DESIGN AND ANALYSIS OF A PISTON FOR COMPRESSED NATURAL GAS (CNG) ENGINE

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DESIGN ANALYSIS OF A PISTON FOR COMPRESSED NATURAL GAS (CNG) ENGINE

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

Faculty of Mechanical Engineering
UNIVERSITI MALAYSIA PAHANG

NOVEMBER 2008

SUPERVISOR’S DECLARATION

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

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ACKNOWLEDGEMENTS

First of all, I would like to thank my advisor Mr Abdul Rahim Bin Ismail for his assistance in completing the PSM project. For those who have assisted I on experimental work successfully, the suggestions and encourage have helped me in all time, beginning from the concept design until completing analysis piston process and in writing the report. Without his opinion and ideas it would be difficult for me to complete and success in this project. Besides that, I would like to appreciate those who gave me the possibility to complete this project. As a student, I accept all the guidance given by my advisor. During this project, I have encountered so many problems. Without them, I would not have made it through.

I would also like to acknowledge with much appreciation to the crucial role of Dean Faculty of Mechanical Engineering, Associate Prof. Dr Rosli Bin Abu Bakar, for his advice and instruction toward finishing my project. Especially to my friends who took in this project by giving great idea in designing the Piston, using Solidwork and Algor software.

I would like to thank my family for their continuous support and confidence in my effort. They inspires me for what I have achieved today most importantly, is their guidance and motivation, in order for me to become a worthy person for the religion, race and state.

ABSTRACT

Engine pistons are one of the most complex components among all automotive or other industry field components. The engine can be called the heart of a car and the piston may be considered the most important part of an engine. There are lots of research works proposing for engine pistons, new geometries, materials and manufacturing techniques, and this evolution has undergone with a continuous improvement over the last decades and required thorough examination of the smallest details. Notwithstanding all these studies, there is huge number of damaged pistons. Damage mechanisms have different origins and are mainly wear, temperature, and fatigue related. Among the fatigue damages, thermal fatigue and mechanical fatigue, either at room or at high temperature, play a prominent role.

This work is concerned only with the analysis of fatigue-damaged pistons. Pistons from diesel engines will be analyzed. Damages initiated at the crown, ring grooves, pin holes and skirt are assessed. A compendium of case studies of fatigue-damaged pistons is presented. An analysis of both thermal fatigue and mechanical fatigue damages is presented and analyzed in this work.

A linear static stress analysis, using “Algor works”, is used to determine the stress distribution during the combustion. Stresses at the piston crown and pin holes, as well as stresses at the grooves and skirt as a function of land clearances are also presented. A fractographic study is carried out in order to confirm crack initiation sites.

ABSTRAK

Piston enjin adalah merupakan komponen yang complex di dalam bidang automotif atau dalam bidang komponen-komponen industri. Enjin boleh dipanggil sebagai hati untuk sebuah kereta dan piston boleh juga di ketegorikan perkara yang amat penting dalam bahagian enjin. Terdapat ramai pengkaji yang mengkaji tentang piston enjin, geometri terbaru, bahan dan teknik pemprosesan dan pengkembangan ini telah berterusan berkembang hingga lebih terperinci. Walaupun pengkaji masih lagi mengkaji tentang piston enjin, kini masih banyak piston yang rosak. Mekanisme kerosakan mempunyai pelbagai titik permulaan dan kebanyakannya adalah haus, suhu dan kelesuan.

Projek ini hanya tertumpu kepada analisis kesan keatas kerosakan kelesuan dan mengkaji tahap ketahanan piston kesan daripada suhu dan tekanan di dalam pembakaran dalaman enjin. Piston ini diambil daripada enjin diesel dan diubah suai agar boleh digunakan di dalam CNG enjin. Tempat yang paling kerap berlakunya kerosakan seperti pada permukaan atas piston dan dinding piston. Satu ujikaji mengenai kelesuan haba dan kelesuan mekanikal kerosakan di kaji.

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.

LIST OF ABBREVIATIONS

CNG	Compressed natural gas
LPG	Liquid gas
RON	Relatively octane number
BDC	Bottom dead centre
TDC	Top dead centre
CAE	Computer-aided engineering
MEP	Mean effective pressure
CMM	Coordinate measuring machine
FEA	finite element analysis

LIST OF SYMBOLS

$Vbowl$	Bowl volume
$Vbdc$	Bottom dead center volume
$Vswept$	Swept volume
$Vclearance$	Clearance volume
Cr	Compression ratio
Db	Bowl diameter
Vs	Swept volume
Vc	Clearance volume
$Vtdc$	Top dead center volume
h	Height of bowl
σ_f	True tracture strength
S_f	Fatigue strength
S'_f	Fatigue strength coefficient

CHAPTER 1

INTRODUCTION

1.1 Background

Global environment pollution gives effect to many health problems world wide. Therefore extensive studies have been conducted all over the world to use alternative fuels such as alcohol, ether and gaseous fuels (CNG & LPG) which can reduce the air pollution level by existing fuels (Petrol & Diesel) & bring a sigh of relief. CNG means Compressed Natural Gas. Its main constituents are Methane (90-95%) & marginal quantities of Propane, Iso-Butane & Butane. Natural Gas is stored in cylinders under high pressure of about 200 bars.

CNG is cheaper in price thus saves more on compared to petrol and diesel. Another advantage of having high octane number is drastic reduction in pollution thus making CNG less dangerous. In case of leakage it dissipates very easily in air as it is lighter than air & risk of any hazard is considerably reduced and CNG is available. CNG is available in abundant quantity in the earth's crust. It leads to higher thermal efficiency. It is non toxic.

In recent years, CNG has been promoted as a promising clean fuel alternative to spark ignition engines because of its relatively higher octane level. Due to its high research octane number (RON>130), CNG allows the combustion at higher compression ratio without knocking. It also offers much lower greenhouse gas emissions than those from the burning of other hydrocarbons as a result of its higher hydrogen to carbon ratio. Recently, the exact understanding of the physical and chemical processes is required to speed up the design process due to the increasing market demands of making new engines.

1.2 Problem Statement

- 2D analysis using 8 types of meshing density and for 3D analysis using 4 types meshing percentage.
- The compression ratio is range 12- 17.

1.3 Objective

- To design piston model 2D and 3D appropriate with real dimension.
- To analyze the design with finite element analysis (FEA)

1.4 Project Scope

- Modification of piston diesel engine.
- To understand the function of piston and its material properties.
- To convert the diesel engine into CNG engine.

1.4 Gantt Chart FYP 1

Table 1.1: Gantt Chart/ Project Schedule For FYP 1

GANTT CHART/ PROJECT SCHEDULE FOR FYP 1																	
	PROJECT ACTIVITIES	WEEKS															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Discuss on the title of the FYP 1	■															
2	Discuss on the objectives and the scopes of the FYP 1		■														
3	Chapter 1 include the objectives, scopes, and the problem statements		■														
4	Submit the chapter 1. Discuss on the format of project		■	■													
5	Literature study. Find the information related to the literature review	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
6	Discuss on chapter 2, the literature review, journal and related information				■												
7	Chapter 2.1, the introduction of piston.				■												
8	Discuss on chapter 2.1				■												
9	Chapter 2.2, introduction of CAE and CAD and method analysis				■	■											
10	Discuss on the analysis and the methodology					■											
11	Chapter 3, The methodology					■	■	■	■								
12	Preparation for the presentation									■	■	■	■	■	■		

1.5 Gantt Chart FYP 2

Table 1.2: Gantt Chart/ Project Schedule For FYP 2

GANTT CHART/ PROJECT SCHEDULE FOR FYP 2																	
	PROJECT ACTIVITIES	WEEKS															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	Forms filled to use the laboratory lab (CMM room)	■	■														
2	Literature Review	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	
3	Measure the dimension of piston	■	■														
4	Design 2D analysis using Algor software		■	■													
5	Design Piston 3D using solidwork software		■	■	■	■						■					
6	Discussion on analysis, the constraint, load					■	■	■	■	■	■						
7	Analysis the assembly using the Algor software					■	■	■	■	■	■	■					
8	Conclusion based on discussion										■	■	■	■			
9	Discussion on chapter 4 and 5											■	■	■	■	■	■
10	Discuss on the analysis and the methodology										■	■	■	■			
11	Preparations for presentation 2												■	■			
12	Final report submission															■	■

CHAPTER 2

LITERATURE REVIEW

2.1 COMPRESSED NATURAL GAS (CNG)

2.1.1 Typical composition of natural gas

2.18% nitrogen, 92.69% methane, 3.43% ethane, 0.52% carbon dioxide, 0.71% propane, 0.12% *iso*-butane, 0.15% *n*-butane, 0.09% pentane and 0.11% hexane.

Table 2.1: Parameter of compressed natural gas fuel [19].

Parameter	**CNG Fuel**
Relative Density of diesel fuel	0.844
Viscosity	0.045
Net Calorific Value	34.83 MJ/m^3
Gross calorific value	38.59 MJ/m^3
Net calorific value of diesel fuel	42.70 MJ/kg
Gross Wobbe number	49.80 MJ/m^3
Stoichiometric air/fuel ratio	14.5:1

Source: John B. Heywood. McGRAW-HILL (2009)

2.1.2 Rated power (using CNG fuel)

CNG has higher values for these ratios, which means that CNG has higher potential to convert initial fuel availability to do useful work, even without taking advantage of its higher octane number rating. If compression ratio is raised, it can be expected that CNG fuelling would outperform the gasoline fuelled engine in both the IMEP and the second law efficiencies [7]. CNG has higher availability transfer with work (38.2%) than gasoline operation (33.4%). Availability destruction due to combustion is about the same for CNG and gasoline. However, availability destruction due to heat transfer is lower with CNG operation (13.8%).

2.2 EXPERIMENTAL REVIEW

2.2.1 Setup and Procedures

Referring to research conducted by Ke Zheng etall [6], A single cylinder engine was modified into a natural gas direct-injection engine. To increase the flow rate for natural gas application, the swirler near the tip of nozzle was taken off. Natural gas is injected into cylinder at the constant pressure of 8 MPa. Besides installing the natural gas high-pressure injector, a spark plug is also installed into the centre of combustion chamber as the ignition source.

Table 2.2: Engine specifications [6]

Engine specifications	
Bore (mm)	100
Stroke (mm)	115
Displacement (cm3)	903
Compression ratio	8
Injection pressure (MPa)	8
Ignition source	Spark plug
Combustion chamber	Bowl-in-shape

Source: Ke Zeng, Zuohua Huang (2006)

2.3 INTERNAL COMBUSTION ENGINE

The compressed ignition or diesel engine had been developed by Rudolf Diesel in 1892 [1]. The normal internal combustion engine is generally one of two types, spark ignition petrol or gas engines and diesel engine [2]. In this engine, the piston reciprocates in the cylinder between two fixed position called the top dead centre (TDC) and the bottom dead centre (BDC) [3][4]. TDC is the position of the piston when it forms the smallest volume in cylinder and BDC is the position of the piston when it forms the largest volume in the cylinder. The distance between TDC and BDC is called the stroke of the engine while the diameter of the piston is called the bore [3]. The minimum volume formed in the cylinder when the piston is at TDC is called the clearance volume while the displacement volume is the volume displaced by the piston as it moves between TDC and BDC [3]. The compression ratio is the ratio of maximum volume formed in the cylinder to the minimum volume [3][5].

$$r = \frac{Vmax}{Vmin}$$

Equation 2.1.1: Compression ratio [3]

The other important term that is frequently being used in conjunction with reciprocating engine are the mean effective pressure (MEP). It is a fictitious pressure that, if it acted on the piston during the entire power stroke, would produce the same amount of net work as that produced during the actual cycle [3].

$$MEP = \frac{Wnet}{Vmax - Vmin}$$

Equation 2.1.2: Mean effective pressure [3]

2.4 PISTON

2.4.1 Introduction

The piston is one of the most stressed components of an entire vehicle. Pressures at the combustion chamber may reach about 180–200 bar [10]. Speeds reach about 25 m/s and temperatures at the piston crown may reach about 400 °C [10]. As one of the major moving parts in the power-transmitting assembly, the piston must be designed so that it can withstand the extreme heat and pressure of combustion. Pistons must also be light enough to keep inertial loads on related parts to a minimum. It also transmits heat to the cooling oil and some of the heat through the piston rings to the cylinder wall [14].

Notwithstanding this technological evolution there are still a significant number of damaged pistons. Damages may have different origins: mechanical stresses, thermal stresses, wear mechanisms, temperature degradation, oxidation mechanisms and etc. Fatigue is a source of piston damages. Although, traditionally, piston damages are attributed to wear and lubrication sources, fatigue is responsible for a significant number of piston damages. And some damages where the main cause is attributed to wear and/or lubrication mechanisms may have in the root cause origin a fatigue crack.

Fatigue exists when cyclic stresses/deformations occur in an area on a component. The cyclic stresses/deformations have mainly two origins: load and temperature. Traditional mechanical fatigue may be the main damaging mechanism in different parts of a piston depending on different factors. High temperature fatigue (which includes creep) is also present in some damaged pistons. Thermal fatigue and thermal–mechanical fatigue are also present in other damaged pistons. A finite element linear static analysis, using “cosmos works”, is used for stress and temperature determination. Only aluminum pistons are assessed in this work because most of the engine pistons are in aluminum.

The fatigue-damaged pistons may be divided into two categories: the mechanical and high temperature mechanical damaged pistons and the thermal and thermal–mechanical damaged pistons. The mechanical and high temperature mechanical damaged pistons may be divided according to the damaged area: piston head; piston pin holes; piston compression ring grooves; and piston skirt. The analysis, in this work, will be made according to this classification.

2.4.2 Mechanical and high temperature mechanical fatigue

By mechanical fatigue means that in a piston a crack will nucleate and propagate in critical stressed areas. The stresses in this context are due to the loads acting externally on the piston. Although stresses on pistons change with piston geometries and engine pressures, Figure 2.1 and Figure 2.2 show a typical stress distribution on an engine piston. In Figure 2.1 and Figure 2.2 pressures are merely indicative and are used only with the purpose of determination of the most stressed areas. It is not intended to determine the real stresses acting on the piston. The dynamic and thermal stresses are not also included in Figure 2.1 and Figure 2.2.

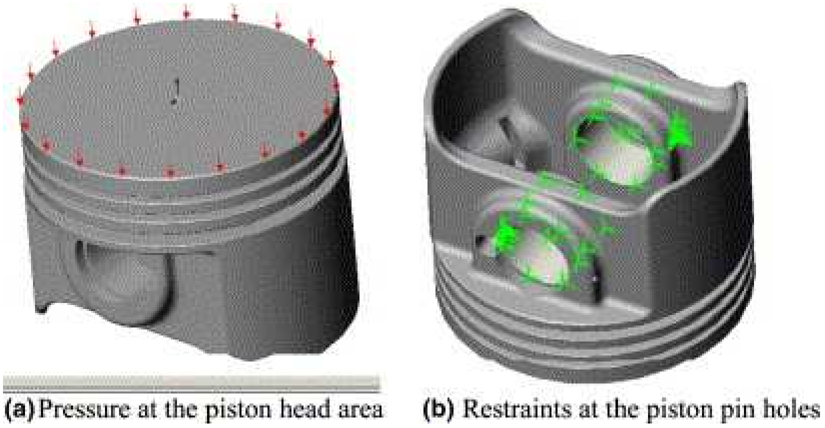

Figure 2.1: Typical engine piston [14]

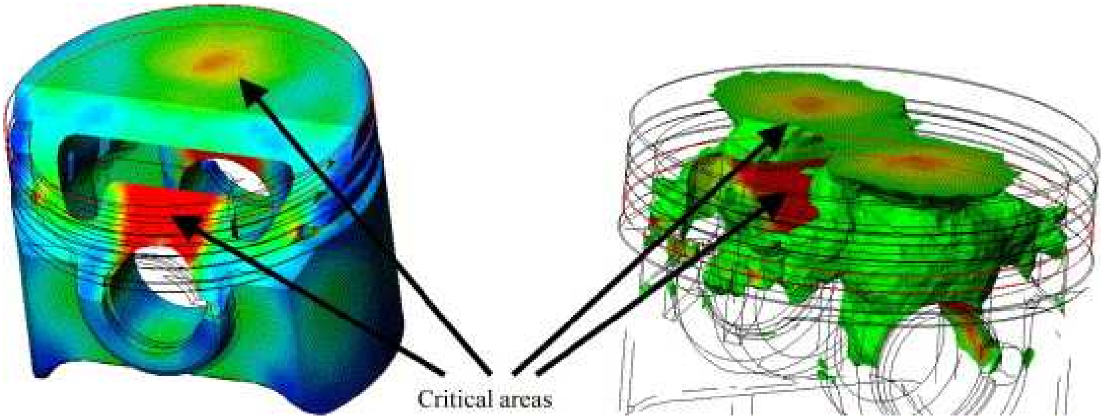

Figure 2.2: Typical stress distribution on an engine piston [14].

It is clear that there are mainly two critical areas: the top side of piston pin hole and two areas at the piston head. Stress analyses on diesel pistons show the same critical areas. If holes or grooves are introduced on the pin hole it is possible to introduce critical stressed areas on those discontinuities.

2.4.3 Piston head and piston pin hole

As observed in Figure 2.1 and Figure 2.2, due to the pressure at the piston head, there are mainly two critical areas: piston pin holes and localized areas at the piston head. On pistons in Figure 2.3 and Figure 2.4 the cracks initiated on the piston head near the combustion chamber.

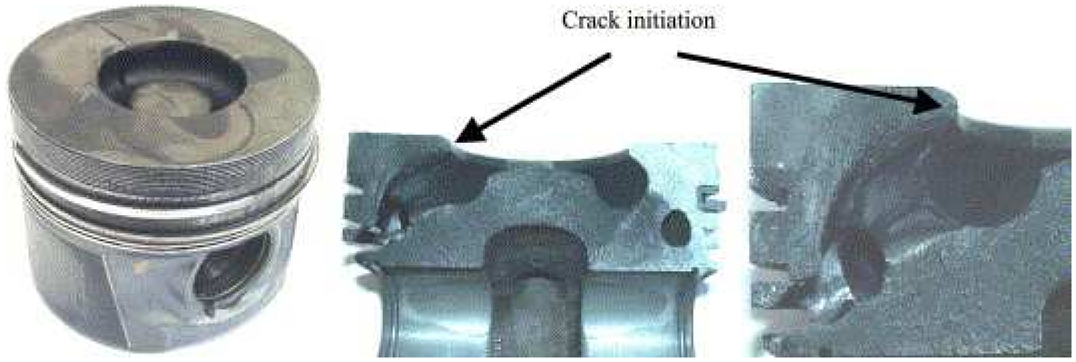

Figure 2.3: Diesel engine piston (with cooling gallery) with a crack from one side of the pin hole to the head [14]

Figure 2.4: Diesel engine piston with a crack from one side of the pin hole to the other pin hole going through the head of the piston [14].