

STRATIFIED-CHARGE TWO-STROKE STEPPED-PISTON ENGINE

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To my beloved late father and mother,
Your love brings me the happy and successful life

To my beloved wife and children,
Your encouragement and patience always give me spirit to achieve success

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ABSTRACT

A two-stroke stepped-piston prototype engine, in carbureted version was designed and developed. It incorporates a unique three-port transfer system with an accumulator for high induction efficiency, so as to perform very much like a two-stroke engine but equipped with a four-stroke crankcase lubrication system. *GT-Power* software was used in the development stage to predict the engine output. The data predicted was then compared with the experimental results. A computational fluid dynamic software, *COSMOS/Floworks*, was used to develop a computational model to investigate the scavenging and compression processes of the prototype engine. The prototype was subjected to a series of laboratory trials for engine performance and emissions tests. Emission characteristics were established for regulated and unregulated gases. From the engine performance test, maximum pressures attained from *GT-Power* simulation and prototype engine were 54.62 bars at 5000 rpm and 26.12 bars at 4500 rpm respectively. Maximum indicated power produced is 11.25 kW at 8000 rpm and 3.86 kW at 4500 rpm for *GT-Power* simulation and prototype engine respectively. Torque, brake power and brake fuel consumption were also determined. For comparative reason, a *Yamaha 125Z* engine was selected as the cylinder capacity with similar working principle as the prototype engine. Torque produced by *Yamaha 125Z* was highest, followed by *GT-Power* simulation and prototype engine. The average difference of torque between *Yamaha 125Z* and *GT-Power* simulation was about 13.06%. The minimum values of brake specific fuel consumption for *Yamaha 125Z*, *GT-Power* simulation and prototype engine were 280.42 g/kWh at 3500 rpm, 351.08 g/kWh at 5000 rpm and 510 g/kWh at 3500 rpm respectively. The maximum peaks differences were attributed to the differences of combustion chamber design used and assumptions made in *GT-Power*.

ABSTRAK

Dalam kajian ini sebuah enjin prototaip dua lejang ombok bertangga telah direkabentuk dan dibangunkan dalam versi karburetor. Ia digabungkan dengan sistem tiga liang hantaran dan pengumpul yang unik untuk kecekapan aruhan yang tinggi dan berkelakuan seperti enjin dua lejang tetapi sistem pelinciran bersifat seperti kotak engkol empat lejang. Perisian *GT-Power* digunakan di peringkat pembangunan untuk meramal keluaran enjin. Data teramal kemudian dibandingkan dengan keputusan ujikaji. Perisian dinamik bendalir berkomputer, *COSMOS/Floworks*, digunakan untuk membina model komputer untuk mengkaji proses menghapus sisa dan pemampatan enjin prototaip. Kemudian prototaip menjalani satu siri ujian makmal untuk menentukan prestasi dan emisi enjin. Emisi enjin ditentukan untuk gas terkawal dan tidak terkawal. Daripada ujian prestasi enjin, tekanan maksimum simulasi *GT-Power* dan enjin prototaip masing-masing adalah 54.62 bar pada 5000 ppm dan 26.12 bar pada 4500 ppm.. Kuasa tertunjuk maksimum adalah 11.25 kW pada 8000 ppm dan 3.86 kW pada 4500 ppm untuk simulasi *GT-Power* dan enjin prototaip. Dayakilas, kuasa brek dan penggunaan bahan api tentu brek juga ditentukan. Bagi tujuan perbandingan, sebuah enjin *Yamaha 125Z* dipilih memandangkan kapasiti silinder dan prinsip kerja yang sama dengan enjin prototaip. *Yamaha 125Z* menghasilkan dayakilas tertinggi diikuti simulasi *GT-Power* dan enjin prototaip. Perbezaan dayakilas purata antara *Yamaha 125Z* dan simulasi *GT-Power* adalah 13.06%. Nilai minimum penggunaan bahan api tentu brek untuk *Yamaha 125Z*, simulasi *GT-Power* dan enjin prototaip masing-masing adalah 280.42 g/kWh pada 3500 ppm, 351.08 g/kWh pada 5000 ppm dan 510 g/kWh pada 3500 ppm. Perbezaan puncak maksimum yang terhasil adalah disebabkan oleh perbezaan rekabentuk kebuk pembakaran dan andaian yang digunakan dalam *GT-Power*.

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LIST OF SYMBOLS

A_p	-	Piston area
AFR	-	Air-fuel ratio
AFR_s	-	Stoichiometric air-fuel ratio
AFR_t	-	Trapped air-fuel ratio
a	-	Crankshaft offset
B	-	Bore
BP	-	Brake power
B_{fin}	-	Breadth of single fin
b	-	Cylinder wall thickness
b MEP	-	Brake mean effective pressure
bsfc	-	Brake specific fuel consumption
C	-	Specific heat
C_p	-	Specific heat at constant pressure
C_v	-	Specific heat at constant volume
C_D	-	Coefficient of discharge
CR_{cc}	-	Crankcase compression ratio
CR_g	-	geometric compression ratio
CR_t	-	trapped compression ratio
C_{fl}	-	Low calorific value for fuel
D_{cw}	-	Counter weight diameter
D_{fw}	-	Flywheel diameter
E	-	Energy
F	-	Force

F_{gas}	-	Force of gas
F_i	-	Inertia force
F_{res}	-	Total force acting on the piston
g	-	Gravitational acceleration
H	-	Piston height form TDC
h_c	-	Heat transfer coefficient
I	-	Inertia
IP	-	Indicated power
$isfc$	-	indicated specific fuel consumption
j	-	Cylinder perimeter
K_s	-	Coefficient of fluctuating speed
k	-	Thermal conductivity
k_x	-	Thermal conductivity in X direction
k_y	-	Thermal conductivity in Y direction
k_z	-	Thermal conductivity in Z direction
L_{st}	-	Stroke length
L_{ts}	-	Trapped stroke length
L_{cr}	-	Connecting rod length
L_{ct}	-	crank throw length
L_{fin}	-	Length of single fin
l_c	-	Clearance volume height
m_{air}	-	Mass of air
m_{ca}	-	Mass of cooling air
m_f	-	Mass of fuel
m_{fw}	-	Mass of flywheel
m_{cp}	-	Mass of crank pin
m_{crbe}	-	Mass of connecting rod (big end)
m_{crm}	-	Mass of connecting rod (main)
m_{crse}	-	Mass of connecting rod (small end)
m_{cw}	-	Mass of counter weight
m_p	-	Mass of piston

m_{pp}	-	Mass of piston pin
m_{ppb}	-	Mass of piston pin bearing
m_{tcrbe}	-	Total mass of connecting rod (big end)
m_{rot}	-	Mass of rotating components
m_{rec}	-	Mass of reciprocating components
m_{ta}	-	Mass of trapped air
m_{tf}	-	Mass of trapped fuel
m_{tr}	-	Total mass of charge
N	-	Speed
n	-	Number of cylinder
P	-	Pressure
Q	-	Volumetric heat generation rate
Q_{cool}	-	Heat to be cooled
Q_R	-	Heat released from combustion
q	-	Heat flux
R	-	Ratio of connecting rod length to crank radius
R_a	-	Gas constant for air
R_{tr}	-	Gas constant at trapped point
r_{fw}	-	Flywheel radius
S_p	-	Mean piston speed
S_{exh}	-	Exhaust perimeter
S_{main}	-	Main port perimeter
S_{side}	-	Side port perimeter
sfc	-	Specific fuel consumption
T	-	Temperature, torque
T_f	-	Tangential force
T_i	-	Indicated torque
T_o	-	Specified temperature
T_s	-	Surface temperature
T_{at}	-	Ambient temperature
T_{tr}	-	Trapped temperature

T_{∞}	-	Ambient temperature
t	-	Time
t_{cw}	-	Counter weight thickness
t_l	-	Thickness cylinder liner
U	-	Thermal load
V	-	Volume
V_{cc}	-	Crankcase volume
V_{cv}	-	Clearance volume
V_{cw}	-	Counter weight volume
V_{sv}	-	Swept volume
V_{ts}	-	Trapped swept volume
V_{tr}	-	Trapped volume
\bar{V}_{fw}	-	Flywheel velocity
X	-	Piston position

Greek Symbols

Φ	-	Angle of obliquity
γ	-	Specifics heat ratio
ε	-	Emissivity
ω	-	Angular velocity
ρ	-	Density
ρ_{at}	-	Air density
ρ_{cw}	-	Density of counter weight
σ	-	Stefan-Boltzmann constant
σ_{fw}	-	Stress of the flywheel
σ_c	-	Stress of cast iron
θ	-	Crank angle

η_c	-	Combustion efficiency
η_i	-	Indicated thermal efficiency
η_t	-	Thermal efficiency

LIST OF ABBREVIATIONS

AC	-	Alternate current
AFR	-	Air-fuel ratio
ATDC	-	After top dead center
A/D	-	analogue/digital
BDC	-	Bottom dead center
BTDC	-	Before top dead center
CA	-	Crank angle
CAD	-	Computer-aided design
CCD	-	Charge-coupled device
CDI	-	Capacitive discharge ignition
CFD	-	Computational fluid dynamics
CI	-	Compression ignition
CO	-	Carbon monoxide
CPU	-	Central processing unit
CVT	-	Continuous variable transmission
DAS	-	Data acquisition system
DFI	-	Direct fuel injection
DHA	-	Detail hydrocarbons analysis
ECU	-	Electronic control unit
EFIC	-	Electronic fuel injector controller
EGR	-	Exhaust gas recirculation
EPA	-	Environmental Protection Agency
EMS	-	Engine management system

FEA	-	Finite element analysis
GDI	-	Gasoline direct injection
HC	-	Hydrocarbons
HCCI	-	Homogenous charge compression ignition
HPSGDi	-	High pressure swirl gasoline direct injector
ICE	-	Internal combustion engine
I/O	-	Input/output
MAP	-	Manifold absolute pressure
MTBE	-	Methyl tertiary-butyl ether
NO	-	Nitric oxides
NO _x	-	Nitrogen oxides
PCB	-	Printed circuit board
PFI	-	Port fuel injection
PID	-	Proportional, integral and differentiate
PM	-	Particulate matter
PRV	-	Pressure relief valve
PWM	-	Pulse-width modulation
RAM	-	Read-access memory
ROM	-	Read-only memory
R&D	-	Research and development
SI	-	Spark ignition
SMD	-	Sauter mean diameter
SOI	-	Start of injection
TDC	-	Top dead center
TPS	-	Throttle position sensor
UTM	-	Universiti Teknologi Malaysia
ULEV	-	Ultra low emission vehicle
2-T	-	Lubrication oil

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Internal combustion engine (ICE) technologies have undergone changes through a series of phases since the 18th centuries. In the old days ICE was purely on mechanical principles. With the advancement of technology, ICE had change from totally mechanical dependent to electronic and computerized controlled system. No matter what new technology was incorporated onto the engine, the main objective is to improvise and develop a more efficient ICE in terms of output and emissions.

The improvement is basically to reduce fuel consumption or in other words to utilise fuel efficiently. To achieve this goal, several concepts can be implemented. The concepts are briefly shown in Figure 1.1.

Particularly for combustion efficiency, the combustion concepts basically based on flow pattern are swirl, forward tumble and reverse tumble. Some of these concepts have already been commercialized while others are still in research stage.

In the last twenty years, the environmental implications of ICE exhaust emissions have resulted in greater effort in reducing harmful pollutants to meet stringent legislation. The investigation and the study on combustion and pollutant formation processes in ICE are clearly necessary to increase their efficiency and economic of operation. This lead to the evolution and invention of new engines with emphasise on increased efficiency and emissions reduction.

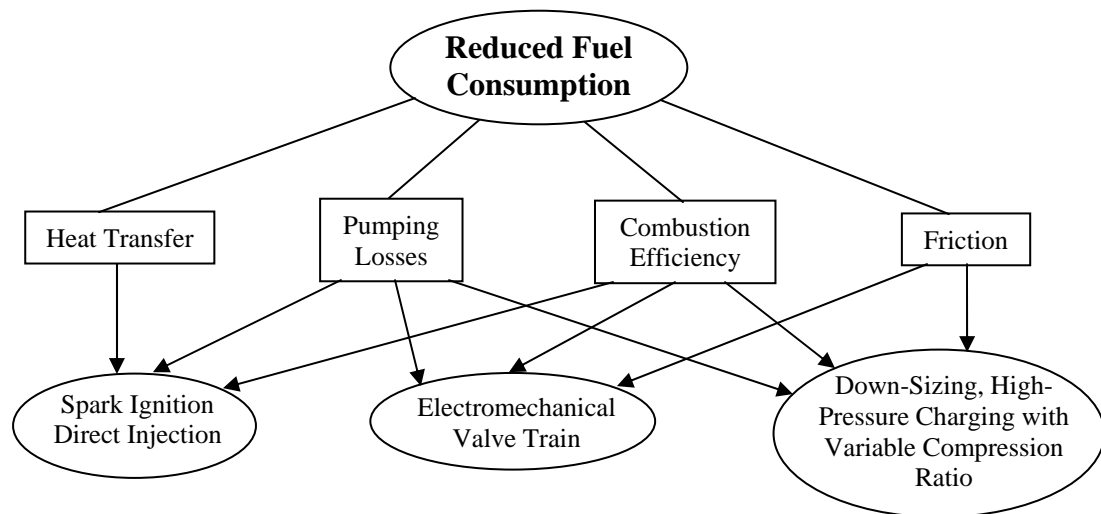


Figure 1.1: Concepts of current/future engine design

Motorcycles and motorised scooters are popular form of transport throughout the world. They are particularly popular in congested cities in Asia and Europe. In Asian regions they are dominant mode of transport because of their low initial and ongoing costs. Traditionally, two-stroke engines have powered the most popular models of motorcycles and scooters. Powered tools such as chainsaw, trimmer, fruit harvester, grass cutter and even bicycle utilised the two-stroke engine as their prime mover.

Two-stroke engines are popular because they produce relatively high power from a small size and are also inexpensive to manufacture and maintain. This is because the two-stroke engine requires no valvetrain which contribute in major cost, weight and complexity.

The current two-stroke designs are inefficient and impart environmental implications to human and plants in urban and non-urban areas where they operate. In Asian cities, they constitute the bulk of the engines for use in motorcycles and three-wheelers. With the hazardous nature of the pollutants emitted by the vehicles they are banned in Taipei, while in Bangkok the authority is seriously considering doing the same. The somewhat low combustion efficiency of today's two-stroke engine design can be improved through various means, making it possible to compliment the four stroke version. The latter is a more complicated engine configuration having lesser power-to-weight ratio characteristic. During the last decade, there have been many improved versions of the two-stroke engines produced. A few have found commercial ventures while many are still at the prototype level or even on the drawing board.

1.2 Background of the Problem

The simplistic nature of the design of a two-stroke engine, with relatively simple machining process (compared to four stroke engine), will provide improved power-to-weight ratio characteristic and lower production cost. Development of new two-stroke engines must address scavenging and emission problems. This can be achieved through improvising the scavenging process. By means of multi-ports intake system and eliminating crankcase compression, better scavenging process could be

achieved. The integration of transfer ports design to create better flow angle for blowdown and loop scavenging of exhaust gases will help improve fuel consumption and exhaust emissions in general. In this study the three numbers of ports was selected due to the constraints of surface area. As for the eliminating of the crankcase compression, stepped-piston configuration was selected in order to prepare the compress air-fuel mixture for the scavenging process.

1.3 Research Challenges

The key research challenge that must be resolved is can a multi-port intake system improve the performance and emission of a stratified-charged two-stroke stepped-piston gasoline engine.

1.4 Research Questions

Some of the persistent questions at this juncture would be:

- i) How multi-ports intake system and stepped-piston can fit in a two-stroke engine?
- ii) How is the optimise condition be achieved?
- iii) What effect will it have on performance and emission?
- iv) What aspect of performance (torque, brake power, sfc, etc)?
- v) What speed regime? Low speed? Typically idle to maximum speed?
- vi) What load range?
- vii) What are the impacts towards the unregulated and regulated exhaust emission?

1.5 Hypothesis

- i) Multi-ports and stepped piston provides an effective mean of discarding exhaust gases by introducing fresh charge through the circumference of the cylinder.
- ii) It also improves the scavenging process by reducing the short-circuiting of fresh charge air-fuel mixture.

1.6 Objectives of the Study

By introducing the multi-ports concept into the design of stratified-charged stepped-piston engine the associated problems of the conventional design of two-stroke engine can be addressed. The objectives of this research are as follows,

- i) to analyse the impact of multi-ports and stepped-piston configuration towards improving engine performance and emission,
- ii) to determine the appropriate ports design configuration and location, and
- iii) to compare the deviation between simulation and experimental results.

1.7 Importance of the Study

The study could benefit toward enhancing stratified-charged, two-stroke, stepped-piston gasoline engine design with the potential for application in transport, industrial and agriculture sectors. Furthermore, the future of the two-stroke engine will

depend upon how far a successful combination of scavenging, charging, combustion technology improvement (this study) can be made without jeopardising its classical advantages in terms of power density and simple construction.

1.8 Scope of the Study

Scopes of the study are as follows:

i) Design and simulation.

Preliminary study of the workability of the device is vital before the actual device is being fitted to the actual engine. The best configuration of the device will be design based on the actual boundary condition from the actual engine operation.

ii) Development and testing the prototype engine in laboratory for performance and emission.

A two-stroke engine will be developed to distinguish the workability of the system.

iii) Engine testing for performance and emission.

In this exercise two intensive testing will be conducted. Firstly the developed engine characteristic will be defined and secondly an engine which is available in the market which has the same capacity will be undergoing the same testing for comparative study.

iv) Data analysis.

All the data obtained from the testing will be analysed in order evaluate engine performance and emission.

In general, the outline constitutes three major areas in meeting the objectives and they are:

i) Simulation of flow and engine performance

To observe the flow characteristic during scavenging of exhaust gases and also the compression of fresh air-fuel mixture by the steppe-piston. As for the engine performance simulation is to observe the typical engine characteristics based on the engine geometry.

ii) Engine development

To look into the appropriate design features in order to have a optimize engine. This exercise will involve decision making in choosing the right method in producing each component of the engine without compromising with the vital features.

iii) Engine performance testing.

The testing comprises of conventional two-stroke and prototype engine. The purpose of the conventional engine testing is intended for comparative study.

The overall perspective of the research program is shown in Figure 1.2.

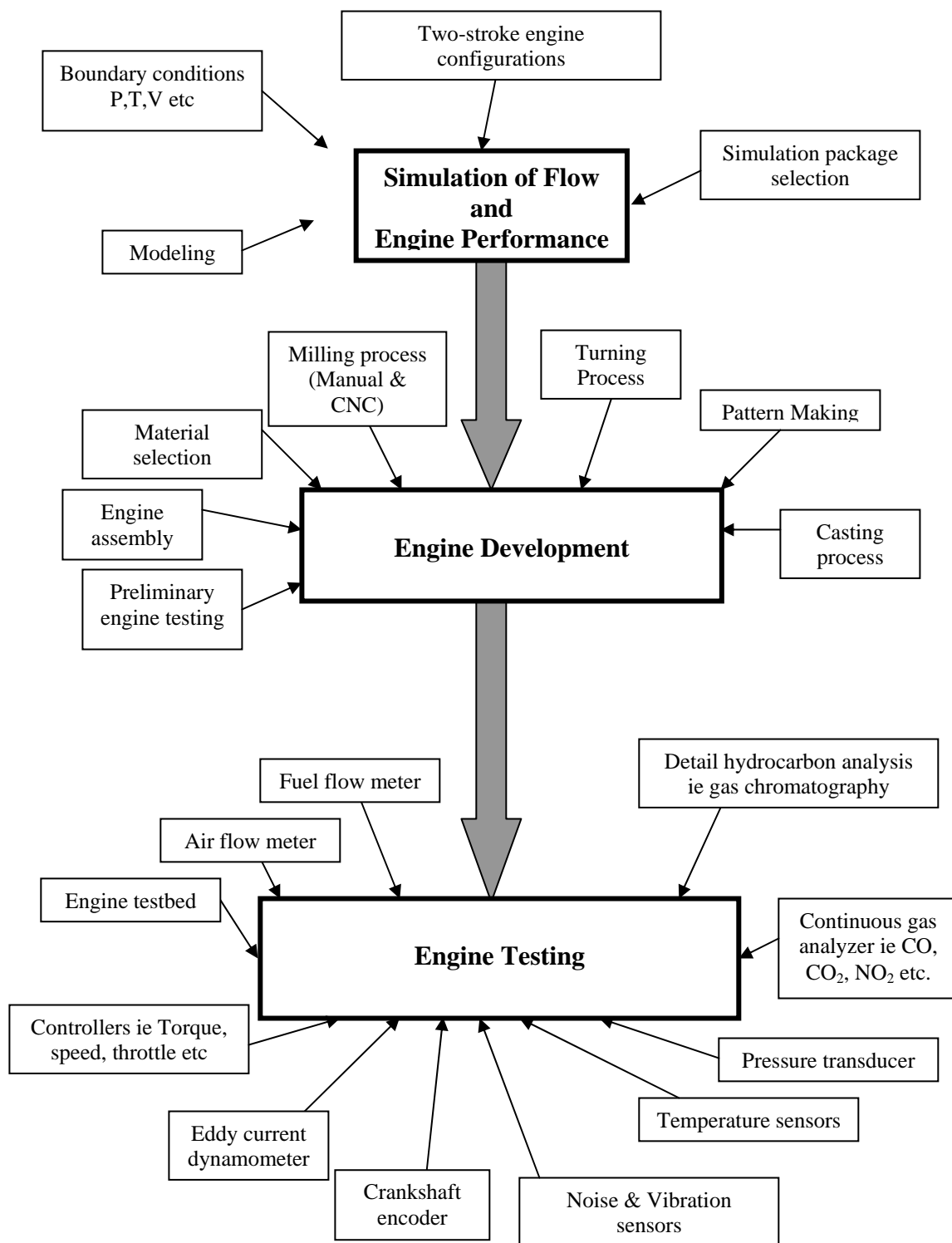


Figure 1.2: Overall perspective of research program

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