



**Enhancement of Engine Performance by Studying the
Effect of Cam Profiles Design on Modenas Motorcycle
using 1-D Simulation Analysis**

by

**Mohamad Syafiq bin Abdul Khadir
(1531411631)**

A thesis submitted in partial fulfillment of the requirements for the degree
of Master of Science in Mechanical Engineering

**School of Mechatronic Engineering
UNIVERSITI MALAYSIA PERLIS**

2017

UNIVERSITI MALAYSIA PERLIS

DECLARATION OF THESIS

Author's full name : Mohamad Syafiq bin Abdul Khadir

Date of birth : 26 August 1989

Title : Enhancement of Engine Performance by Studying the Effect of Cam Profiles Design on Modenas Motorcycle using 1D Simulation Analysis

Academic Session : 2015/2016/2017

I hereby declare that the thesis becomes the property of Universiti Malaysia Perlis (UniMAP) and to be placed at the library of UniMAP. This thesis is classified as :

CONFIDENTIAL (Contains confidential information under the Official Secret Act 1972)*

RESTRICTED (Contains restricted information as specified by the organization where research was done)*

OPEN ACCESS I agree that my thesis is to be made immediately available as hard copy or on-line open access (full text)

I, the author, give permission to the UniMAP to reproduce this thesis in whole or in part for the purpose of research or academic exchange only (except during a period of _____ years, if so requested above).

Certified by:

SIGNATURE

SIGNATURE OF SUPERVISOR

(NEW IC NO. / PASSPORT NO.)

NAME OF SUPERVISOR

890826-06-5343

Date : _____

Date : _____

NOTES : * If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

ACKNOWLEDGEMENT

In the name of *ALLAH* s.w.t, the Most Compassionate, the Most Merciful. On top of all, words cannot express my deep and sincere appreciation towards my supervisor, Associate Professor Dr. Shahrman bin Abu Bakar for his guidance, advice, and encouragement. I am also deeply thankful to Dr. Mohd Sani bin Mohamad Hashim, my co-supervisor, who assisted me on this project and spending his time and provides ideas during this project implementation.

Besides that, I would like to dedicate my deepest gratitude to MODENAS team especially the CEO of MODENAS, Mr. Amirudin Abu Bakar and RnD team, Mr. Wan Sahar, Mr. Azizul Ishak and Mr Khairul Anuar Hamid and other team members in providing the required tools and knowledge transfer besides experience sharing for me in completing my Master of Science.

Special thanks also go to Universiti Malaysia Perlis especially Motorsport Technology Research Unit (MoTECH) for supporting and providing equipment and information sources that assisted my studies and projects. A lot of thanks to Kementerian Pengajian Tinggi and FTK UniMAP, who willingly to support my study in completing my Master of Science.

To my lovely wife, Ku Fatin Azirah binti Ku Yahya and my parent, Abdul Khadir bin Abdul Razak and Anita Fauziah bt Ismail, who always willingly assist and support me throughout my journey of education, you all deserve my wholehearted appreciation. Many thanks. Without their support and encouragement, impossible for me in completing this project.

TABLE OF CONTENT

	PAGE
DECLARATION OF THESIS	i
ACKNOWLEDGEMENT	ii
TABLE OF CONTENT	iii
LIST OF TABLES	vi
LIST OF FIGURES	viii
LIST OF ABBREVIATIONS	xi
ABSTRAK	xiii
ABSTRACT	xiv
CHAPTER 1 INTRODUCTION	1
1.1 Project Background	1
1.2 Problem Statement	4
1.3 Objectives	5
1.4 Scopes	5
1.5 Organization of Thesis	5
CHAPTER 2 LITERATURE REVIEW	7
2.1 Fundamental of the Engine Cycle	7
2.1.1 Definition of Internal Combustion (IC) Engine	11
2.1.2 Components of Piston Engine	12
2.1.4 Engine Parameter	12
2.2 Work	14
2.3 Mean Effective Pressure	15
2.4 Torque	16
2.5 Power	18
2.6 Air Standard Cycle	20
2.6.1 Volumetric Efficiency	21
2.7 Intake and Exhaust Valve	22
2.8 Exhaust System	23
2.8.1 Exhaust Valve	25

2.9	Camshaft	26
2.9.1	Basic Principles and Performance of Cam	27
2.9.2	Angle of Cam	31
2.9.3	Impact of Valve Lift on Engine	31
2.10	Cam Profile Curve	33
2.10.1	Shape Parameterisation	33
2.10.2	Description of Cam Curve Problem	35
2.10.3	Optimization of Acceleration, Velocity and Displacement Curve	35
2.10.4	Polynomial	35
2.10.5	Polydyne	39
2.10.6	Steady Acceleration Cam Profile (STAC)	39
2.10.7	B-Spline	40
2.10.8	1-D Engine Simulation	44
2.11	Summary and Gap Statement	45
CHAPTER 3 METHODOLOGY		47
3.1	Related Engine Component	49
3.2	Intake Passage Dimension	51
3.3	Specification of CT15S Engine	53
3.4	Exhaust Dimension Measurement	54
3.4.1	Parameter in Exhaust	56
3.5	Camshaft	57
3.6	Definition of the Mass Data of the Crank Gear	58
3.7	Benchmarking	59
3.7.1	Valve Lift	59
3.7.2	Air Flow	61
3.7.3	Engine Performance Test	65
3.8	Data Configuration	67
3.8.1	Valve Lift	69
3.8.2	Cam Design	77
3.8.3	1-D Model Modenas Engine	82
3.8.3.1	Air Cleaner	84
3.8.3.2	Piping/Ducting	86

3.8.3.3 Cylinder	89
3.8.3.4 Combustion Model	90
3.8.8.5 Exhaust	94
CHAPTER 4 RESULTS AND DISCUSSION	97
4.1 Real Data Comparison with Simulation Data	97
4.2 Cam Lobe Profile	103
4.2.1 Cam Profile A	105
4.2.2 Cam Profile B	108
4.2.3 Cam Profile C	111
4.2.4 Cam Profile D	114
4.2.5 Cam Profile E	116
4.2.6 Valve Lifts Comparison	118
4.3 Engine Performance Curve	121
4.3.1 Cam Profile A	122
4.3.2 Cam Profile B	123
4.3.3 Cam Profile C	124
4.3.4 Cam Profile D	135
4.3.5 Cam Profile E	136
4.3.6 Overall Engine Performance Curve	127
CHAPTER 5 CONCLUSION	136
5.1 Summary	136
5.2 Future Work	138
REFERENCES	139
LIST OF PUBLICATION	145
LIST OF AWARD	145

LIST OF TABLES

NO.		PAGE
2.1	The components in engine	9
2.2	Parts of exhaust system	24
2.3	Effect changing lobe separation angle	32
2.4	Cam follower motion curve comparison	36
2.5	Summary of available in designing cam profiles	43
3.1	Internal part of camshaft system	51
3.2	CT115S Engine Specification	53
3.3	The dimension of internal exhaust parts	55
3.4	The dimension of muffler parts	55
3.5	Parameter in the exhaust system	57
3.6	Results of the measurements	58
3.7	Data obtained by using Super Flow Bench 110 E for intake	63
3.8	Data obtained by using Super Flow Bench 110 E for exhaust	64
3.9	The parameter of rocker arm	73
3.10	The dimension for valve stem and mechanical tappet	74
3.11	Spring's parameter	75
3.12	The components inside MODENAS engine	83
3.13	The parameters inside air cleaner	85
3.14	Detail of pipe 1	86
3.15	Piping dimension for piping 2 until piping 7	87
3.16	Table radius for exhaust piping	88
3.17	Cylinder properties	89
3.18	Combustion model for CT115S engine	90
3.19	Valve port specification	92
3.20	Detail description for exhaust muffler	95
4.1	Design parameter for intake cam (Benchmarking)	98
4.2	Design parameter for exhaust cam (Benchmarking)	100
4.3	Design parameter for intake cam (Cam Profile A)	106
4.4	Design parameter for exhaust cam (Cam Profile A)	106
4.5	Design parameters for intake cam (Cam Profile B)	109
4.6	Design parameter for exhaust cam (Cam Profile B)	109
4.7	Design Parameter for intake cam (Cam Profile C)	111

4.8	Design parameter for exhaust cam (Cam Profile C)	111
4.9	Design parameter for intake cam (Cam Profile D)	112
4.10	Design parameter for intake cam (Cam Profile D)	112
4.11	Design parameter for intake cam (Cam Profile E)	114
4.12	Design parameter for exhaust cam (Cam Profile E)	114
4.13	Maximum valve lift for all designs	121
4.14	Summary of engine performance for all designs	129

© This item is protected by original copyright

LIST OF FIGURES

NO.		PAGE
1.1	The performance of available motorcycle in Malaysia	3
2.1	Cross-sectional components of engine components	9
2.2	Cycle of combustion process	10
2.3	Major component of piston engine	12
2.4	The relationship between r_c versus time	14
2.5	Load/torque versus speed	17
2.6	Intake (blue) and exhaust (red) valves	23
2.7	Motorcycle exhaust	24
2.8	Exhaust valve of CT115S engine	26
2.9	Schematic diagram of cam system	27
2.10	Lobe lift	28
2.11	Valve lift diagram	29
2.12	Cam lift versus crankshaft degrees	29
2.13	Difference of overlap in 2 camshaft	30
2.14	Schematic diagram of cam	31
2.15	Lobe separation angle	32
2.16	Displacement curve of cam follower by using 6th order B-spline	34
2.17	Displacement curve of conventional design and cam shape design	34
2.18	Curve for displacement, velocity and acceleration of cam follower motion	36
2.19	Displacement of initial and optimal profile	37
2.20	Velocities and Accelerations of initial and optimal profile of polynomial	38
2.21	Acceleration of a cam profile in general constant acceleration	40
2.23	Typical boundary condition of cam profile in automotive engine	41
2.25	Displacement profile for 3 different method	42
3.1	Technical flowchart for methodology process	48
3.2	CT 115S Cylinder head	49
3.3	Intake port	50
3.4	The exhaust component of CT115S engine	50
3.5	The internal part in CT115S engine	50
3.6	Multi view of intake port	52
3.7	Several intake models that has been created	53
3.8	Model of the rubber silicone	54

3.9	Exhaust pipe of CT115S engine	55
3.10	Exhaust muffler of CT115S engine	56
3.11	Camshaft for CT115S engine	57
3.12	Coordinate Measuring Machine	58
3.13	Measuring the piston mass	59
3.14	The tools arrangement in measuring valve lift	59
3.15	Graph displacement of valve lift versus cam angle	61
3.16	Super Flow Bench SF 110 E	62
3.17	Chassis Dyno for motorcycle	66
3.18	Engine performance curve using Dyno Test	67
3.19	1-D model for camshaft analysis	69
3.20	The basic cam lobe properties	70
3.21	The original design and circle base radius value from 3-D drawing	71
3.22	The parameter for cam follower	71
3.23	The parameters for rocker arm	72
3.24	The rocker arm diagram	73
3.25	The diagram of valve stem and mechanical tappet	74
3.26	The parameter of valve stem and mechanical tappet	74
3.27	Graph force versus elongation of spring	76
3.28	The spring properties in AVL EXCITE cam design	76
3.29	Valve Face elements parameter	77
3.30	The general data for cam design	78
3.31	The window for cam design data	79
3.32	The dynamic model in high acceleration cam-follower system	80
3.33	1-D engine model in AVL Boost	82
3.34	The icon of air cleaner	85
3.35	The window for piping parameters	88
3.36	Graph piston motion versus crank angle	90
3.37	Parameter for Heat Release Characteristics	92
3.38	Flow Coefficient for Exhaust Valve	93
3.39	Intake Flow Coefficient	93
3.40	The internal design for exhaust muffler	95
3.41	Flush eccentric connection	96
3.42	Inlet and outlet extension	96

4.1	Valve lift curve for intake cam (Benchmarking)	98
4.2	Polar representation of intake cam profile	99
4.3	Valve lift curve for exhaust cam (Benchmarking)	100
4.4	Polar representation of exhaust cam profile (Benchmarking)	101
4.5	Verification of measured valve lift and simulation valve lift	101
4.6	Brake Torque Value for Dyno Data and AVL Baseline Engine Model	102
4.7	Brake Power Value for Dyno Data and AVL Baseline Engine Model	103
4.8	Result for cam profile	104
4.9	The valve side characteristics for cam	104
4.10	Valve lift for intake and exhaust cam	107
4.11	Cam lobe profile (Cam Profile A)	108
4.12	Valve lift curve (Cam Profile B)	110
4.13	Polar representation of cam profile (Cam Profile B)	111
4.14	Valve lift curve (Cam Profile C)	113
4.15	Polar representative of cam (Cam Profile C)	113
4.16	Valve lift curve (Cam Profile D)	115
4.17	Polar representation of cam profile (Cam Profile D)	116
4.18	Valve lift curve (Cam Profile E)	118
4.19	Polar representation of cam profile (Cam Profile E)	118
4.20	Valve lift curve for intake (All Designs)	119
4.21	Valve lifts for exhaust cam (All Designs)	120
4.22	Engine performance curve (Cam Profile A)	122
4.23	Engine performance Curve (Cam Profile B)	123
4.24	Engine performance curve (Cam Profile C)	124
4.25	Engine performance curve (Cam Profile D)	125
4.26	Engine performance curve (Cam Profile E)	126
4.27	Brake Torque versus engine speed (All Designs)	127
4.28	Brake Power versus engine speed (All Designs)	129
4.29	Result of Volumetric Efficiency	131
4.30	Result of Residual Gasses	132
4.31	Mass Flow Rate of Intake Valve	134
4.32	Mass Flow Rate of Exhaust Valve	134

LIST OF ABBREVIATIONS

A_d	Displacement of volume
A_p	Area of piston wall
a	Crank offset
B	Bore
BDC	Bottom dead center
bMEP	Brake mean effective pressure
D	Displacement
F	Force
IC	Internal Combustion
k	Ratio of Specific heat
MEP	Mean effective pressure
m	unit mass of gas
N	Engine speed
N_c	Number of engine cylinder
n_R	Amount of crank revolution
n	Number of revolution per cycle
OPD	Output per displacement
P	Pressure
R	Ratio of connecting rod length to crank offset
R_o	Gas constant
r_c	Compression ratio
S	Stroke
SI	Spark ignition
SP	Specific power
SV	Specific volume
SW	Specific weight
T	Torque
TDC	Top dead center
U_p	Average piston speed
V_c	Clearance volume
W	Work
W_b	Brake work of one revolution
x	Distance of piston traveled

η_m	Mechanical efficiency
η_v	Volumetric efficiency
α	Crank angle
α_o	Start of the combustion process
Δ_a	Combustion duration
\dot{m}	Mass flow rate
ρ_a	Air density

© This item is protected by original copyright

Peningkatan Prestasi Enjin Motosikal Modenas Melalui Variasi Aci Sesondol Menggunakan Analisis Parameter

ABSTRAK

Dalam dunia permotoran, meningkatkan prestasi sesuatu enjin merupakan satu tugas utama bagi menambah baik keseluruhan prestasi bagi sesuatu enjin dan kenderaan. Peningkatan dan setiap penambahbaikan, mampu menyelesaikan setiap isu atau permasalahan yang timbul dalam edisi enjin yang terdahulu di samping meningkatkan kuasa dan daya kilasan sesuatu enjin. Terdapat banyak komponen yang boleh diambil kira bagi mencapai objektif tersebut seperti laluan kemasukan campuran udara dan minyak ke dalam enjin, bahagian ekzos dan juga aci sesondol. Oleh hal yang demikian, penyelidikan ini dicadangkan bagi meningkatkan prestasi keseluruhan enjin dengan menambah baik dari segi aspek aci sesondol untuk model MODENAS CT115S. Prestasi semasa motosikal MODENAS CT115S masih tidak mencapai piawai pesaing-pesaing lain. Dengan menjalankan analisis geometri, lima reka bentuk baru telah dicadangkan dengan berlainan nilai jejari tapak aci sesondol dan juga bentuk profil aci sesondol tersebut. Dengan bantuan perisian teknologi simulasi AVL, data bagi prestasi semasa enjin telah dikenalpasti dan dibandingkan dengan data sebenar bagi memastikan simulasi 1-D yang dicadangkan adalah tepat. Apabila data simulasi tersebut berada dalam julat yang dibenarkan, reka bentuk-reka bentuk baru yang dicadangkan akan diuji bagi mendapatkan keputusan injap yang terbuka dan juga sifat aci sesondol tersebut. Daripada graf injap yang dibuka, bentuk aci sesondol yang baru akan mengalami simulasi bagi mendapatkan graf prestasi enjin. Berdasarkan kelima-lima reka bentuk, reka bentuk D yang dengan jejari tapak sebanyak 14.5 mm menghasilkan nilai bukaan injap yang kedua tertinggi namun menghasilkan nilai kuasa dan daya kilasan yang tertinggi. Oleh hal yang demikian, aci sesondol D adalah rekaan bentuk yang terbaik antara lima reka bentuk, dengan nilai yang terhasil adalah 8.89 N-m pada kelajuan 7000 RPM dan 7.25 kW kuasa pada 9000 RPM.

Enhancement of Engine Performance by Studying the Effect of Cam Profiles Design on Modenas Motorcycle using 1-D Simulation Analysis

ABSTRACT

In the automotive industry, enhancing and improving the engine performance is one of the major work for improving the overall performance of the engine and vehicle. Every iteration of the engine, will overcome the issues raised in the previous batch of the engine as well as improve the brake power and brake torque of the engine. There are a lot of aspects need to be considered in achieving this objective such as intake part, exhaust part, camshaft and cam profiles. Thus, this research is proposed to enhance overall engine performance by improving current cam profiles for MODENAS CT115S model. The current performance for MODENAS CT115S below than other competitors. By using geometrical analysis, five new designs were proposed with different cam parameters including circle base radius and cam profile. By the aid of AVL Advance Simulation Technology software, the benchmarking of real and baseline data were conducted in order to verify 1-D simulation planning for the simulation purposes. Once the result of the simulation was in the acceptable range, the new designs can be investigated to find the valve lift and cam characteristics. From the valve lift curve, new cam designs were undergoing simulation to determine the engine performance curve. Among all new cam designs, cam design D, with 14.5 mm plotted the second highest maximum valve lift but generated the highest brake power and brake torque curve. Therefore, this cam design was the optimum design among all five designs with the best performance curve, with 8.89 N-m at 7000 RPM of brake torque and produced 7.25 kW of brake power at 9000 RPM.

© This item is protected by original copyright

CHAPTER 1

INTRODUCTION

This chapter briefly discusses and describes the research background, problem statement, objectives and the scope of the research. All of the listed sections are discussed in detail and as an introduction to the whole research which includes the interest and area of research.

1.1 Research Background

Syarikat Motosikal dan Enjin Nasional Sdn Bhd or well known as MODENAS is the national automotive company that produces moped and scooter type motorcycles normally below 200cc, two stroke and four stroke motorcycle engines. Basically, internal combustion applications, either for two strokes or four stroke engines, are powered by both compression and spark setting ignition. There are four vital processes in four-stroke internal combustion engine which are intake, compression, exhaust and power stroke. During the intake stroke, the mixture of air and fuel is driven into the internal combustion chamber. Meanwhile, in the compression stroke, the pushed air-fuel mixture is compressed for ignition purpose. Then, the compressed air-fuel mixture is ignited by sparks from spark plug before the disposal gas is pushed from the combustion chamber in the exhaust stroke.

The internal combustion engine is the engine where normally an oxidizer like air will take place in the combustion of the process. The combustion process happens in the combustion chamber as a fundamental role of the operational fluid flow path. Throughout

the combustion process, the extension of pressure gasses and critical heat temperature produces the combustion force that applies a direct force for certain engine components. The corresponding force moves the component for a certain distance and converts chemical energy from fuel or gasoline to mechanical energy.

Recently, many active research activities have been conducted in improvising engine performance. MODENAS, as one of motoring commercial enterprises, is also involved in research activity since there is tight competitiveness among motorcycle industry in Malaysia. To enhance the performance of a motorcycle engine, a lot of aspects can be improved and researched such as exhaust system, intake system, chassis modification, the suspension and fuel system. Besides, the camshaft can also contribute in increasing the engine performance. Basically, the camshaft is used to control the movement of the exhaust and intake valves in adjusting the volume of air-fuel mixture entering the combustion chamber and disposal gasses exiting through the exhaust valve after combustion are complete.

Figure 1.1 shows the performance for almost all the available motorcycles in Malaysia with 110 CC until 115 CC. The best performance is Yamaha Lagenda 115ZR, in which the brake torque value is 9.9 Nm at 6500 RPM and the brake power is 7.4 kW at 7750 RPM. The next one is Suzuki Smash. Its peak output brake power is 6.4 kW, while the output brake torque is 9 Nm. The brake torque value for Suzuki Smash is higher than MODENAS CT115S but the value of brake power is below CT115S value. Then, it is followed by Honda Wave Dash 110cc with 8.15 Nm at 5500 RPM and 6.1 kW at 7500 RPM. The fourth motorcycle with the highest value of brake torque and brake power is MODENAS CT115S, with 6.6 kW output brake power at 9000 RPM and 8.1 Nm at 5000 RPM. The last one with lowest output performance is SYM Sport Bonus. Its brake torque

value is 7.94 Nm at 4000 RPM and the brake power is 5.3 kW at 7500 RPM of engine speed.

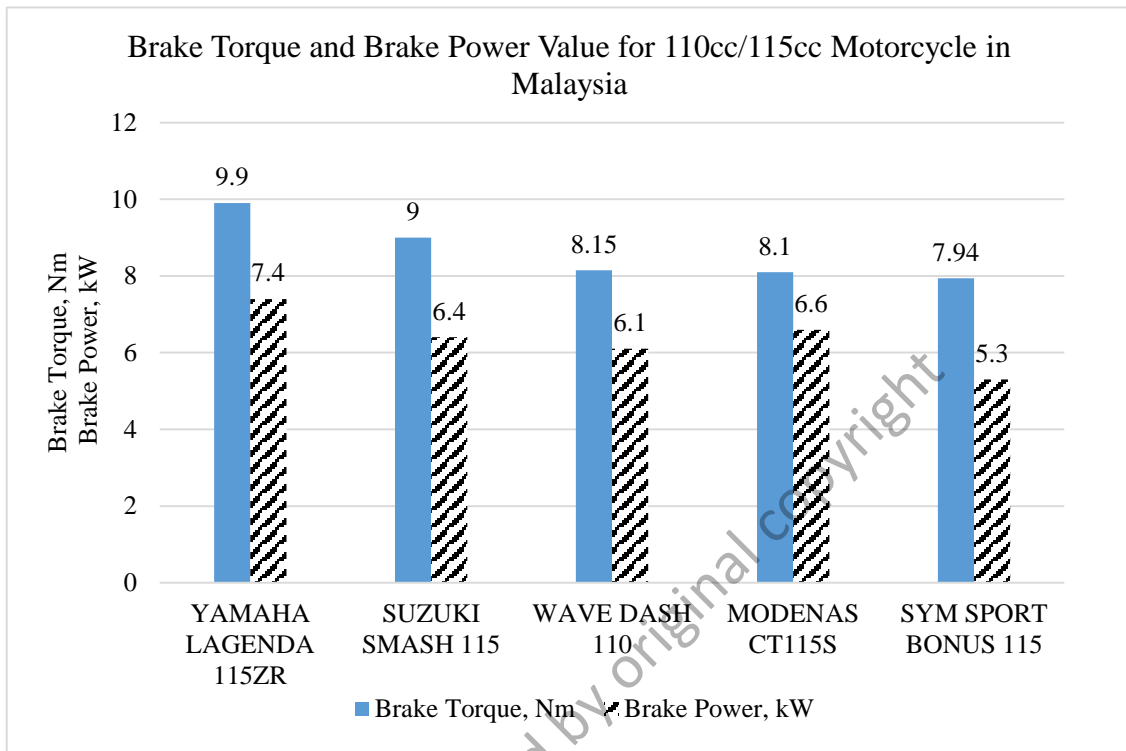


Figure 1.1: The performance of available motorcycle in Malaysia, retrieved on September 2015 (<http://www.yamaha-motor.com/>, <http://suzuki.com.my/>, <http://www.sym.net.my/sym/>, <http://www.boonsiewhonda.com.my/>).

It can be observed that MODENAS overall position in terms of brake power and brake torque ranking is in the fourth position. Therefore, the task is to increase the engine performance of MODENAS engine to a certain level that matches or exceeds the competition in the same class.

Cam lobe profile controls the valve timing by controlling the time taken to open and close the engine intake and exhaust valve; thus, it affects the engine performance. By applying the fitting outline of the angle between intake and exhaust with cam profile, it can help to improve the valve timing and consequently increase the engine performance.

1.2 Problem Statement

MODENAS is producing a motorcycle with a small capacity engine. There are numerous of motorcycle that been produced since being founded in 1995. For the example is Kriss, GT130, MR1, MR2, Krisstar and CT series. The latest CT series that been launched is MODENAS CT115S. Among all the available motorcycle in Malaysia with the same or near the category of engine size, the performance of MODENAS CT115S ranked in the fourth position by referring to Figure 1.1. The value of maximum brake torque for CT115S is 8.1 Nm and 6.6 kW for maximum brake power output. The best motorcycle in the same category is Yamaha Lagenda 115ZR.

There is plenty reason that contributes to the overall performance of MODENAS CT115S, which is including the engine parts of MODENAS CT115S such as intake manifold and port, exhaust port and muffler, camshaft and airbox. Apart from that, the camshaft is another element that impacts the engine performance. Camshaft controls the opening of the intake and exhaust valve in order to allow the mixture of air fuel mixture to enter the combustion chamber for combustion stroke.

One of the technique to boost the performance of an engine is inducing more air fuel mixture into the combustion chamber. Theoretically, a greater amount of air fuel mixture generates more combustion rate and producing a higher value of maximum brake torque and brake power (Abdullah, Shahrudin, Mamat, Mamat, & Zulkifli, 2014). Among the vital parameter in the camshaft is cam lobe profile. The various cam lobe profile producing the variety of valve lift and overlapping region. Valve lift referring to the distance of valve lifted once the cam rotates (František, Oto, & Danka). In the meantime, overlapping a region determine the angle for both valves open simultaneously (Dhavale, 2012). Best value for both consideration needed in the cam lobe profile in order

to boost the overall engine performance for both maximum values of brake torque and brake power.

1.3 Objectives

The target of this research is to enhance MODENAS engine performance in terms of brake power and brake torque. This aim can be fulfilled by achieving the following objectives:

- I. To study and analyze camshaft parameters that affect engine performance curve by using parametric analysis.
- II. To obtain a new cam profile design, with the best valve lift graph that increases the engine performance.

1.4 Scopes

The scopes for this research are:

- I. Identify the geometric parameter that can improve valve lift for MODENAS CT115S.
- II. Benchmark the current cam profiles and engine with several designs of cam lobe profiles.
- III. Verify proposed designs and simulations of high engine performance between baseline data by using 1-D simulation software.
- IV. Analyze new proposed cam lobe profiles by using the AVL Excite Timing Drive and verify its effect to overall engine performance curve in AVL Boost.

1.5 Organization of Thesis

Generally, this thesis consists of five main chapters. Every chapter is elaborated in detail with regard to the improvement of the engine performance curve in cam profiles aspects.

The report starts with Chapter 1 which gives a general idea regarding MODENAS Company, internal combustion engine, camshaft function and history of engine development. It is trailed by a brief explanation regarding current problem statements as well as the research objectives. Apart from that, Chapter 1 also includes the research scopes which briefly describe the area of knowledge and methodology in this research.

Chapter 2 provides the relevant literature reviews of a research topic that will act as a guideline in the completion of this thesis. It deliberates about the overall engine operation, the function of engine components, intake and exhaust parts, camshaft parts and its function and current research in improving overall engine performance.

Chapter 3 covers all the involved methods and the process applied in order to achieve the research objectives. It includes all related theories, the calculation involved and software simulation. It provides a detail explanation on how to design various cam profiles and how to investigate its effect on engine performance curve.

In chapter 4, it provides all the obtained results for different cam profiles and the improvement of the engine performance curve so that to investigate the consequences of cam profiles to the performance of MODENAS CT115S engine. Every single aspect that is related and contributes to the result is discussed in detail.

Chapter 5 presents the summary of overall research which includes research conclusion and the future work for further development.

CHAPTER 2

LITERATURE REVIEW

This chapter represents the literature reviews associated with internal combustion engine. The latest findings related to the research question are listed, reviewed and scrutinized in this chapter. Reading materials like book chapters, journal and articles are reviewed first before the useful and important information contributing to research flow was accumulated. The information is needed with the significantly modernized knowledge for much better understanding and upgrading the current knowledge regarding research topics.

2.1 Fundamental of Engine Cycle

Nowadays, the automotive sectors have experienced rapid growth in remarkable trend. State of the art technology and innovation ideas assisted in conceiving the new design and upgraded technology for engines. From the basic principle engine cycle, the internal combustion was introduced in the year 1876 until now considering enhancement of the engine technology. Internal combustion (IC) engine consists of the fuel, which entered the combustion chamber after mixing together with the air for the combustion process and the power stroke was generated in the combustion chamber in the cylinder block (Johanson, 2009).

Currently, there are two major categories of IC engine; an ignition engine and compression engine which operate at four cycles or two cycle engines. The spark ignition (SI) engine requires spark plug which is the indispensable piece to ignite the air fuel

mixture, whereas the compression ignition will apply the auto ignition process to set up the engine (Pulkrabek, 2013). Diesel engine provides higher efficiency in term of consistency and power compared than a gasoline engine, with 45% conversion of fuel energy into the actual power, meanwhile gasoline engine converts 30% of fuel energy into the actual power output (Rabault, Vernet, Lindgren, & Alfredsson, 2016).

Normally in small capacity motorcycle, the small spark ignition (SI) engine was applied and installed. This kind of engine normally operates with a single cylinder engine. The main aims in producing this kind of engine are low cost, light weight and small size, besides the other aspects such as fuel consumption, engine vibration and engine robustness. Consequently, the torque improvement is widely spaced, and the smoothness and engine vibration shuddering are significantly complicated (Heywood, 1988).

These kind of fundamental cycles are commonly standard for all those applications. In a four stroke motor, the first stroke is called as an intake stroke. At this stage, cylinder at the inside burning will go to bottom dead center (BDC) from the top dead center (TDC) which is parallel with the intake valve open and exhaust valve will completely shut when the cylinder reaches the BDC (Noor et al., 2008).

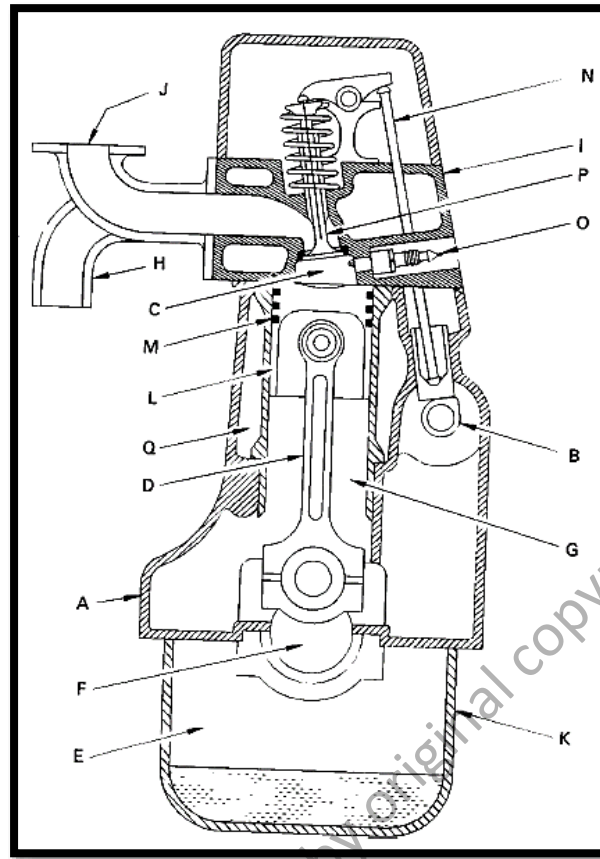


Figure 2.1: Cross-sectional components of engine components (Pulkrabek, 2013).

Table 2.1: The components of the engine (Pulkrabek, 2013).

Components	Components Name
A	Block
B	Camshaft
C	Combustion Chamber
D	Connecting rod
E	Crankcase
F	Crankshaft
G	Cylinder
H	Exhaust manifold
I	Head
J	Intake manifold
K	Oil pan
L	Piston
M	Piston rings
N	Push rod
O	Spark plug
P	Valve
Q	Water jacket