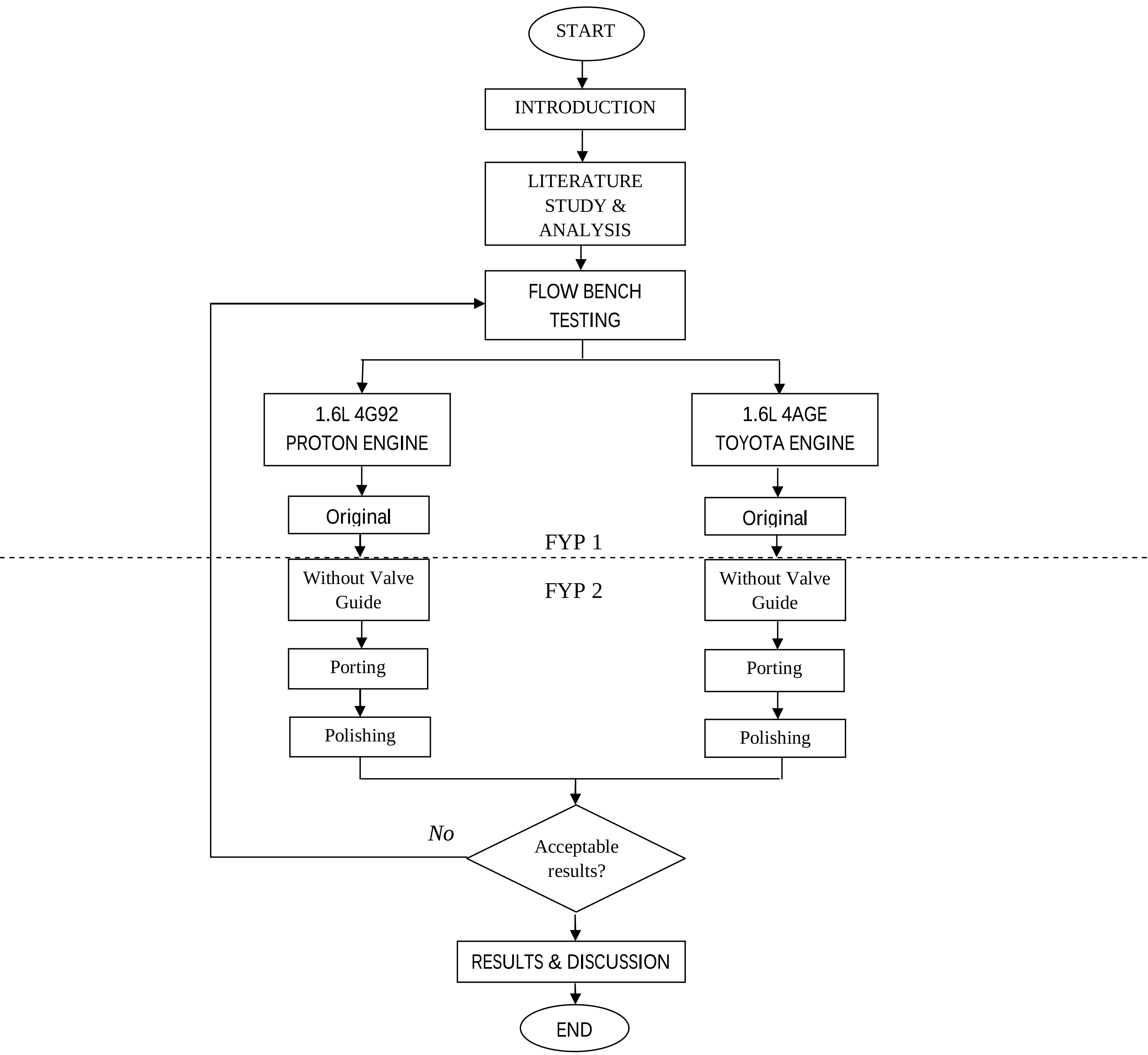

Figure 1.1: Flow chart for final year project

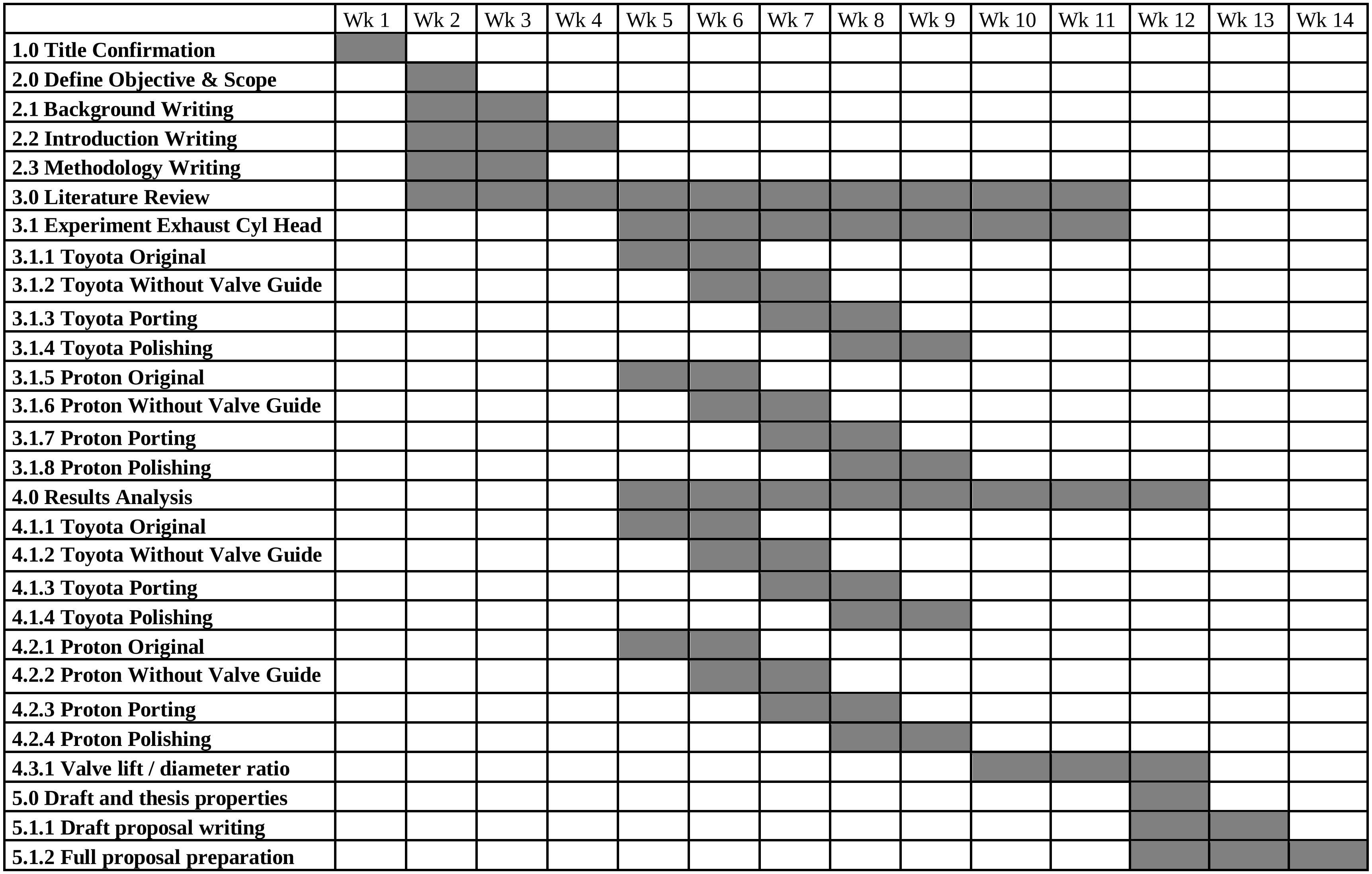

Figure 1.2: Gantt chart for Final Year Project 1

	Wk1	Wk2	Wk3	Wk4	Wk5	Wk6	Wk7	Wk8	Wk9	Wk10	Wk11	Wk12	Wk13	Wk14	Wk15
1.0 Cylinder Head Modification															
1.1.1 Eliminate Valve Guide Toyota Exhaust Port															
1.1.2 Eliminate Valve Guide Proton Exhaust Port															
1.2.1 Porting Toyota Exhaust Port															
1.2.2 Porting Proton Exhaust Port															
1.3.1 Polishing Toyota Exhaust Port															
1.3.2 Polishing Proton Exhaust Port															
2.0 Experiment Exhaust Cyl Head															
3.0 Results Analysis															
3.1.1 Toyota Without Valve Guide															
3.1.2 Toyota Porting															
3.1.3 Toyota Polishing															
3.2.1 Proton Without Valve Guide															
3.2.2 Proton Porting															
3.2.3 Proton Polishing															
4.0 Full Preparation For FYP II															
5.0 FYP II Presentation															
6.0 FYP Book Binding															

Figure 1.3: Gantt chart for Final Year Project2

CHAPTER 2

LITERATURE STUDY & ANALYSIS

2.1 Cylinder Head

A cylinder head is bolted to the top of each bank of cylinders to seal the individual cylinders and contain the combustion process that takes place inside the cylinder (Peter Burgess, David Gollan, 2007). Most cylinder heads are made of cast aluminum or cast iron. The cylinder head contains at least one intake valve and one exhaust valve for each cylinder. This allows the air-fuel mixture to enter the cylinder and the burned exhaust gas to exit the cylinder. Engines have at least two valves per cylinder, one intake valve and one exhaust valve. Many newer engines are using multiple intakes and exhaust valves per cylinder for increased engine power and efficiency.

2.2 Poppet Valves

Poppet valves are a very robust and resilient construction for use in industrial directional control valves. They are usually very tolerant of typical air line contaminants (rust, scale, etc) when used in compressed air service. This type of valve construction is typically characterized as being a high flow, fast acting design due to the large flow paths through the body that can be opened quickly. Think of a poppet valve very much like a stopper or plug in a bath tub drain. When the plug is pulled, the flow path opens quickly and the area that opens is quite large. The large opening of a poppet allows particulate to pass through the valve easily (Peter Burgess, David Gollan 2007).

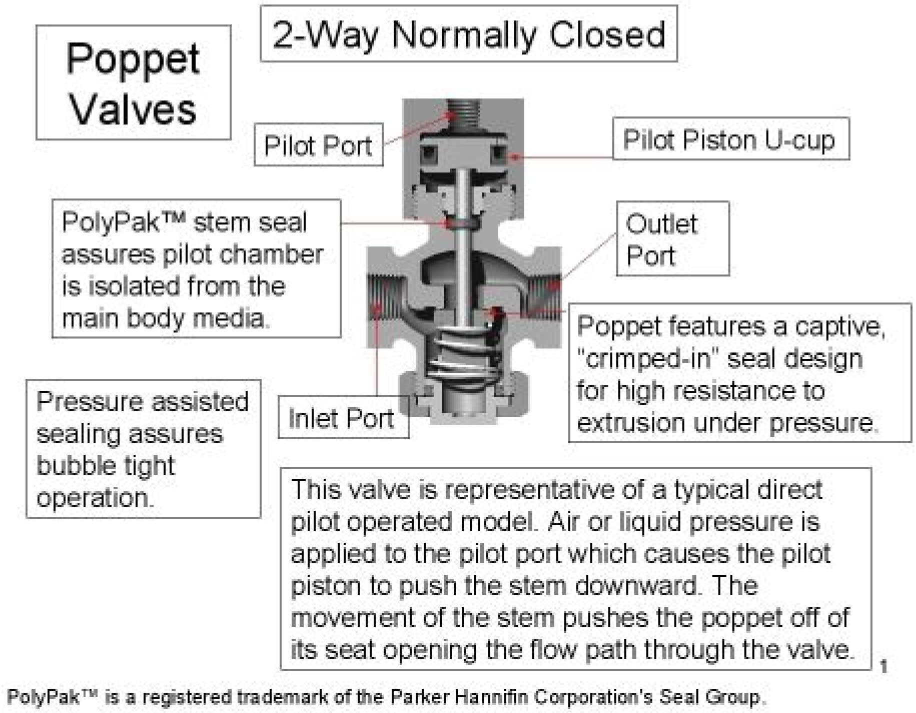

Figure 2.1: Poppet valve diagram

Source: www.howstuffworks.com

2.3 Exhaust Valves

The specification of material used for the standard exhaust valves in most cylinder heads is 21/4N Austenitic Stainless steel with a chrome plated stem and a hard Stellite tip which providing greater wear resistance for where the rocker pad contacts the valve. The new wave treatment is to tuft ride the valve stems as an alternative to the chrome plating. This is a chemical process that leaves the stem with a hardened wear resisting surface without actually altering its diameter by depositing layer on it. This gives a stem finish with none of the high spots or the sharp bits that can arise from chrome plating. 21/4N is the best material for the job. Such valves are already well capable of withstanding the rigors of unleaded fuel. (Peter Burgess, David Gollan 2007)

Some heads that have already been reconditioned may have had new exhaust valves of a lesser material specification fitted to replace existing ones if they were badly worn or damaged in some way. If the existing valves from the head are not too worn, it can be reused by a quick test of the exhaust valve material is whether or not they stick to a magnet. The Austenitic stainless used for valves is non-magnetic. If the magnet sticks to the valves, it will need changing. Many manufacturers' exhaust valves are now of a bi-metal construction, having wear resistant EN52 stems (magnetic) friction welded to a 21/4N valve head (non-magnetic), this is all right for most read applications where standard revs are not exceeded (Peter Burgess,David Gollan 2007).

It might be useful to offer an explanation of the thinking behind favoring the standard size exhaust valve. It is based on the pressure differences that exist in the cylinder at the end of the power stroke or beginning of the exhaust stroke, and the area of valve curtain available for the exhaust gas to flow through. After the work has been extracted from the fuel by the piston being pushed down the bore, the residual gas in the cylinder is still at a considerably higher pressure than the pressure existing in the exhaust manifold and exhaust system. When the exhaust valve opens, the gas leaves the cylinder at very high speed due to large pressure difference.

Exhaust blowdown takes a certain length of time to occur, irrespective of the speed (rpm) of the engine. But increased engine speed (rpm) means the exhaust valve physically open for less time. So, above a certain rpm, complete blowdown cannot occur as there is insufficient valve open time for the volume of exhaust gas to be expelled. Some exhaust gas is left in the cylinder. This remaining exhaust gas, besides occupying some of the space in the cylinder that should be filled by the incoming charge of fresh mixture, and power is lost (deliberate contamination with exhaust gas is used as a means of reducing emissions). Some of the remedies for this involve increasing the valve area, opening the valve sooner (earlier), higher (more lift), longer (more duration) or combinations of all four. The first solution is achieved by fitting a larger exhaust valve, giving more area (bigger hole) for the exhaust gas to flow through.

Figure 2.2: Exhaust valves used in the cylinder head

2.4 Valve Spring

Valve spring is selected to complement the system and must be matched with the entire valve train in order for the engine to reach its full potential. It provides a positive means of closing the valve and keeping the follower in contact with the camshaft lobe so the motion of the valve train is controlled.

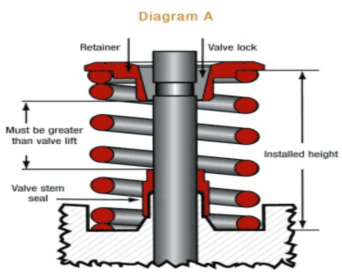

Figure 2.3: Valve spring attach to the valve at cylinder head

Source: www.howstuffworks.com

2.5 Air Flow Fundamental

Air flow is more sensitive to shape than size. A huge port may flow well, but if the resulting gas speed is too low for proper cylinder filling, the engine will not give its best. Air flow hates experiencing sudden changes in direction, volume or shape. These concepts are supported by the fact that the areas of the port that are easy to get at normally have a small to moderate effect on airflow. Big ports are fine for race engines where high rpm is called for and low speed drivability and emissions are not a consideration. Torque and some low speed capability are essential for an engine seeing use in an everyday road going vehicle (Peter Burgess, David Gollan 2007).

Volumetric efficiency is usually defined as the ratio of the volume of air drawn into the engine to the engine's swept volume. Filling such a large void at the cylinder through a small passage at the port very quickly means the incoming air is made to travel fairly quickly to do so. The average speed at which at travels through the port as mean gas velocity depends upon the volume of the cylinder, the speed in RPM of the engine and the size of the port.

2.5.1 Laminar Flow

Laminar or streamline flow occur when a fluid flows in parallel layers, with no disruption between the layers. In fluid dynamics, laminar flow is a flow regime characterized by high momentum diffusion, low momentum convection, pressure and velocity independent from time. It is the opposite of turbulent flow. In nonscientific terms laminar flow is smooth, while turbulent flow is rough.

The dimensionless Reynolds number is an important parameter in the equations that describe whether flow conditions lead to laminar or turbulent flow. Reynolds numbers of less than 2000 are generally considered to be of a laminar type. When the Reynolds number is much less than 1, creeping motion or stokes flow occurs. This is an extreme case of laminar flow where viscous (friction) effects are much greater than inertial forces (Bruce R. Munson, Donald F. Young, Theodore H. Okiishi 2006).

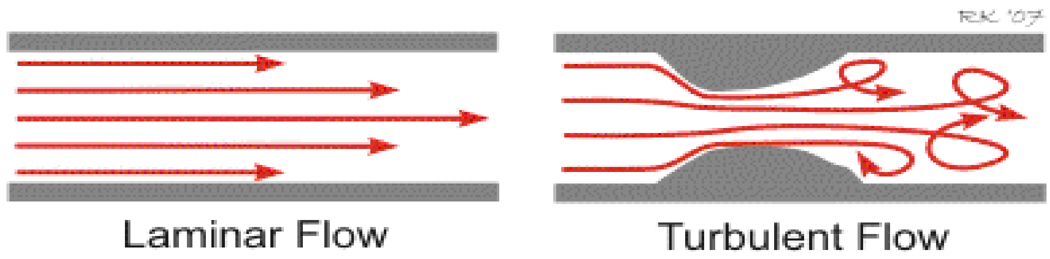

Figure 2.4: Laminar and turbulent flow occur

Source: www.howstuffworks.com

2.5.2 Turbulent Flow

When the flow is turbulent, the flow contains eddying motions of all sizes, and a large part of the mechanical energy in the flow goes into the formation of these eddies which eventually dissipate their energy as heat. As a result, at a given Reynolds number, the drag of a turbulent flow is higher than the drag of a laminar flow. Also, turbulent flow is affected by surface roughness, so that increasing roughness increases the drag. Transition to turbulence can occur over a range of Reynolds numbers, depending on many factors, including the level surface roughness, heat transfer, vibration, noise, and other disturbances.

In fluid flow, the Reynolds number is the ratio of the inertia force that is the force given by mass x acceleration to the viscous force. At low Reynolds numbers, therefore, the viscous force is large compared to the inertia force. Small disturbances in the velocity field, created perhaps by small roughness elements on the surface, or pressure perturbations from external sources such as vibrations in the surface or strong sound waves, will be damped out and not allowed to grow. This is the case for pipe flow at Reynolds numbers less than the critical value of 2300 (based on pipe diameter and average velocity), and for boundary layers with a Reynolds number less than about 200,000 (based on distance from the origin of the layer and the free stream velocity).

As the Reynolds number increases, however, the viscous damping action becomes comparatively less, and at some point it becomes possible for small perturbations to grow. The flow can become unstable, and it can experience transition to a turbulent state where large variations in the velocity field can be maintained. If the disturbances are very small, as in the case where the surface is very smooth, or if the wavelength of the disturbance is not near the point of resonance, the transition to turbulence will occur at a higher Reynolds number than the critical value. So the point of transition does not correspond to a single Reynolds number, and it is possible to delay transition to relatively large values by controlling the disturbance environment. At very high Reynolds numbers, however, it is not possible to maintain laminar flow since under these conditions even minute disturbances will be amplified into turbulence.

Turbulent flow is characterized by unsteady eddying motions that are in constant motion with respect to each other. At any point in the flow, eddies produce fluctuations in the flow velocity and pressure (Bruce R. Munson, Donald F. Young, Theodore H. Okiishi 2006).

2.6 Cylinder Head Porting

Cylinder head porting refers to the process of modifying the intake and exhaust ports of an internal combustion engine to improve the quality and quantity of the air flow. Porting the heads provides the finely detailed attention required to bring the engine to the highest level of efficiency. The porting process is responsible for the high power output of modern engines. This process can be applied to a standard racing engine to optimize its power output as well as to a production engine to turn it into a racing engine, to enhance its power output for daily use or to alter its power output characteristics to suit a particular application (Peter Burgess, David Gollan 2007).

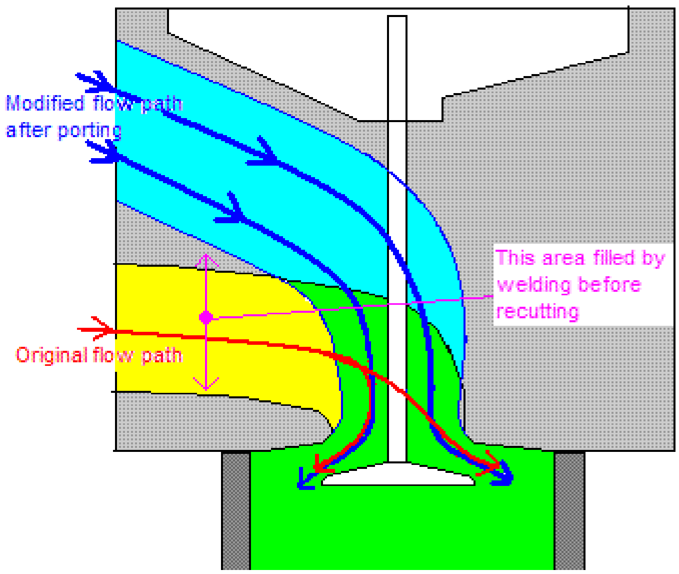

Figure 2.5: This illustration shows the difference between a poor performing port and an excellent design after porting modification

Source: www.howstuffworks.com

2.7 Cylinder Head Polishing

It is a process of smoothing the exhaust cylinder head surface using abrasive kits such as Cartridge rolling and Flapper Sticking. The cartridge roll process removes all the stone marks and leaves a smooth but non uniform finish to the surface of the port. Flapper sticking is to refine the process finishing.

2.8 Toyota 4 AGE Engine

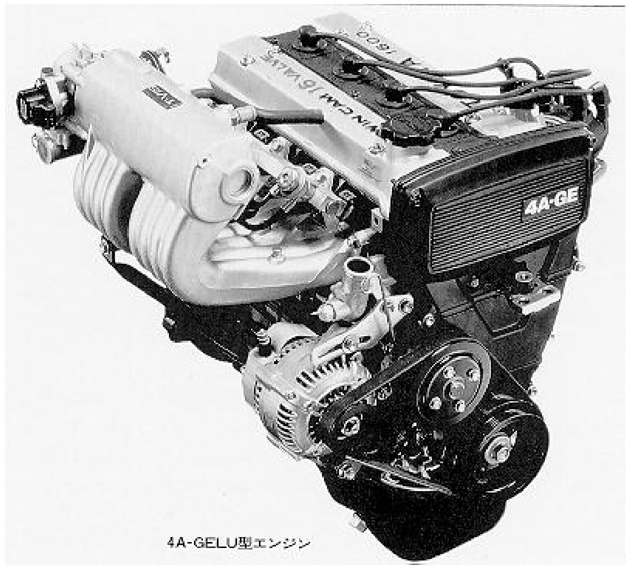

Figure 2.6: Toyota 4AGE engine

Source: www.ae92gts.com

Table 2.1: Toyota 4AGE engine specifications

DESCRIPTION	SPECIFICATIONS
Type	1.6L four cylinder 16-valve DOHC
Number of cylinders	4
Total displacement	1.600 cm^3 (96.8 cu. In.)
Cylinder bore	81.0 mm (3.19 in)
Piston Stroke	77.0 mm (3.03 in)
Compression ratio	9.4 : 1
Maximum output HP @ RPM	115kW @ 6600 RPM
Maximum torque	100Nm @ 4800 RPM
Fuel system	PFI

A smooth revving, high redline, DOHC EFI engine is the main focus for many manufacturers to build as good as the new 16V 4 cylinders 4AGE engine. The block was an updated Toyota design, while the head had been commissioned to Yamaha. Toyota at the time had taken the lead in high-tech engines with the 4AGE along with other models.

The 4 AGE is not known for its torque. The engine is definitely likes to make power high in rpm range. It was made to rev the engine in higher rpm. The 4AGE is used in many different racing applications. The original block 4 AGE block indeed is a good, light, strong block that is able to handle 190+ hp in stock form and for modified block, it can reach as high as 200+ hp.

Toyota strengthened the block by adding more nickel content along with other physical structural reinforcements. Included along with this were larger crank journals and piston pins so that it would be able to handle the rigors of forced induction. The older block has 4 ribs.

The G in 4 AGE signifies the type of head the engine has. The G designation stands for the 50 degree valve angle head, which was designed for performance rather than for fuel economy. The 4 AGE is a non-interference design meaning that if the timing belt brakes, no damage will be done. This of cause will change it the engine is modified to have a higher compression ration or more aggressive cams.

2.9 Proton 4G92 Engine

Figure 2.7: Proton 4G92 engine

Source: www.wikipedia.org

Table 2.2: Proton 1.6L 4G92 engine specifications

DESCRIPTION	SPECIFICATIONS
Type	In line OHV, SOHC
Number of cylinders	4
Total displacement	1.597 cm^3 (97.4 cu. In.)
Cylinder bore	81mm (3.19in.)
Piston stroke	77.5mm (3.05in.)
Compression ratio	10.0 : 1
Maximum output	83kW @ 6000 RPM
Maximum torque	138 Nm @ 5000 RPM
Fuel system	MPI

2.10 Flowbench Machine

Flowbench machine is designed to measure air-flow resistance of engine cylinder heads, intake manifolds, velocity stacks and restrictor plates. For four-cycle engine testing, air is drawn in through the head pump and exits through the vents at each side of the flowbench.

Flowbench testing consists of blowing or sucking air through a cylinder head or other component at a constant test pressure. Then the flow rate is measured at various valve lifts. A change can be made and the component can be retested. Greater air flow will indicates an improvement. If the tests are made under the same condition, no corrections for atmospheric conditions or machine variations are required. The results maybe compared directly.

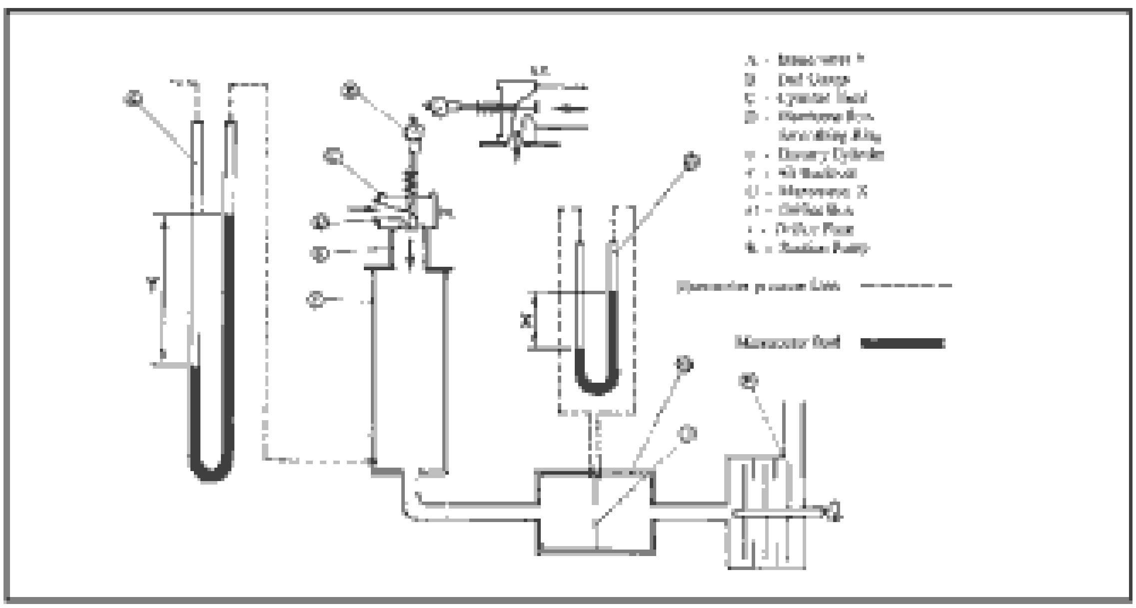

Figure 2.8: Schematic of flowbench layout

Source: Peter Burgess, David Gollan 2007

2.11 Source Of Flow Loss

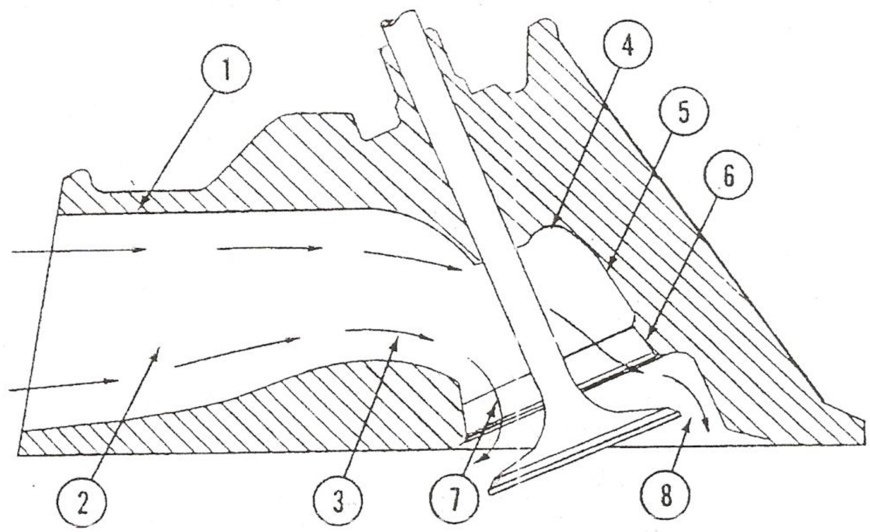

Figure 2.9: Source of flow loss at the restricted area

Source: SuperFlow Technology Group 2004

Table 2.3: Expected area decrease air flow in exhaust port

Source of flow loss	% of loss
Wall friction	4%
Contraction at push-rod	2%
Bend at valve guide	11%
Expansion behind valve guide	4%
Expansion, 25 degrees	12%
Expansion, 30 degrees	19%
Bend to exit valve	17%
Expansion existing valve	31%

CHAPTER 3

PROBLEM SOLVING

3.1 Cylinder Head

Cylinder head is one of the engine compartment that mount together with engine block. Cylinder head can be made of cast iron or aluminum alloy and seals the top of cylinders. It must be rigid enough to withstand the gas pressures exerted in it during the engine cycle. It is constructed to contain passages for coolant flow and accommodate various other components such as spark plugs, valves and valve train.

3.1.1 Toyota 1.6L 4AGE Cylinder Head

Figure 3.1: Toyota 1.6L 4AGE cylinder head

Table 3.1: Toyota 4AGE cylinder head specifications

Cylinder type	Toyota 1.6L 4 AGE
No of valve	16
No of exhaust valve	8
Valve train system	DOHC
Exhaust Valve size	24.4mm
Valve spring size	43.4mm

3.1.2 Proton 4G92 Cylinder Head

Figure 3.2: Proton 1.6L 4G92 cylinder head

Table 3.2: Proton 4G92 cylinder head specifications

Cylinder type	Proton 1.6L 4G92
No of valve	16
No of exhaust valve	8
Valve train system	SOHC (rocker arm & camshaft)
Exhaust Valve size	27.0mm
Valve spring size	50.9mm

3.2 Cylinder Head Modification

Cylinder head modification is refers to the process of modifying the exhaust ports of an internal combustion engine to improve the quality and quantity of the air flow. Original standard manufactured cylinder head are usually suboptimal due to the design and manufacturing constrains.

3.2.1 Remove Valve Guide

Standard manufactured cylinder head is build through casting process. Valve guide is build due to the casting process and it impinges upon air flow. Usually, the area of the port around the guide will be bigger to compensate for the obstruction. If the valve guide is an isolated lump, air flow probably improve if it is removed. The first modification for both Toyota 4AGE and Proton 4G92 cylinder head are removing the valve guide. The first exhaust port flow for both cylinder head remain in standard condition while other 3 ports have been removed the valve guide.

Figure 3.3: Valve guide removed in Proton cylinder head

Figure 3.4: Valve guide removed in Toyota cylinder head

3.2.2 Porting Cylinder Head

Porting cylinder head is more about how well air flows through the port rather than the port size. The goal is to create a smooth flowing path with less restriction for the air to travel from the combustion chamber to the exhaust port. Restriction such as sharp edges, ridges and rough surface need to be eliminate during the porting process. Removing too much material will create serious sealing problems and this is needed to be taken under consideration.

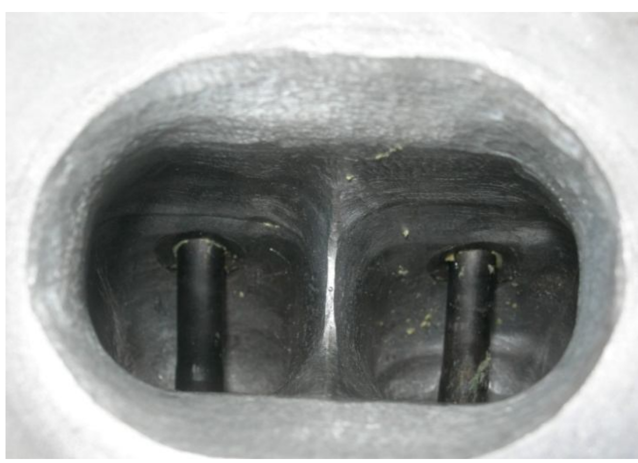

Figure 3.5: Proton cylinder head after porting process

Figure 3.6: Toyota cylinder head after porting process

3.2.3 Polishing Cylinder Head

Polishing is the process where the rough surface being removed using polishing kits such as abrasive tools and grindstones. When porting process involved, it creates concave area within the port and disturbs the air flow. It is need to eliminate so that the entire port should feature a continuous smooth radius. The full potential of the engine will gain when the smooth breathing of the air flow achieved.

Figure 3.7: Proton cylinder head after porting and polishing process

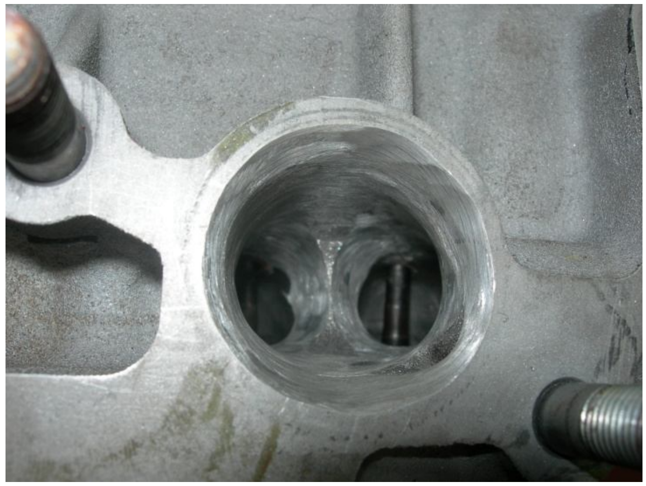

Figure 3.8: Toyota cylinder head after porting and polishing process

3.3 SF 1020 Flowbench Machine

The SuperFlow SF-1020 flowbench machine is designed to measure air-flow resistance of engine cylinder heads, intake manifolds, velocity stacks and restrictor plates. For four-cycle engine testing, air is drawn in through the head pump and exits through the vents at each side of the SF-1020 flowbench.

Flowbench testing consists of blowing or sucking air through a cylinder head or other component at a constant test pressure. Then the flow rate is measured at various valve lifts. A change can be made and the component can be retested. Greater air flow will indicates an improvement. If the tests are made under the same condition, no corrections for atmospheric conditions or machine variations are required. The results maybe compared directly.

Figure 3.9: SF-1020 Flowbench machine

3.3.1 Cylinder Head Adapter

Cylinder head are mounted onto the Superflow SF-1020 Flowbench by a cylinder adapter. The adapter consists of a tube about 4 inch, (10cm) long with the same bore as the engine and a flange on one end. The flange is bolted to the flow tester and the upper flange is bolted and clamped by G-clamp to the test cylinder head. The flanges must be flat or need to put on gasket paper to make an airtight seal. The adapter tube may be 0.06 inch, (1.5mm) larger or smaller than the actual engine cylinder.

A device must be attached to the cylinder head to open the engine valves to the various test positions. The usual method is to attach a threaded mount so the end of the threaded part contacts the end of the valve stem. As the screw thread is rotated, it pushes to open the valve.

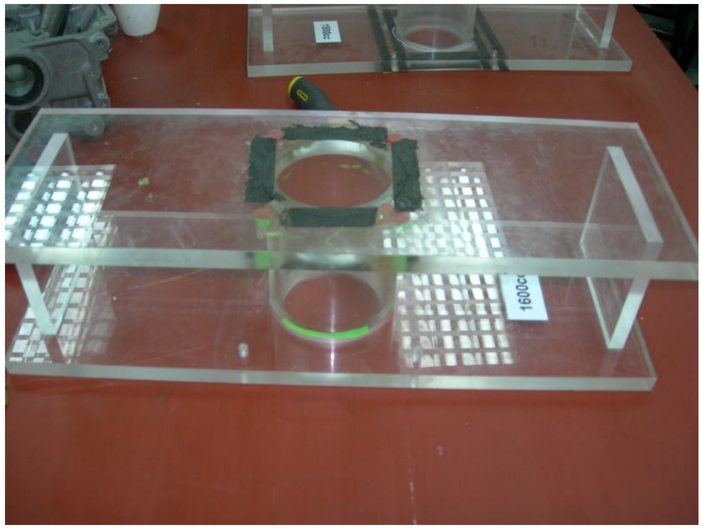

Figure 3.10: Cylinder head adapter for 1600cc engine

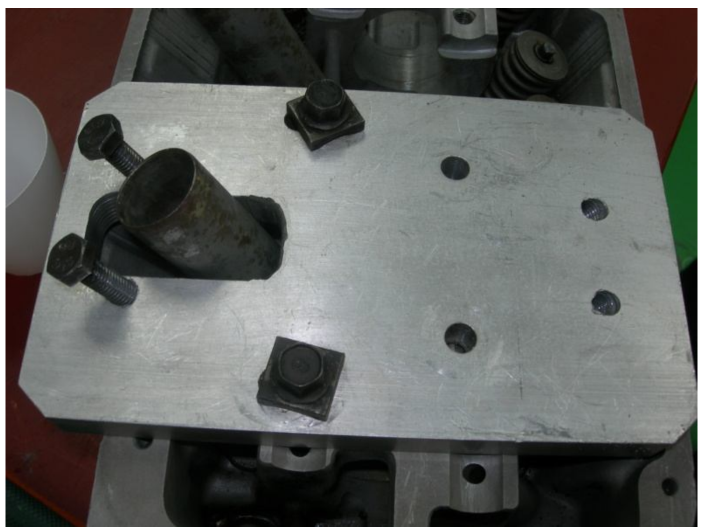

Figure 3.11: Thread screw mounting on the top of the cylinder head

3.3.2 Valve Lift And Air Flow

The air flow through the engine is directly controlled by the valve lift. The wider the valve open, the greater flow will gain up to a point. For this experiment, two different exhaust valves are used in order to get the data for the flow testing. It is stated that valve diameter for Toyota 4AGE is smaller compared to the Proton 4G92 valve. For this situation, the performance of the engine can be measure in terms of the ratio of valve lift to valve diameter or L/D ratio. Stock engines usually have a peak lift of 0.25 of the valve diameter while racing engines open the valve to 0.30d.

The Valve Flow Potential graph can be used as a guide for judging the performance of these Toyota and Proton valves. The formula for flow rate:

Flow rate for a valve = flow / area (from the graph) x the valve area – the valve stem area (3.1)

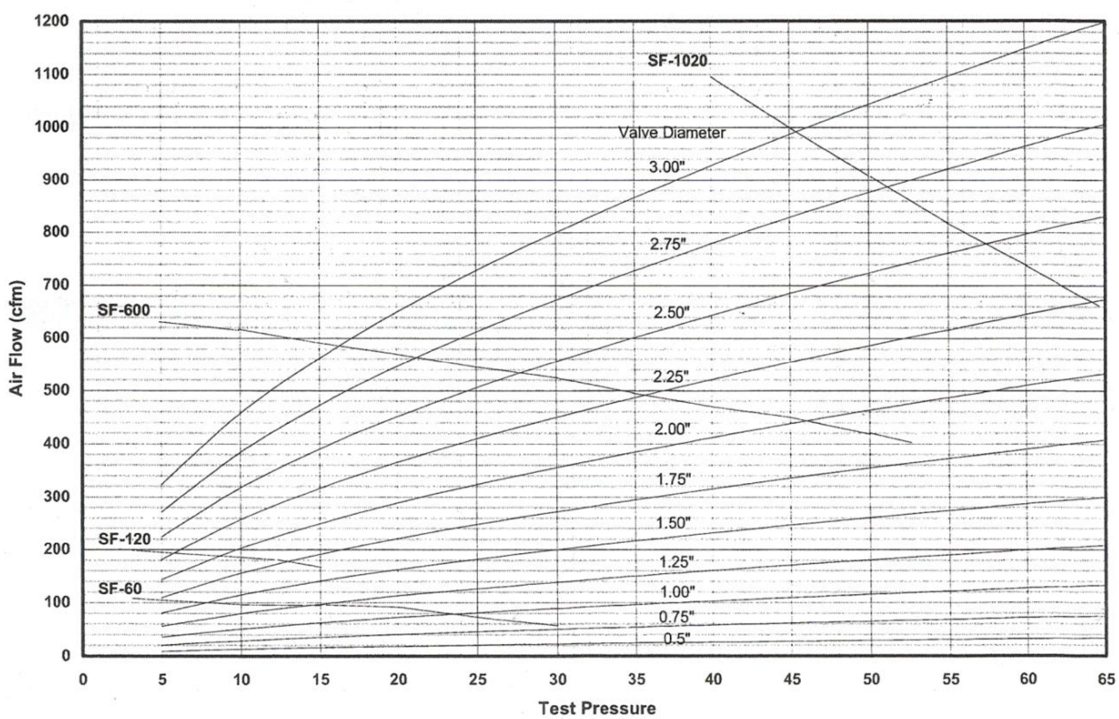

Figure 3.12: Potential flow vs test pressure graph

Source: SuperFlow Technology Group 2004

3.3.3 Porting And Polishing Tools

Figure 3.13: Air grinder and porting carbide burr

Air grinder is a tooling that usually use for porting and polishing modification. Air grinder is a tool that connected with air compressor for the source of power. It has various types of carbide burr which allow different usage in porting modification. The carbide burr shape such as cylinder, flame, ball and oval shape has its own dimension.

Figure 3.14: Polishing stones and flap wheel

Abrasive kits are used to eliminate the rough surface after porting modification has been made. It has different types of kits such as stones and flap wheel. For flap wheel, it is suitable for narrow strips of cloth designed to shank and it is perfect for chamber roof, wall and round port.

3.4 Test Setup

Turn on the power indicator button at the display panel. The screen display will show Superflow Corporation, Flowcom SF-1020. This message will be quickly followed by the words, Simple Mode. Notice the blinking cursor under the InH_2O label. This is the test pressure reading in inches of water. The middle reading is the corrected test flow in cfm. The reading on the right is the % of maximum velocity when the velocity probe is used.

With the cursor positioned under any of the three displayed measurements, push the Enter key. A new menu will appear showing the units of measurement. Use the Up/Down arrow keys to select other units. Push Enter when already made a selection and it will return to the first screen. To freeze the readings during a test, push the Up key and solid bar will appear between the readings and the reading will be frozen until the Down arrow key is pushed.

Push the Cycle key once to change Screen #2, and again for the Test Configuration screen #3. Use screen #3 to enter the test pressure, leakage, and Flow Range at the beginning of a test. Push the Enter key when the cursor is under each function, followed by the Up/Down arrow keys to change each value. Push Enter when done, and then the Cycle key to return to screen #1for the tests. Run the experiment with both intake and exhaust valve fully closed. Check the leakage between the cylinder head and the adapter. Put on sealant at the possible leakage part and run the experiment again. Finally, put on the leakage value at screen #3 for automatically correct the test error and run the experiment (SuperFlow Technology Group 2004).

3.4.1 Adapting Heads for Testing

Cylinder head are mounted onto the Superflow SF-1020 Flowbench by a cylinder adapter. The adapter consists of a tube about 4 inch, (10cm) long with the same bore as the engine and a flange on one end. The flange is bolted to the flow tester and the upper flange is bolted and clamped by G-clamp to the test cylinder head. The flanges must be flat or need to put on gasket paper to make an airtight seal. The adapter tube may be 0.06 inch, (1.5mm) larger or smaller than the actual engine cylinder.

A device must be attached to the cylinder head to open the engine valves to the various test positions. The usual method is to attach a threaded mount so the end of the threaded part contacts the end of the valve stem. As the screw thread is rotated, it pushes to open the valve.

Figure 3.15: Cylinder head attached to the adapter by clamping with G-clamp

3.4.2 Performing Flow Test

Remove the test orifice plate from the flowbench and install the test head, cylinder adapter and valve opener for the actual flow tests. Set the dial indicator to read zero with the valve closed.

Figure 3.16: Dial gauge indicator attached to the thread screw

Next, turn on the flowbench motor and observe if the test pressure reads the test pressure that intends to use. Assuming test pressure is 25.00 InH_2O. (60.0cm)

Figure 3.17: Test pressure for the experiment set up

Then, determine the leakage flow with the valve closed. The leakage flow needs to be considered because it may affect the test flow results. If there is no leakage, the corrected test flow may read zero. The leakage will not affect the test as long as the leakage is considered on the display screen.

Figure 3.18: The leakage value in cfm

Next, all engine valve tests should be performed at the same ratio of valve lift to valve diameter, or L/D ratio. Then the flow efficiencies of any valve can be compared, regardless of size. Different valve diameter will used different range orifice setting. This is to make sure the test results are valid and the flow of the maximum valve lift can be measured. For greatest accuracy, a flow range which gives readings above 70% of the flow range at full lift. If the reading is not high enough, lower range setting need to be entered.

Figure 3.19: Orifice range flow at the test setup

For the exhaust port flow analysis, blowing the air from the flowbench to the atmosphere is needed. It shows the exhaust process in the internal combustion engine where exhaust gasses and fumes is blow out of the cylinder through the exhaust port. Hence, exhaust test orifice need to choose and blue light indicator will turn on after the orifice is selected.

Figure 3.20: Setting the exhaust orifice flow at the flowbench display screen

3.5 Test Procedures

Before running the test, general inspection was done to check any problem that may occur because any error of the measurement system and apparatus may affect the outcomes results. Firstly, switch on the SF-1020 Flowbench machine and make sure the display screen appear. Set the parameters for the test flow such as Test Pressure, Exhaust Flow Setup, Range Of Orifice, Leakage and others.

When all parameters have been set up, attach the 1600cc adapter between the cylinder head and flowbench machine and tighten 4 screws on the adapter. Next, put on the cylinder head on the top of the adapter and tighten the cylinder head using G-clamp. Make sure any possible areas that will leak and affect the flow are sealed using plastercin and double sided tape such as adapter screw, area between adapter and cylinder head, and others. Adding gasket paper between the cylinder head and adapter also can give the sealing effect.

Run the test flow by setting the Test Pressure at 25 InH_2O and set the leakage value to 0. When test pressure value obtained, stop the machine and set back the leakage value to get the corrected value before running the test. Finally, run the test and the reading for percent velocity and air flow (cfm). The lift valve per valve area for both cylinder head is measured using feeler gauge. The general inspection, instruments preparation and machine procedure are apply to both original and modified cylinder head testing.

3.6 Calculation Methods

Effective valve area = (Valve diameter^2- Stem diamter^2) x 0.785 (3.2)

Test Flow = Correction Test Flow / Effective valve area (3.3)

% Potential Flow = Test Flow / Potential Flow (3.4)

Cd = Test Flow / Potential Orifice Flow (3.6)

HP = 0.27 x (Corr. Test Flow cfm) x (25 / Test Pressure inches)$^{0.5}$ x 4 cyl (3.7)

kW = 0.44 x (9.0 l/s) x (60 / 63.5 cm)$^{0.5}$ x 4 cyl (3.8)

CHAPTER IV

RESULTS AND DISCUSSIONS

4.1 Introduction

The main objectives of this project are to study on the air flow characteristics of the exhaust port in cylinder head. Studies have been done in investigate the engine power and performance improvement by the amount of air drawn out of the engine between different shape and size of the Toyota 1.6L 4AGE and Proton 1.6L 4G92 cylinder head.

The main characteristics that were taken into consideration in analyzing the performance of this cylinder head are test flow, LD ratio, horsepower and volumetric efficiency.

4.2 Test Data

The testing done on the both Toyota and Proton cylinder head was to determine the maximum horsepower produced by the engines with different modification done at the cylinder head port. Maximum power generated by the cylinder head at specific test pressure achieved when the maximum flow gained at maximum valve lift opened.

For the original port condition, the cylinder head has been tested with the same test pressure and range for every valve lift increment. The testing was done for the purpose of setting the reference point of the original stock condition before further modification at the cylinder head.

The cylinder head was tested at 25.00 InH_2O and range 4 for both Proton and Toyota cylinder head. The range is set based on the valve diameter size. For proton, the valve size is 27.0 mm and for Toyota, the valve size is 24.4mm. There were two methods that been used to gained the air flow reading, valve lift method and LD ratio method. Valve lift method was used to compare the air flow between original and modification for the same cylinder head. The LD ratio method was used to compare the air flow between different cylinder head.

The data were recorded in tables in Appendix A for the Proton 4G92 cylinder head and Appendix B for the Toyota 4 AGE cylinder head.

4.3 Data Analysis

After the experiment data were recorded in tables in Appendix A, B and C, the data were analyzed using calculation methods. Selected formulas have been chosen to calculate potential flow, effective valve area, percent potential flow, coefficient of discharge, test flow and horsepower. The analysis based on performance parameters described previously.

For this analysis, potential flow graph is used to determine the constant parameters based on valve diameter for each cylinder head. Different valve area shows different results and it is contributes to the final output engine performance based on cylinder head.

4.4 Comparison Tables

The comparison tables show the different results between original cylinder head and modification cylinder head for both Toyota 4 AGE and Proton 4G92. The comparison table based on the horsepower and the coefficient of discharge are displayed to show the potential of this both cylinder head.

4.5 Graph Plotting

The analysis results are best presented in a graph form for the purpose of comparisons, explanations, evaluations and understanding the cylinder head for original and modification parameters. The graphs plotted are:-

i. Air flow comparisons of original and modification cylinder head for Proton 4G92 and Toyota 4AGE.
ii. Horsepower comparisons of original and modification cylinder head for Proton 4G92 and Toyota 4AGE.
iii. Lift valve to diameter ratio comparisons of original and modification cylinder head for Proton 4G92 and Toyota 4AGE.
iv. Coefficient of discharge comparisons of original and modification cylinder head for Proton 4G92 and Toyota 4AGE.

4.6 Discussions

From the experiment done, it is clear that all of the modification applied for the cylinder head shows the improvement to the air flow. It was also found that both Proton 4G92 and Toyota 4AGE have its own potential towards further modification. Experiment has been done under four working conditions:-

i. Original stock condition
ii. Without valve guide condition
iii. Porting condition
iv. Polishing condition

4.6.1 Effect on the modification methods to the cylinder head

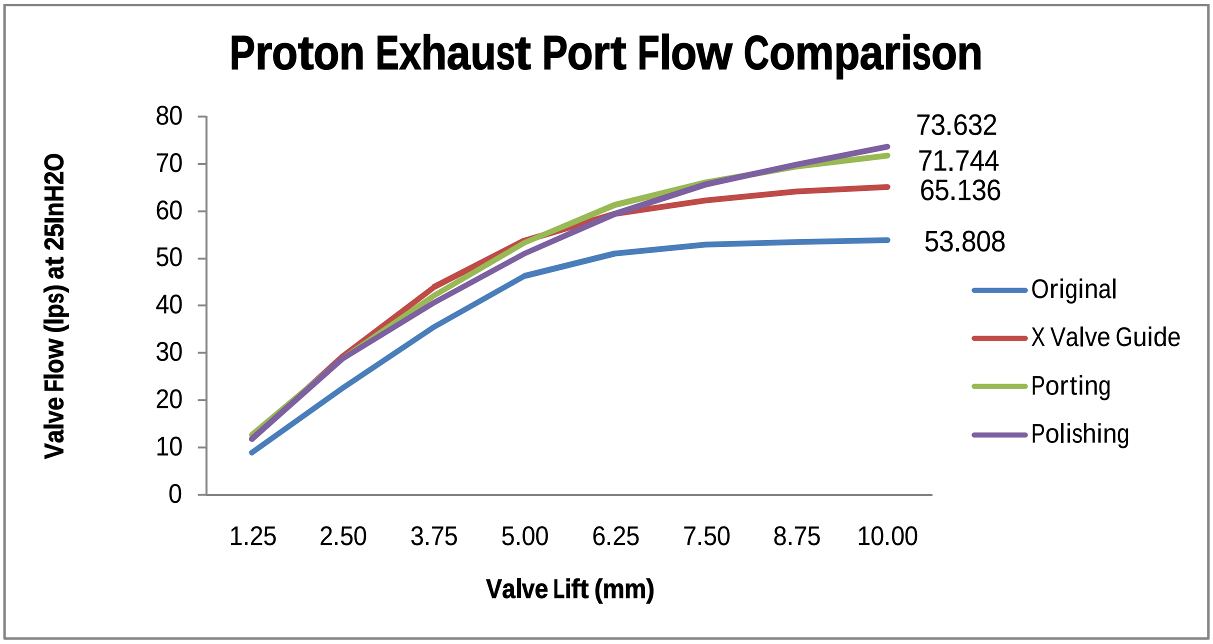

Figure 4.1: Proton 4G92 exhaust port flow cylinder head comparison

Figure 4.1 illustrates that by the modification applied to the exhaust port flow, the cylinder head is capable to increase the air flow. The original stock exhaust port flow can drawn the air flow up to 53.808 lps. By eliminate the valve guide, the air flow increase up to 65.136 lps at 10.00mm valve lift. The increment is 21.05% from the original condition.

Next, implementing porting modification to the exhaust port shows the increment of air flow up to 71.711 lps at 10.00mm valve lift. The percent increment of air flow is 33.33% from original condition. The maximum air flow is obtained when polishing modification method implement at the exhaust port. The results shows at 10.00mm valve lift, the air flow is 73.632 lps and it is 36.84% increment of air flow from original exhaust port condition.

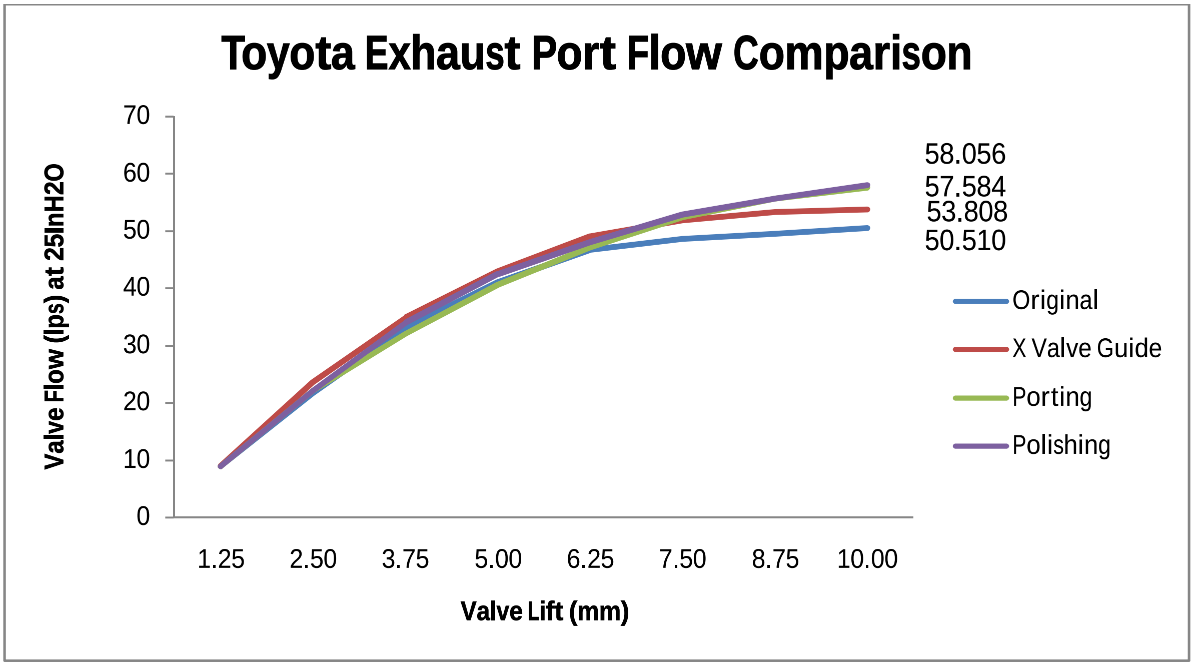

Figure 4.2: Toyota 4AGE exhaust port flow cylinder head comparison

Figure 4.2 illustrates that by the modification applied to the exhaust port flow, the cylinder head is also capable to increase the air flow of Toyota 4AGE cylinder head. The original stock exhaust port flow can drawn the air flow up to 50.510 lps. By eliminate the valve guide, the air flow increase up to 53.808 lps at 10.00mm valve lift. The increment is 6.53% from the original condition.

Next, implementing porting modification to the exhaust port shows the increment of air flow up to 57.584 lps at 10.00mm valve lift. The percent increment of air flow is 14.06% from original condition. The maximum air flow is obtained when polishing modification method implement at the exhaust port. The results shows at 10.00mm valve lift, the air flow is 58.056 lps and it is 14.94% increment of air flow from original exhaust port condition.

4.6.2 Valve lift to diameter ratio comparison to the different cylinder head

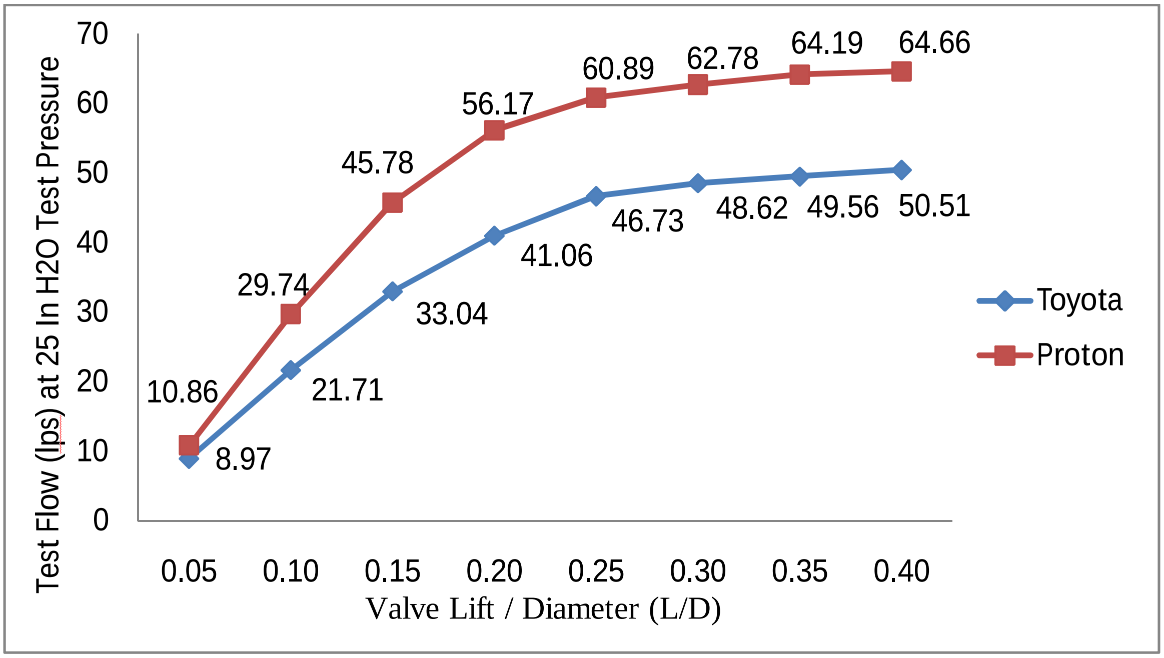

Figure 4.3: Test flow at exhaust port flow for original standard condition

In this experiment, Figure 4.3 shows that the test flow trend from 0.05L/D to 0.30L/D is increase and after 0.30L/D, the value of test flow is stable until the maximum lift at 0.40L/D ratio. Proton exhaust port cylinder head can flow more air compared to Toyota exhaust port cylinder head in standard condition. The maximum test flow at 0.40L/D or 10.8mm for Proton exhaust port is 64.66 lps while for Toyota at 0.40L/D or 9.76mm is 50.51lps.

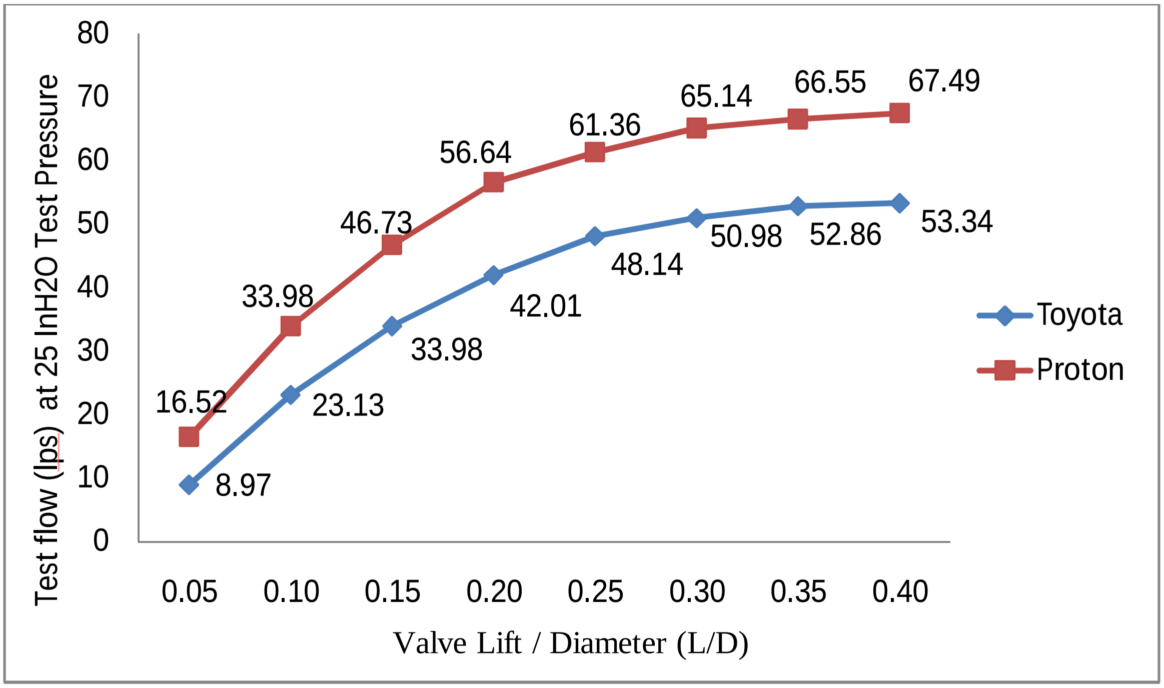

Figure 4.4: Test flow at exhaust port flow by eliminating the valve guide

For the next experiment, both cylinder head have been modified by eliminating the valve guide inside the exhaust port. Figure 4.4 shows the analysis of the Proton and Toyota cylinder head. The minimum test flow at 0.05L/D for Proton is 16.52 lps and Toyota is 8.97 lps. The maximum test flow achieved at 0.04L/D for Proton is 67.49 lps and Toyota is 53.34 lps. For this experiment, by eliminating the valve guide, it shows the increment of the test flow and still Proton exhaust port cylinder head can generate higher air flow compared to Toyota exhaust port cylinder head.

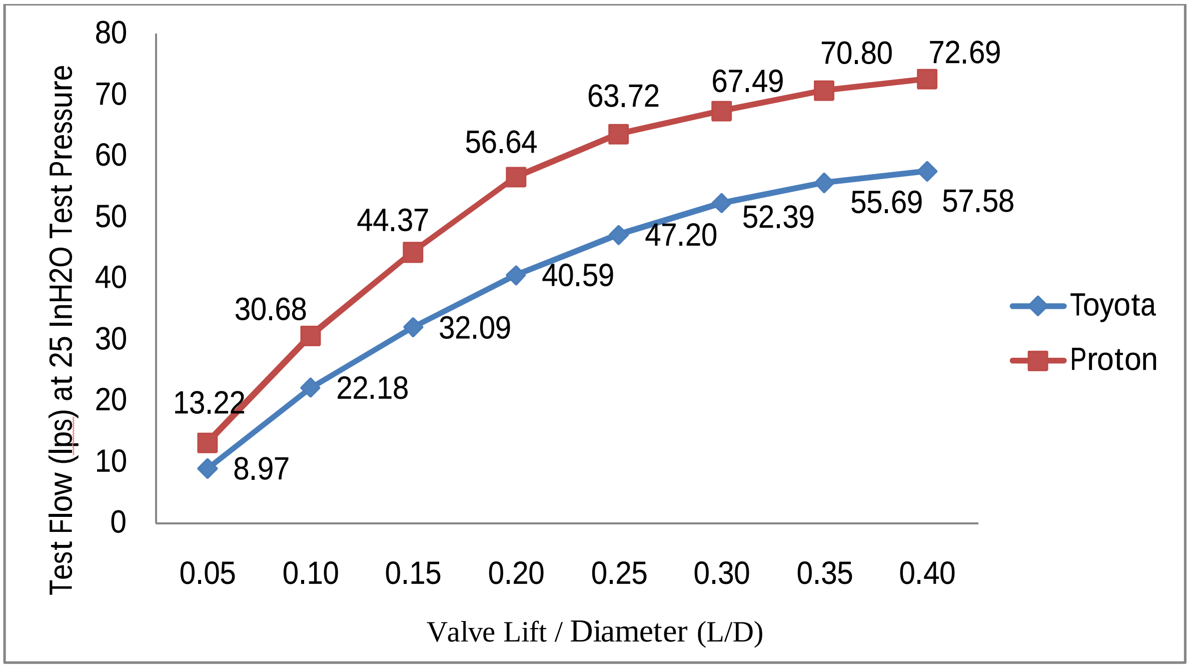

Figure 4.5: Test flow at exhaust port flow by porting modification done at the exhaust port

Figure 4.5 shows the results of test flow at exhaust port flow by porting modification have been done at the exhaust port flow. The minimum test flow for Proton is 13.22 lps at 0.05L/D or 1.35mm and Toyota is 8.97 lps at 0.05L/D or 1.22mm. The test flow is increase for every valve lift increment and the maximum test flow is obtained at 0.40L/D or 10.8mm for Proton is 72.69 lps and 0.40L/D or 9.76mm for Toyota is 57.58 lps. The trend of this graph is increase for every valve lift increase and at maximum test flow, Proton exhaust port can allow more air out of the cylinder head compared to Toyota exhaust port.

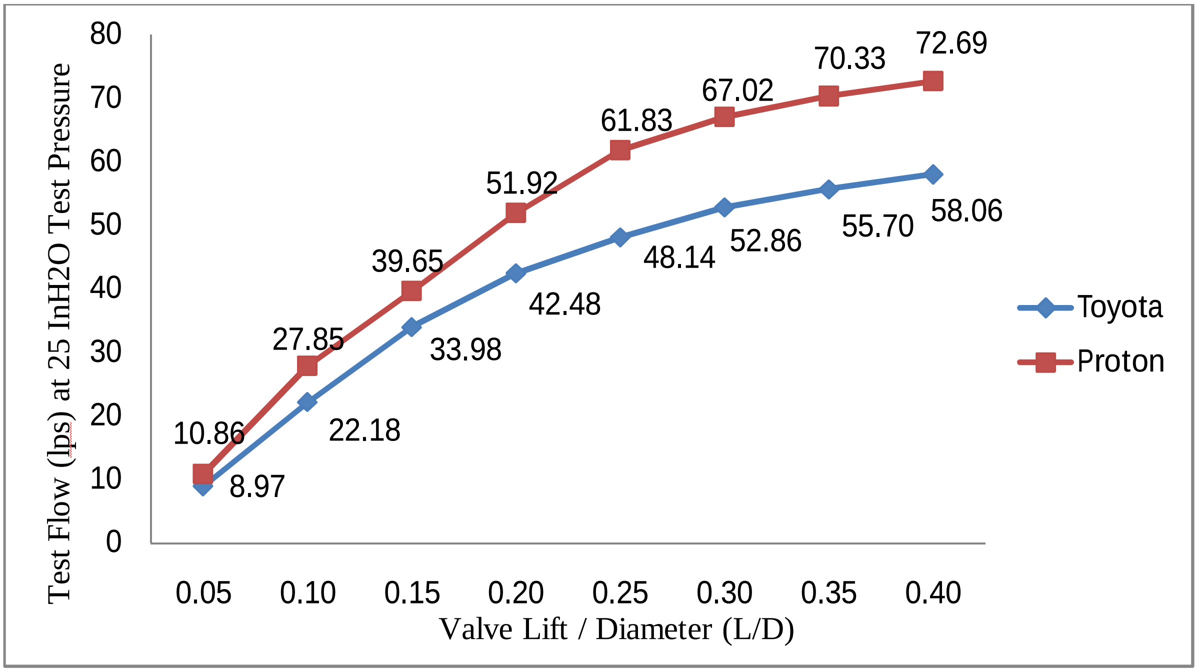

Figure 4.6: Test flow at exhaust port flow by polishing modification done at the exhaust port

In this experiment results have shown that, increasing valve lift from 0.05L/D until 0.40L/D can be increasing the test flow in the exhaust port flow. Figure 4.6 shows that the test flow trend from 0.05L/D to 0.35L/D is increase and after 0.35L/D is stable. It is shown that the maximum test flow for original and modified port cylinder head occur at 0.40L/D for Proton and Toyota cylinder head. Proton exhaust port shows increment from 64.66 lps to 72.69 lps after polishing modification applied to the exhaust port and Toyota exhaust port from 50.51 lps to 58.06 lps after modification. By comparing the valve lift to diameter ratio, it shows that Proton cylinder head can produce more air flow at exhaust port compare to Toyota exhaust port. Proton cylinder head can adapt more on modifying application to the cylinder head and it shows greater improvement of air flow while Toyota cylinder head is already build up for performance so not much modification in terms of port and polish can be applied.

4.6.3 Coefficient of discharge

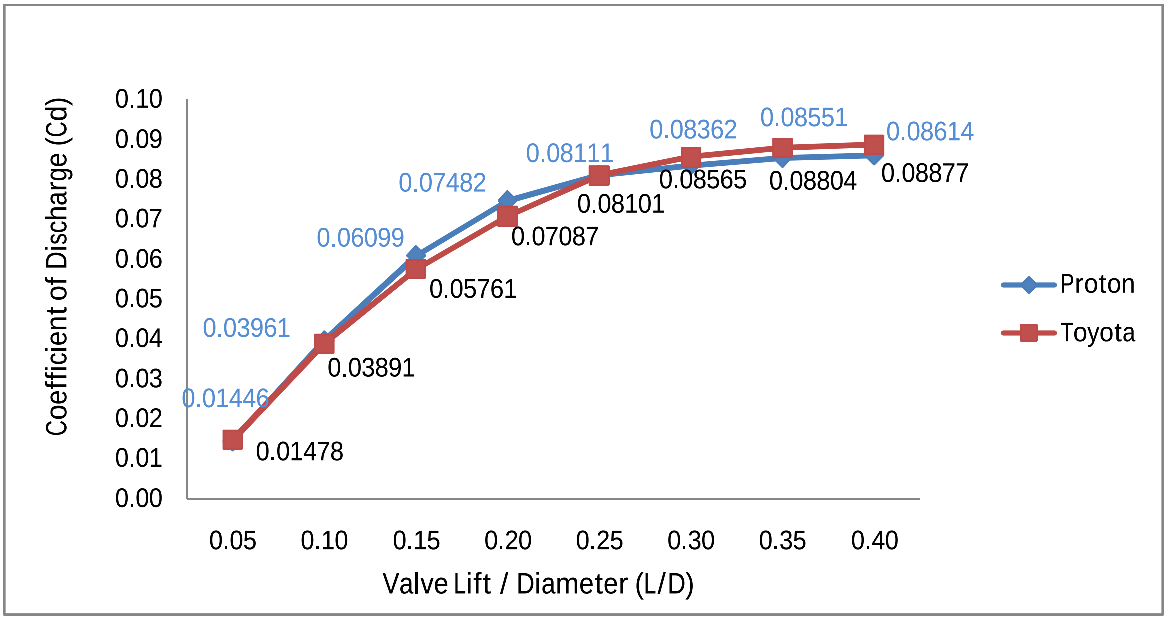

Figure 4.7: Coefficient of discharge for original standard condition

Figure 4.7 shows the Coefficient of Discharge (CD) for original standard condition for both Proton and Toyota cylinder head. The CD investigation is based on valve lift per diameter. From the graph, CD for Toyota is increase from 0.05L/D or 1.22mm to 0.40L/D or 9.76mm exhaust valve lift and CD for Proton also increase from 0.05L/D or 1.35mm to 0.40L/D or 10.8mm. After 0.25L/D, the CD for Toyota cylinder head is increase more than Proton cylinder head and the results become stable. For Proton cylinder head, at 0.15L/D to 0.20L/D the results of CD achieved more than Toyota cylinder head. For every valve lift increment, the trend of CD also increases and after certain, the results are stable. The maximum CD for Proton is 0.08614 and Toyota is 0.08877.

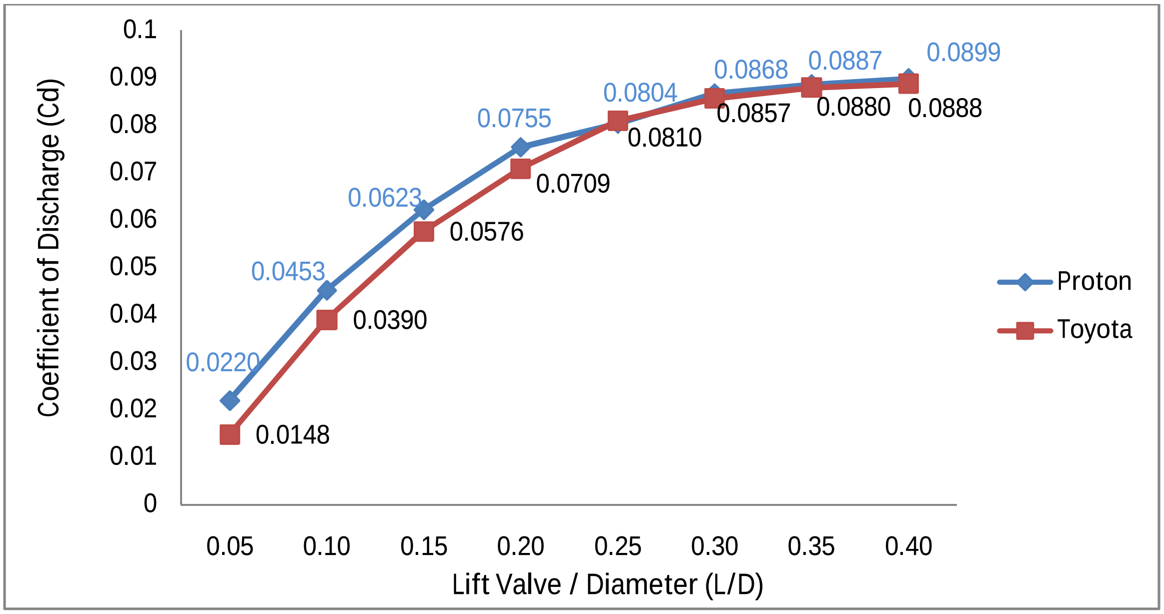

Figure 4.8: Coefficient of discharge of exhaust port flow by eliminating the valve guide

Figure 4.8 shows the Coefficient of Discharge (CD) for modification of the cylinder head by eliminating the valve guide for both Proton and Toyota cylinder head. The CD investigation is based on valve lift per diameter. From the graph, CD for Toyota is increase from 0.05L/D or 1.22mm to 0.40L/D or 9.76mm exhaust valve lift and CD for Proton also increase from 0.05L/D or 1.35mm to 0.40L/D or 10.8mm. The maximum CD for Proton is 0.0899 and Toyota is 0.0888. The CD for both cylinder head increases starting from 0.05L/D until 0.25L/D. At 0.25L/D and above, the CD for both cylinder head are start to become stable.

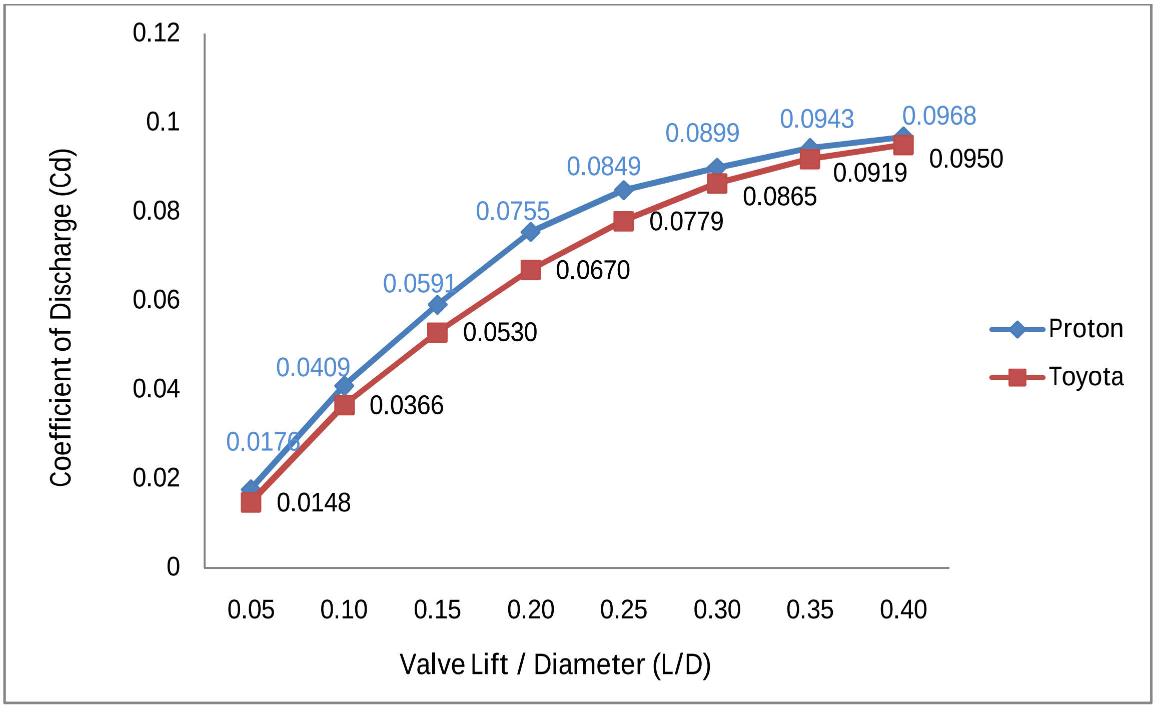

Figure 4.9: Coefficient of discharge of exhaust port flow by porting modification

Figure 4.9 shows the Coefficient of Discharge (CD) of exhaust port flow by porting modification applied to both cylinder head. From the graph, there is some different margin for both cylinder head at 0.20L/D. For Toyota, the CD is 0.0670 and for Proton is 0.0755. After 0.30L/D, the CD for both cylinder head becomes stable. The maximum CD is achieved at 0.40L/D or 10.8mm for Proton is 0.0968 and 0.40L/D or 9.76mm for Toyota is 0.0950. The trend of CD for both cylinder head shows for every valve lift per diameter increment, the CD also increases and at certain point it becomes stable.

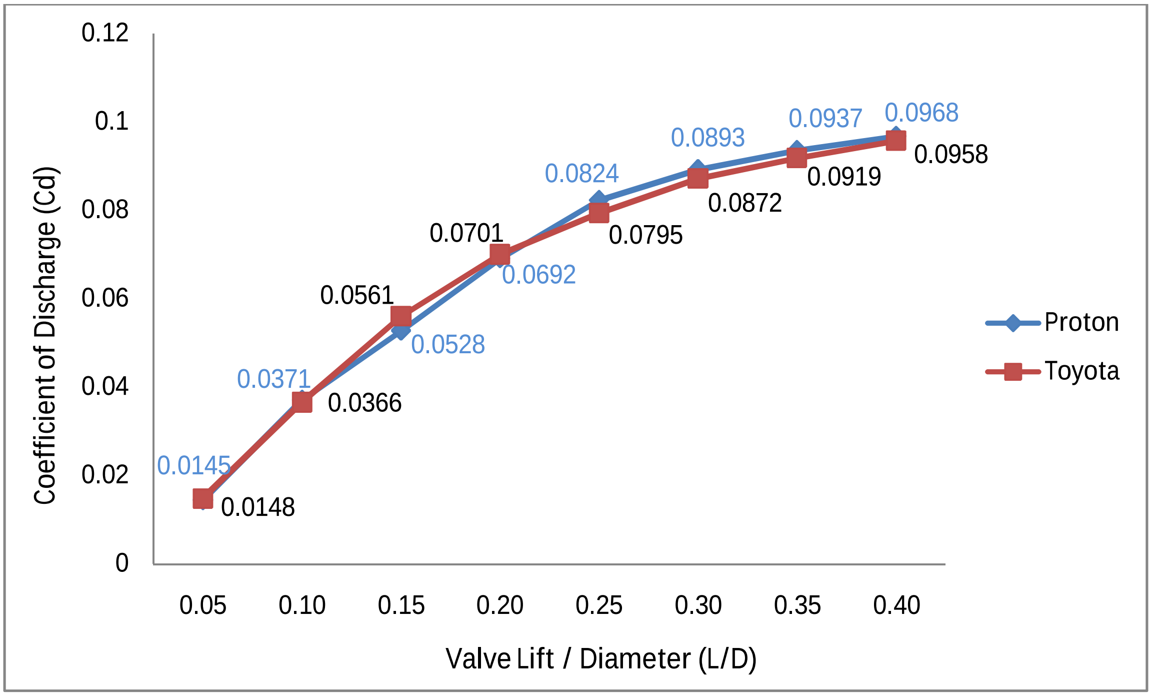

Figure 4.10: Coefficient of discharge of exhaust port flow by polishing modification.

The coefficient of discharge (CD) of the superflow flowbench test flow from this experiment results is shown in Figure 4.10. The CD investigation is based on valve lift per diameter (L/D ratio) for polishing modification of exhaust port cylinder head. From coefficient of discharge, it shows that increasing the valve lift from 0.05L/D to 0.40L/D for exhaust valve lift can be increasing the coefficient of discharge in the exhaust CD. For Proton cylinder head, it shows the increment for CD for every valve lift until it reaches the point where the value is stable and cannot increase. The maximum CD is 0.0968 for Proton cylinder head. Toyota cylinder head also shows the increment for every valve lift and the modification applied shows the positive value for the increment of air flow. The maximum CD for Toyota cylinder head is 0.0958.

4.7 Sample Calculation

For every testing in the experiment, the results of air flow that obtained from the flowbench machine are calculated using theoretical formula. These are the example of Proton 4G92 cylinder head results that have been calculated for original standard condition. (refer to Appendix A)

Diameter valve = 27mm = 1.0629in

Potential flow = 120cfm=56.64(l/s)

(The results is obtained from Potential Flow vs Test Pressure graph)

Calculating the effective valve area for the Proton exhaust valve:

Effective valve area = (Valve diameter^2- Stem diamter^2) x 0.785

= $(2.7^2-0.6^2)$ x 0.785

= 5.440 cm^2

Calculating the test flow for the experiment results:

Test Flow = Correction Test Flow / Effective valve area

= 9.0 / 5.440

= 1.65 (l/s) / (cm^2)

Percent potential flow is obtained using formula given:

% Potential Flow = Test Flow / Potential Flow

= 1.65 / 56.64 x 100

= 2.91 %

Coefficient of Discharge can be obtained by:-

Cd = Test Flow / Potential Orifice Flow

Cd = 1.65 / 138 = 0.01195

Horsepower can be calculated using formula below and it is assumed based on 4 cylinders:-

HP = 0.27 x (Corr. Test Flow cfm) x (25 / Test Pressure inches)$^{0.5}$

HP = 0.27 x (19 cfm) x (25 / 25 InH_2O)$^{0.5}$ x 4 cyl

= 20.52HP

kW = 0.44 x (Corr. Test Flow l/s) x (60 / Test Pressure cm)$^{0.5}$

kW = 0.44 x (9.0 l/s) x (60 / 63.5 cm)$^{0.5}$ x 4 cyl

= 15.34kW

4.8 Limitation for the project

For this final year project, there are limitations when experiment and analysis for this cylinder head. Firstly, the analysis will not be compared to Toyota and Proton factory engine specification. This is because the analyses only focus on one Toyota 4AGE and one Proton 4G92 cylinder head. The results obtained are between this boundary and only available in the comparison between standard condition cylinder head and modification for this experiment.

Next, the analyses are not in engine operational practise. The cylinder head are only attached with the adapter and the flowbench machine. The horsepower obtained is limited to the cylinder head without attachment with the major engines component. This analysis conducted to study the flow behaviour of both exhaust port and the validation of the results is between this parameter.

Finally, the results can be compared to the outside engine if three major things have been considered. The considerations of the engine are it needs to have maximum compression for every stroke, right and suitable camshaft and it has tuned exhaust system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

This project has successfully achieved the objectives based on the results analysis that calculated from the data obtained. From the experiment, the air flow, coefficient of discharge and the horsepower are increased when modification applied to the cylinder head. Proton 4G92 shows the increment of air flow from original standard condition to modification of the exhaust port. This cylinder head can adapt modification and it gives positive feedback for every modification applied.

Next, surface finish of the exhaust port has gives different results for the exhaust port flow cylinder head. Reducing the turbulence flow in the port by neglecting the potential restriction in the exhaust port can allow smooth air flow out the cylinder head. This can increase the performance of the cylinder head and higher horsepower obtained.

Furthermore, every cylinder head has its own capability based on shape and design of the cylinder head. From the experiment, Proton 4G92 cylinder head can adapt more on modification and still has potential to modify while Toyota 4 AGE is highly development and only few modification can be applied.

Finally, from the experiment, applying modification on the cylinder head such as eliminating the valve guide, porting and polishing can improve the power and performance of the engine and it is recommended for car enthusiast to get the benefits of cylinder head modification.

6.0 Recommendation For The Future Research

For further improvement when doing the experiment, it is recommended to improve the leakage problem when attaching the cylinder head and adapter to the flowbench machine. Good sealant is important so that it can reduce the leakage and more accurate data can be obtained. Besides, there still need some guidance when dealing with the modification tools so it can get the best results. Porting and polishing modifications is an art and skills are needed for beginners to do the modification.

Next, it is better if more cylinder head of the same specification can be modified to get the average data of the cylinder head. The parameter such as production made, period of usage and wear components need to be monitor. This is important so that the validity of the results can be compared with manufacturer specification and the results obtained are totally proven.

Finally, it is suggested that the original and modified cylinder head is being testing using engine dyno test so that it can get the actual data and can be compared with the theoretical value. This is important because in actual results, the cylinder head is combined with internal combustion engine and all the systems are related.

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APPENDIX A

PROTON 4G92 STANDARD AND MODIFICATION TEST DATA

Proton Exhaust Valve Test Data (Original Condition)Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	9.00	22.66	35.00	46.00	50.98	52.86	53.34	53.81
Test flow[l/s]/cm2	1.65	4.17	6.43	8.46	9.37	9.72	9.81	9.89
Potential Valve Flow	56.64	56.64	56.64	56.64	56.64	56.64	56.64	56.64
% Potential Flow	2.91%	7.35%	11.49%	15.01%	16.54%	17.16%	17.31%	17.46%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01195	0.03018	0.04715	0.06162	0.06791	0.07042	0.07104	0.07167
% Velocity	4.06%	3.78%	3.78%	3.38%	3.86%	3.96%	3.32%	3.94%
HP for 4 cylinders	20.52	52.00	81.00	105.84	116.64	120.96	122.04	123.12
kW for 4 cylinders	15.34	38.76	60.57	79.14	87.22	90.45	91.25	92.06

Proton Exhaust Valve Test Data (Without Valve Guide)Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	12.00	29.26	44.00	54.00	59.47	62.30	64.19	65.13
Test flow[l/s]/cm2	2.17	5.38	8.07	9.89	10.93	11.45	11.80	11.97
Potential Valve Flow	56.64	56.64	56.64	56.64	56.64	56.64	56.64	56.64
% Potential Flow	3.83%	9.50%	14.25%	17.46%	19.30%	20.22%	20.83%	21.14%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01572	0.03898	0.05847	0.07167	0.07922	0.08299	0.08551	0.08677
% Velocity	2.53%	2.87%	2.33%	2.70%	3.23%	3.17%	3.17%	1.83%
HP for 4 cylinders	27.20	67.46	101.18	124.03	137.09	143.62	147.97	150.14
kW for 4 cylinders	20.19	50.07	75.10	92.06	101.75	106.59	109.82	111.44

APPENDIX A

PROTON 4G92 STANDARD AND MODIFICATION TEST DATA

Proton Exhaust Valve Test Data (Porting)Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	13.00	28.79	42.00	53.00	61.36	66.08	69.38	71.74
Test flow[l/s]/cm2	2.39	5.29	7.72	9.74	11.28	12.15	12.75	13.19
Potential Valve Flow	56.64	56.64	56.64	56.64	56.64	56.64	56.64	56.64
% Potential Flow	4.14%	9.35%	13.66%	17.30%	19.91%	21.45%	22.52%	23.28%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01698	0.03836	0.05607	0.07104	0.08173	0.08802	0.09242	0.09557
% Velocity	3.23%	2.43%	3.13%	2.60%	2.50%	2.63%	2.23%	2.63%
HP for 4 cylinders	29.38	66.37	96.83	122.94	141.44	152.32	159.94	165.38
kW for 4 cylinders	21.80	49.26	72.01	91.25	104.98	113.05	118.70	122.74

Proton Exhaust Valve Test Data (Polishing)Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	12.00	28.79	41.00	51.00	59.47	65.61	69.86	73.63
Test flow[l/s]/cm2	2.17	5.29	7.46	9.37	10.93	12.06	12.84	13.54
Potential Valve Flow	56.64	56.64	56.64	56.64	56.64	56.64	56.64	56.64
% Potential Flow	3.83%	9.34%	13.17%	16.54%	19.30%	21.29%	22.67%	23.90%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01571	0.03836	0.05407	0.06791	0.07922	0.08739	0.09305	0.09808
% Velocity	5.27%	4.40%	3.77%	5.07%	4.10%	4.33%	4.13%	3.87%
HP for 4 cylinders	27.2	66.37	93.57	117.50	137.09	151.23	161.02	169.73
kW for 4 cylinders	20.19	49.26	69.45	87.21	101.75	112.24	119.51	125.97

APPENDIX B

TOYOTA 4AGE STANDARD AND MODIFICATION TEST DATA

Toyota Exhaust Valve Test Data (Original Condition) Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	8.97	21.71	33.04	41.06	46.73	48.62	49.56	50.51
Test flow[l/s]/cm2	2.04	5.37	7.95	9.78	11.18	11.82	12.15	12.25
Potential Valve Flow	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
% Potential Flow	4.32%	11.38%	16.84%	20.72%	23.69%	25.04%	25.74%	25.95%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01478	0.03891	0.05761	0.07087	0.08101	0.08565	0.08804	0.08877
% Velocity	5.03%	4.73%	4.47%	4.77%	5.23%	5.47%	5.20%	5.43%
HP for 4 cylinders	20.52	49.68	75.60	93.96	106.92	111.24	113.4	115.56
kW for 4 cylinders	15.35	37.14	56.53	70.25	79.95	83.18	84.79	86.42

Toyota Exhaust Valve Test Data (Without Valve Guide) Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	8.97	23.6	34.928	42.952	49.088	51.92	53.336	53.808
Test flow[l/s]/cm2	2,042	5.3746	7.9545	9.7818	11.1792	11.8242	12.147	12.2542
Potential Valve Flow	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
% Potential Flow	4.33%	11.39%	16.85%	20.72%	23.68%	25.05%	25.73%	25.96%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01480	0.03895	0.05764	0.07088	0.0810	0.08568	0.08802	0.08880
% Velocity	5.03%	4.73%	4.47%	4.77%	5.23%	5.47%	5.20%	5.43%
HP for 4 cylinders	20.67	54.4	80.51	99.01	113.15	119.68	122.94	124.03
kW for 4 cylinders	15.35	40.38	59.76	73.48	83.98	88.83	91.25	92.06

APPENDIX B

TOYOTA 4AGE STANDARD AND MODIFICATION TEST DATA

Toyota Exhaust Valve Test Data (Porting) Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	8.97	22.18	32.1	40.59	47.20	52.39	55.70	57.58
Test flow[l/s]/cm2	2.04	5.05	7.31	9.24	10.75	11.93	12.68	13.11
Potential Valve Flow	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
% Potential Flow	4.33%	10.70%	15.49%	19.58%	22.77%	25.28%	26.87%	27.78%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01480	0.03661	0.05296	0.06699	0.07789	0.08646	0.09191	0.09503
% Velocity	4.13%	3.20%	4.37%	3.73%	4.20%	4.33%	3.87%	4.27%
HP for 4 cylinders	20.67	51.14	73.98	93.57	108.8	120.77	128.38	132.74
kW for 4 cylinders	15.34	37.95	54.91	70.06	80.75	89.63	95.29	98.52

Toyota Exhaust Valve Test Data (Polishing)Valve Lift

Test Number	1	2	3	4	5	6	7	8
Test Pressure[InH2O]	25	25	25	25	25	25	25	25
Valve Lift[mm]	1.25	2.50	3.75	5.00	6.25	7.50	8.75	10.00
Flow Range	4EX	4EX	4EX	4EX	4EX	4EX	4EX	4EX
Corr. Test Flow[l/s]	8.97	22.18	33.98	42.48	48.14	52.86	55.69	58.06
Test flow[l/s]/cm2	2.04	5.05	7.74	9.67	10.96	12.04	12.68	13.22
Potential Valve Flow	47.2	47.2	47.2	47.2	47.2	47.2	47.2	47.2
% Potential Flow	4.33%	10.70%	16.40%	20.50%	23.23%	25.51%	26.87%	28.01%
Lift/Diameter Ratio	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40
Cd	0.01480	0.03661	0.05610	0.07010	0.07945	0.08724	0.09191	0.09581
% Velocity	3.40%	3.47%	2.57%	2.53%	2.93%	3.60%	3.50%	3.27%
HP for 4 cylinders	20.67	51.14	78.34	97.92	110.98	121.86	128.38	133.82
kW for 4 cylinders	15.34	37.95	58.14	72.68	82.37	90.44	95.29	99.32

APPENDIX C

COMPARISON BETWEEN ORIGINAL AND MODIFICATION CONDITION

Proton exhaust port flow comparison between original and modification condition

Valve Lift	L/D Ratio	Original	X Valve Guide	Porting	Polishing
1.25	0.05	8.968	11.800	12.744	11.800
2.5	0.10	22.656	29.264	28.792	28.792
3.75	0.15	35.400	43.896	42.088	40.592
5.00	0.20	46.256	53.808	53.336	50.976
6.25	0.25	50.976	59.472	61.360	59.472
7.50	0.30	52.864	62.304	66.080	65.608
8.75	0.35	53.336	64.192	69.384	69.856
10.00	0.40	53.808	65.136	71.744	73.632

Toyota exhaust port flow comparison between original and modification conditions

Valve Lift	L/D Ratio	Original	X Valve Guide	Porting	Polishing
1.25	0.05	8.910	8.968	8.968	8.968
2.50	0.10	21.710	23.600	22.184	22.184
3.75	0.15	33.040	34.928	32.096	33.984
5.00	0.20	41.060	42.952	40.592	42.480
6.25	0.25	46.730	49.088	47.200	48.144
7.50	0.30	48.620	51.920	52.392	52.864
8.75	0.35	49.560	53.336	55.696	55.696
10.00	0.40	50.510	53.808	57.584	58.056

APPENDIX D

LIFT VALVE TO DIAMETER RATIO FOR ORIGINAL AND MODIFICATION CYLINDER HEAD

L/D Ratio for Proton exhaust port flow original and modification cylinder head

L/D Ratio	Original	X Valve Guide	Porting	Polishing
0.05	10.86	16.520	13.216	10.860
0.10	29.74	33.984	30.680	27.850
0.15	45.78	46.728	44.368	39.650
0.20	56.17	56.640	56.640	51.920
0.25	60.59	61.360	63.720	61.830
0.30	62.78	65.136	67.496	67.020
0.35	64.19	66.552	70.800	70.330
0.40	64.66	67.496	72.688	72.690

L/D Ratio for Toyota exhaust port flow original and modification cylinder head

L/D Ratio	Original	X Valve Guide	Porting	Polishing
0.05	8.91	8.968	8.968	8.968
0.10	21.71	23.128	22.184	22.184
0.15	33.04	33.984	32.096	33.984
0.20	41.06	42.008	40.592	42.48
0.25	46.73	48.144	47.2	48.144
0.30	48.62	50.976	52.392	52.864
0.35	49.56	52.864	55.696	55.696
0.40	50.51	53.336	57.584	58.056