DESIGN AND OPTIMIZATION OF THE SCAVENGING SYSTEM OF A MULTI-CYLINDER TWO-STROKE *SCOTCH-YOKE* ENGINE

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ABSTRACT

A two-stroke engine complete with a scavenging system, operating with external pumping mechanism is being developed. The engine comprises of two pair of combustion chambers and a pair of piston pumps that are integrated onto the *Scotch-Yoke* crank mechanism. The *Schnurle* type loop scavenging arrangement was selected for the scavenging arrangement for the engine port design. The pump was to be driven by the engine's pistons linkages. The significant advantages of this opposed piston-driven pump concept is the double action of air pumping at every 180° interval of crankshaft revolution. In addition, extensive work using *Computational Fluid Dynamic* code simulation tools were applied throughout the project to ensure that the scavenging port geometry is optimized. Also developed was a scavenging test rig specifically to verify the simulation results. The unfired tracer gas sampling method was developed for the scavenging measurement purposes. The experimental testing was carried out successfully with the use of instrumentations such as *Dewetron High Speed Data Acquisition* and crank encoder. Both the simulation results and experimental results showed good scavenging characteristic, where the scavenging efficiency is closed to the perfect mixing scavenging model. The development of the scavenging system will allow for the reduction of the pollutant emission, and the overcome short-circuiting problem of the two-stroke engine.

ABSTRAK

Rekabentuk enjin dua lejang telah dibangunakan dengan sistem hapus-sisa lengkap, di mana ia beroperasi dengan pengepaman udara dari luar. Rekabentuk enjin ini adalah berpandukan mekanisme S*cotch-Yoke* yang beroperasi dengan dua pasang kebuk pembakaran dan sepasang pemampat piston. Susunan sistem hapus-sisa jenis *"Schnurle"* telah dipilih untuk mereka pembukaan udara dalam enjin. Pam ini dipandu secara terus oleh penyambungan omboh yang bersalingan. Kelebihan mekanisme yang ketara ialah ia dapat menghasilkan dua kali kerja pengepaman pada setiap 180° putaran aci engkol. Tambahan lagi, kajian yang mendalam pada bahagian penukaran udara telah dijalankan dengan kod program computer *Computational Fluid Dynamic* untuk memastikan rekabentuk pembukaan udara dalam keadaan yang memuaskan. Sementara itu, rangka uji-kaji sistem hapus-sisa telah dibangunkan untuk mengesahkan nilai keputusan daripada simulasi komputer. Teknik pengambilan jenis gas dalam keadaan tanpa bakar, telah dijalankan dengan kelengkapan alat pengukuran seperti *Dewetron High Speed Data Acquisition* dan pengecod engkol. Kedua-dua keputusan daripada simulasi komputer dan ujikaji telah menunjukkan kecekapan hapus-sisa dalam keadaan yang baik, di mana nilainya adalah menghampiri model hapus-sisa yang sempurna. Pembangunan sistem hapus-sisa ini telah menjamin keberkesanannya dalam mengurangkan hasil kotoran daripadan pembakaran dalam enjin dan juga menyelesaikan masalah *short-circuiting* rekabentuk enjin jenis dua lejang.

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LIST OF SYMBOLS

Y_{conv}	=	Piston replacement for conventional engine, m
Y_{sy}	=	Piston replacement for *Scotch-Yoke* engine, m
v_{conv}	=	Piston Velocity for conventional engine, m
v_{sy}	=	Piston Velocity for *Scotch-Yoke* engine
a_{conv}	=	Piston acceleration for conventional engine, m/s^2
a_{sy}	=	Piston acceleration for *Scotch-Yoke* engine, m/s^2
r	=	Crank radius, m
L	=	Conrod length, m
α	=	Crank angle after top dead center (TDC)
ω	=	Angular speed of the crankshaft, °
SE	=	Scavenging Efficiency
TE	=	Trapping Efficiency
CE	=	Charging Efficiency
SR	=	Scavenging Ratio
V_i	=	Intake velocity, m/s
d	=	Cylinder bore, mm
l, s	=	Stroke, mm
V_{et}	=	Swept volume from TDC to exhaust opening, mm^3
V_{to}	=	Total volume in the engine cylinder, mm^3
V_{tr}	=	Trapped volume during TDC, mm^3
t_l	=	Liner thickness, mm
N	=	Engine speed, rpm
σ_c	=	Permissible value of tension, 200 $kgcm^2$, *Cast Iron*
P_m	=	Maximum combustion pressure, 49.07 $kg.cm^2$
D_l	=	Inner liner diameter, mm

n	=	1 for two stroke engine
Q	=	Capacity/cylinder, mm^3
η_v	=	Volumetric efficiency
A	=	area, mm^2
h	=	Height, mm
F_i	=	Inertia Force, N
M_i	=	Moment Inertia, Nm
m_u	=	Unbalanced mass, g
r_m	=	Radius of unbalanced mass from center, mm
L_d	=	The distance from center, mm
r_b	=	The distance of mass gravity of counterweight, mm
M_{ref}	=	The unbalance Moment Inertial System, Nm
AM	=	Angle for main port, °
MT	=	Target point for main point, mm
UPM	=	Upsweep angle of main port, °
UPR	=	Upsweep angle of rear port, °
UPS	=	Upsweep angle of side port, °
DPE	=	Downsweep angle of exhaust port, °
ρ	=	Density, g/ml
TDC	=	Top Dead Center
BDC	=	Bottom Dead Center
ATDC	=	After Top Dead Center, °
γ	=	Specific heat ratio
σ	=	Turbulent Prandtl numbers
k	=	Turbulent kinetic energy
ε	=	Dissipation rate of turbulent kinetic energy
atm	=	Pressure at atmosphere condition
CA	=	Crank angle, °

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CHAPTER 1

INTRODUCTION

1.1 Preface

The emphasis of the research project is to design a scavenging system for a newly conceptualized small capacity (500 cc), multi-cylinder, two-stroke engine based on the *Scotch-Yoke* mechanism. The research work on the *Scotch-Yoke* engine concept was attempted by *CMC SYTECH Corp. of Australia* [2] and was proven to have several advantages i.e. small size, perfect balance, reduction of the engine weight compare to the conventional reciprocating engine of a same displacement.

The scavenging process in the two-stroke cycle engine has direct influent on the performance of their combustion processes and remains one of the fundamental important strategies towards improvement of fuel utilization efficiency and the reduction of pollutant.

Several C*FD* simulation analyses have been done to characterize the scavenging process for the port geometry optimization. In addition, an unfired test rig for scavenging system measurement has been developed in conjunction with this research work.

1.2 Objectives

The objectives of the research project are:

i. To design an external scavenging system of a two stroke *Scotch-Yoke* multi-cylinder engine
ii. To develop a scavenging system test rig to optimize the scavenging process.
iii. To reduce fresh charge short-circuiting problem in the two-stroke engine.

1.3 Statement of Problem

Scavenging process is required in two-stroke engines in assuring the appropriateness of combustion. However it will also result in the short-circuiting of fresh charge (flow directly from the engine's transfer to the exhaust port). The short-circuiting phenomenon is responsible for the low fuel economy/efficiency and high-unburned hydrocarbons emission.

1.4 Hypothesis

An external scavenging system is required to retrofit the small capacity multi-cylinder, two-stroke horizontally opposed *Scotch-Yoke* engine to improve its scavenging efficiency and overcome the mixture short-circuiting problem.

1.5 Scope

The scopes of work prescribed are as follows:

i. Literature reviews on the two-stroke engine, scavenging systems and *Scotch-Yoke* engine concept
ii. Design of a scavenging system for the two-stroke *Scotch-Yoke* engine.
iii. *Computational Fluid Dynamic(CFD)* code simulation for the scavenging flow analysis
iv. Development of an unfired scavenging system test rig
v. Validation of the hypotheses

1.6 Methodology

The methodology applied in the implementation of this project was as follows:

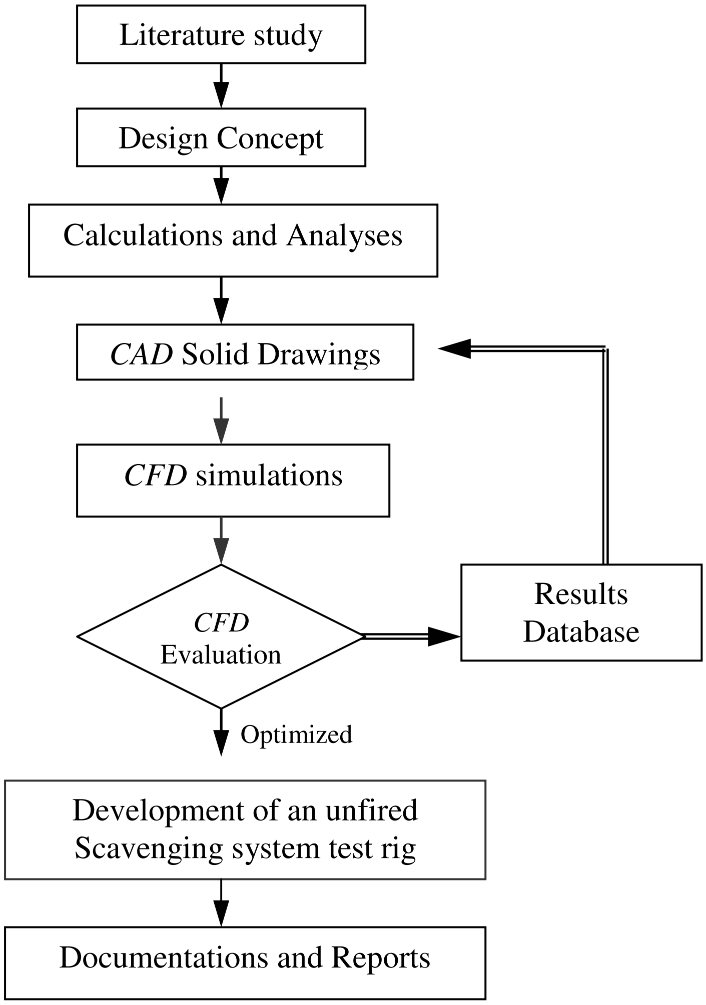

Figure 1.0: Flow chart of project implementation.

1.6.1 Literature Review

The review of recent works is important to provide the understanding of the advancements of two-stroke technologies such as the scavenging systems and *Scotch-Yoke* engine design itself. The previous technical references which are published in the reputable journals such as *Engineering Society for Advancing mobility Land Sea, Air and Space (SAE)* Technical Paper Series, will assist the author in providing new research methods for the scavenging system development. Besides, there are several books and publications on two-stroke engines which will provide first hand knowledge on approaches to engine design and analysis.

1.6.2 Design Concept

With the knowledge obtained from literature study, a design concept of an external scavenging system which is suited to the design of *Scotch-Yoke* mechanism, as well as piston pumps design will be proposed. The loop scavenging arrangement, which is suitable for small capacity gasoline type two-stroke engine, will then be applied for the scavenging port geometry design work.

1.6.3 *CAD* Solid Drawings

It is in the opinion of the author that *Computer-Aided Design* (*CAD*) software, (e.g. *SolidWorks 2004)* is suitable tool to enable engine parts be designed and eventually developed. The specification of the engine parts will be shown in intricate details in finalizing engineering drawings.

1.6.4 *CFD* Simulations

The *Computational Fluid Dynamic (CFD)* simulation work is an important approach to predict the characteristic of the gas exchange processes particularly during the scavenging process. The design of the porting will be improved through the analysis of a series of simulation results.

1.6.5 Development of an Unfired Scavenging System Test Rig

The fabrication works of the unfired scavenging system test rig was done with the assistance of a local engineering company. Prior to this, the engine components detail drawings are prepared for the fabrication works. However, the assembly of the components into a complete unit was not made by the said company, but was made by the author in *UTM*, specifically at the *Automotive Development Center* (ADC).

After the engine model was completely assembled, it was simulated for motion analysis using a specially designed motorized control system. The instrumentations for the scavenging measurement were installed at the engine model. A technique call gas sampling method was applied to evaluate for the engine's overall scavenging system efficiency.

1.7 Gantt Chart

Planning and execution of the project indicates the milestone of the progress of the design and development work within 5 semesters.

Table 1.1: The Gantt chart

Planning and Execution		**Semesters**				
		1	**2**	**3**	**4**	**5**
1. Literature Review	Study on the previous technical paper					
2. Design Concept	Develop the design concept					
3. Calculations and Analyses	1. Engine geometry design					
	2. External pump design					
4. CAD Solid Drawings	*3D* model drawing for the system					
5. CFD simulations	*CFD* code simulation for the design optimization					
6. Fabrication works	Fabrication of the engine model					
7. Test Rig Setting Up	1. Setting up the test rig					
8. Experimental data analysis	Investigation on the Scavenging efficiency					
9. Documentations and Reports	Summary of the Project					

Planned & Execution   Extend For Execution

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