DEVELOPMENT OF INTAKE SYSTEM FOR IMPROVEMENT OF PERFORMANCE OF COMPRESSED NATURAL GAS SPARK IGNITION ENGINE

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"For my wife Siti Oniah and all of my children Abang Harits,
Mba' Tazkia, Abang Asad, Mba' Qonita, Mba' Azimah,
Mba' Raina and my little baby Adib, jazakumullahu
khairan kasiro. May Allah Ta'ala always bless us…"

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ABSTRACT

The improvement of flow strategy was implemented in the intake system of the engine to produce better Compressed Natural Gas engine performance. Three components were studied, designed, simulated, developed, tested and validated in this research. The components are: the mixer, swirl device and fuel cooler device. The three components were installed to produce pressurised turbulent flow with higher fuel volume in the intake system, which is ideal condition for Compressed Natural Gas (CNG) fuelled engine. A combination of experimental work with simulation technique were carried out. The work included design and fabrication of the engine test rig; the CNG fuel cooling system; fitting of instrumentation and measurement system for the performance testing of both gasoline and CNG modes. The simulation work was utilised to design appropriate mixer and swirl device. The flow test rig, known as the steady state flow rig (SSFR) was constructed to validate the simulation results. Then the investigation of the effect of these components on the CNG engine performance was carried out. A venturi-inlet holes mixer with three variables: number of inlet hole (8, 12 and 16); the inlet angles (30^0, 40^0, 50^0 and 60^0) and the outlet angles (20^0, 30^0, 40^0 and 50^0) were studied. The swirl-device with number of revolution and the plane angle variables were also studied. The CNG fuel cooling system with the ability to control water flow rate and the coolant temperature was installed. In this study it was found that the mixer and swirl-device improved the swirl ratio and pressure condition inside the intake manifold. The installation of the mixer, swirl device and CNG fuel cooling system had successfully increased 5.5%, 5% and 3% of CNG engine performance respectively compared to that of existing operating condition. The overall results proved that there is a high potential of this mixer and swirl device method in increasing the CNG engine performance. The overall improvement on engine performance of power and torque was about 11% and 13 % compared to the original mixer.

ABSTRAK

Pembaikan strategi pengurusan aliran pada sistem kemasukan telah digunakan untuk mempertingkatkan prestasi enjin Gas Asli Termampat (CNG). Sebanyak tiga komponen dikaji, direka, disimulasikan, dibangunkan, diuji dan dibuktikan. Komponen-komponen tersebut adalah alat pencampur bahan api (mixer), alat penjana swirl dan sistem penyejukan bahan api. Ketiga-tiga komponen tersebut telah dipasang untuk menghasilkan aliran bertekanan-turbulent dengan ketumpatan bahan api yang lebih tinggi pada system kemasukan enjin. Dan ini merupakan keadaan yang paling sesuai bagi enjin Gas Asli Termampat (CNG).Di dalam penyelidikan ini, beberapa ujikaji dan disertai dengan kaedah simulasi telah dijalankan. Ujikaji ini terbahagi kepada kerja-kerja merekabentuk dan membuat rig pengujian enjin, sistem penyejukan bahan api CNG, dan menyediakan sistem pengukuran untuk ujikaji prestasi enjin menggunakan petrol dan CNG. Simulasi telah digunakan untuk mereka dan memilih rekabentuk alat pencampur bahan api dan penjana swirl yang sesuai. Rig Aliran Mantap (Steady State Flow Rig atau SSFR) telah dibangunkan untuk membuktikan keputusan simulasi. Peringkat terakhir adalah menguji kesan ketiga-tiga pembolehubah keatas prestasi enjin CNG. Pecampur bahan api yang berasaskan prinsip venturi-lubang kemasukan pula mempunyai tiga pembolehubah iaitu bilangan liang kemasukan (8,12 dan 16), sudut kemasukan (30^0 , 40^0,50^0 dan 60^0) dan sudut keluaran (20^0, 30^0 , 40^0 dan 50^0). Alat penjana swirl mempunyai pembolehubah jumlah pusingan bilah dan sudut bilah. Sistem penyejukan bahan api CNG dapat mengawal kadaralir udara dan air termasuk suhu penyejuk. Penggunaan pencampur bahan api, alat penjana swirl dan system penyejukan bahan apo CNG masing-masing telah meningkatkan prestasi enjin sebanyak 5.5%, 5% dan 3% berbanding kondisi operasi petrol. Secara amnya hasil penyelidikan telah membuktikan bahawa pencampur bahan api dan alat penjana swirl memiliki potensi yang tinggi dalam meningkatkan prestasi enjin CNG. Peningkatan am terhadap kuasa dan tork adalah sebesar 11% dan 13% berbanding dengan pencampur bahan api asal.

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CHAPTER 1

INTRODUCTION

1.1 Background

The strategy to implement alternative fuels in internal combustion engines is becoming the subjects of interest nowadays. The reasons are driven by two factors: the environmental effects and the energy independence from petroleum based fuel. With more than one billion vehicles around the world, vehicle pollution is becoming the most significant source of air pollution (Freidman *et al.*, 2000). The World Health Organisation (WHO) estimated that approximately 460,000 people die prematurely each year as a result of exposure to particulate matter in the air (Walsh, 1999). Moreover, the air pollution also contributes to negative health impacts such as respiratory symptoms, chronic bronchitis, asthma exacerbation and the deficit in growth of lung function (Garcia, 2001). Kunzi *et al.* (2000) has calculated as much as ∈360 (equal to RM 1,612)/person/year should be spent as a health cost due to air pollution.

Malaysia, as one of the developing countries, has to deal with this problem too. The situation may even be worst if we consider the following facts that potentially related to air pollution. By the year 2002, 434,954 new vehicles were sold (EON, 2003), making Malaysia on the top of the list compared to other ASEAN countries for four consecutive years. This situation occurs where Kuala Lumpur has already exceed the World Health Organization guidelines in particulate and sulphur dioxide concentration, i.e. exceeding in the value of 119 micrograms/m^3 of particulate and 24 micrograms/m^3 of sulphur dioxide concentration (APEC

Secretariat, 2000). In addition, the ratio of 129 vehicles per 1,000 people in Malaysia is a strong signal to find a better solution systematically.

From these facts, the priority is to find the solution for a cleaner, affordable and better quality of alternative fuels. Among the alternative fuels, Compressed Natural gas (CNG) has been recognized as one of the promising alternative fuel due to its substantial benefits compared to gasoline and diesel. However, the number of vehicle powered by this alternative fuel is still small compared to the number of the conventional vehicle that powered by gasoline and diesel. In the case of gaseous engine, from 5.5 millions – only one million used CNG and the rest used LPG (Vitale, 1998).

The challenge is not only in the technology aspect but also in the economic aspect. In technological aspect, although most of the alternative fuel engine produced less power, some cars manufacturers had successfully manufactured the commercial alternative fuel vehicle. For example, Honda Civic 1.6 with advanced engine technology has produced even higher engine output based on CNG compared to that of gasoline (Nylun and Lawson, 2000).

The problem is that this high performance engine is generated through massive modification in the engine features, especially in the combustion chamber. In the case of Honda (Suga *et al.*, 1997) and Toyota (Kato *et al.*, 1999), the compression ratio, valve seats and also intake valve timing were modified. This implicate on the high cost that has to be spent, either by car manufacturers or the consumers. Therefore, a simpler and a cheaper method to encourage consumers using the CNG fuelled vehicle will be a great contribution to the society.

Up to now, the improvement on CNG engine performance concentrated on the combustion process. By introducing turbulent flow and modified combustion chambers proved to reduce combustion duration due to improve burning rates (Zhang and Hill, 1996), (Evan *et al.*, 1996) and improve rate of heat release during the main combustion period (Johansson and Olsson, 1995). Adding hydrogen into the CNG/air mixture will also improve the burning rate (Swain *et al.*, 1993). Higher compression ratio recommended in CNG fuelled vehicle (Kato *et al.*, 1999). However, Duan

(1996) concluded that low volumetric efficiency is one of the factor that cause drop the CNG engine performance.

It has also known that the inlet port design and the intake manifold configuration has a direct influence on engine performance and emissions (Blaxill, 1999). Based on this fact, the intake process may give a great contribution toward increasing the CNG engine performance. This study considers the novel design of the intake system as economical devices without major modification. The alteration in the intake system is much simpler and cheaper compared to that of modification on combustion chamber.

World Energy Council (Edward, 1998) predicts that Malaysia and Japan each could have 200,000 natural gas vehicles (NGVs) by 2000. However, this estimation was not reached. Data from IANGV (2003) exposed that the quantity NGV's was only 7,700, compared to more than 12 millions vehicles registered in Malaysia (Mustaffa, 2003). One of the reasons of this low percentage is that the car buyers need easier way in converting conventional fuel system into CNG fuel system with less modification. Hence, this design may fulfil the requirements, as it does not need to do major modification to convert their conventional fuel engine to that of CNG fuel.

1.2 The Statement of the Problem

This study is aiming at improving the CNG engine performance by implementing the pressurised turbulent flow. The pressurised flow will increase volume of the fuel and the volumetric efficiency and the turbulent increase the flame speed. To promote this condition during intake process, an advanced intake system consisting of a mixer and swirled-device together with the cooling system for CNG fuel was designed and developed in this study.

1.3 The Objective of the Study

The objective of this study is to improve the CNG engine performance up to that of gasoline through the implementation a modified CNG engine intake system. This advanced system was based on a new mixer and swirled-device that implement pressurised and turbulent flow together with a new cooling system for CNG fuel.

1.4 The Scope of the Research

The study was carried out based on the following scopes:

1. To determine the factors affecting the pressurised and turbulent flow in the intake process
2. To design and fabricate the mixer and swirl devices suitable for the pressurised and turbulent parameter
3. To design and fabricate the cooling system for CNG fuel
4. To simulate the mixer and the designed swirl devices
5. To test the recommended design of mixer and swirl devices
6. To build the rig for engine testing
7. To set up the measurement and the data acquisition system
8. To test and analyse the engine performance fitted with the new design of intake system

1.5 The Research Methodology

The approach of this research was based on the philosophy of adding small, useful and economical devices with the combination of flow principle management without major modification of the intake system. Figure 1.1 showed the methodology flowchart of this research, which combined experimental method with simulation tools.

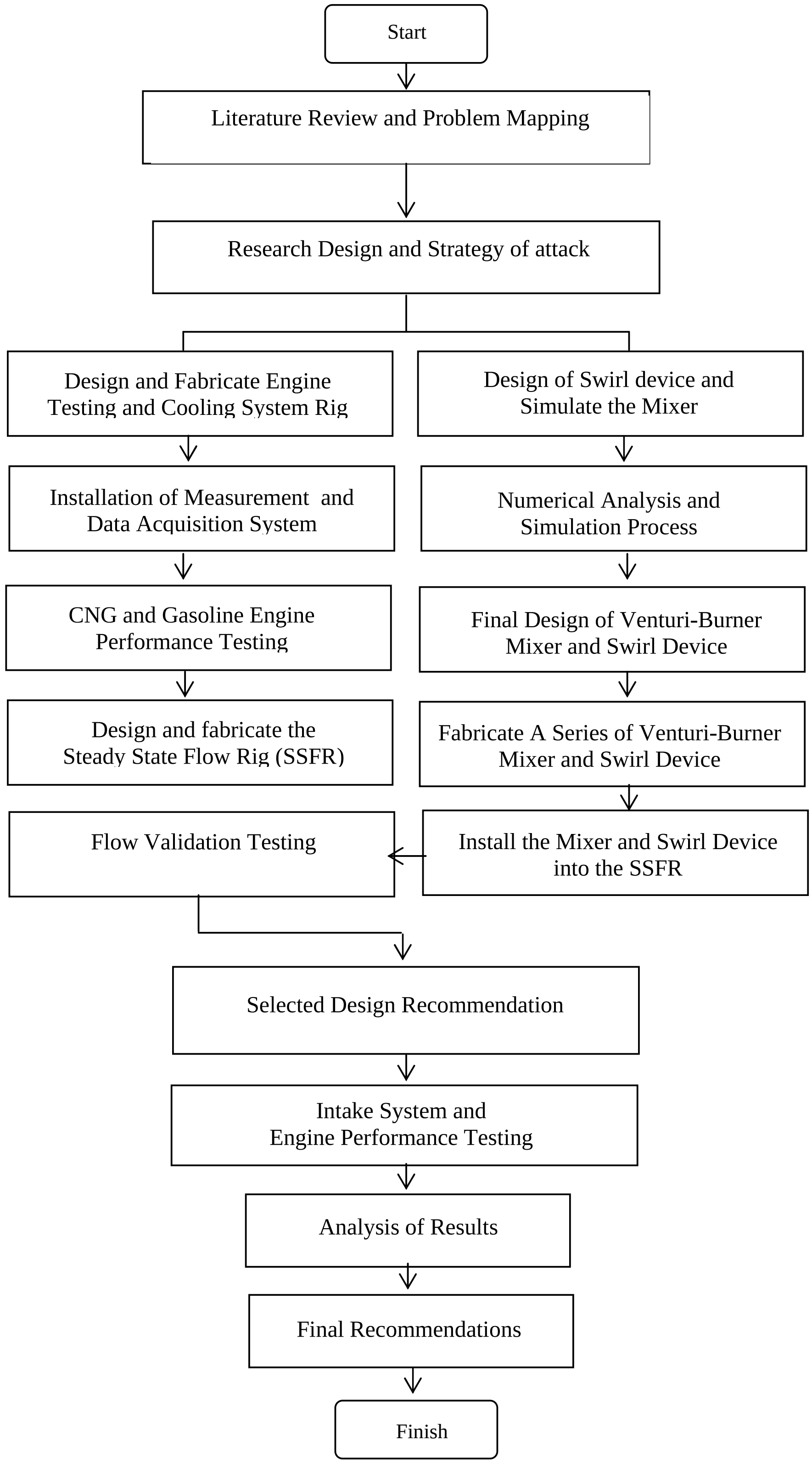

Figure 1.1 Methodology Flowchart

The literature review concentrated on the state of art of the CNG fuel and engine research. The problem-solution map of the CNG fuelled engine research was then developed. The next step was divided into two parts: the experimental works; and design and simulation processes. Experimental part included designed and fabricated the engine testing experimental rig and CNG fuel cooling system; instrumentation of the measurement system and running the engine performance test for both gasoline and CNG mode. The validation flow rig test bed, known as steady state flow rig test (SSFR) was then constructed.

Simultaneously, the design and simulation steps were initiated. The CNG mixer was designed, simulated and then analysed. The Star CD software with the finite volume method with SIMPLE algorithm used in this simulation process. Moreover, the swirl device was then designed based on variable geometrical computation. The recommended mixer and swirl were then fabricated. Subsequently, a series of recommended mixer and swirl-device were validated in the SSFR. The final recommended design was then fabricated and introduced into the intake system.

1.6 Thesis Organisation

Chapter 2 presents a literature review of the state of the arts effort relating to advanced intake system for optimum CNG fuelled engine performance. Beginning with the automotive trends in implementing alternative fuels, a problem-map solution in the CNG engine technology was demonstrated. The literature on the flow management in the intake system as a tool to improve the CNG engine performance was elaborated. The factors affecting the development of the optimum mixer and swirl device were reported.

Chapter 3 describes the approach on designing the mixer and swirl device. Starting from the design and with testing the mixers, then analysing the results. The simulation stage was then proceed.

Chapter 4 explains the validation of mixer design. Experimental results on effect of various inlet and outlet angles and number of holes on the specified parameters were presented and discussed.

Chapter 5 depicts a validation process of the mixer and swirl device. Description on the Steady State Flow Rig (SSFR) and the procedures on validating process are presented. The visualisation results were also examined. The operational process of the cooling system for CNG fuel was also explained. The technique in characterised the CNG engine temperature profiles was also presented. The results was then analysed in term of heat rejection to coolant.

Chapter 6 sets up a comprehensive coverage on the methodology to perform an advanced intake system. Detail of experimental design, procedures and instrumentations were demonstrated. Depiction on the data acquisition system with its sensor and its software were also provided.

Chapter 7 demonstrated the results and discussion on the effect of advanced intake system on the engine performance. The indicator diagram, pressure rise inside the cylinder and the ROHR were analysed for various combination of mixer and swirl device.

Chapter 8 is the general conclusions and a description of suggestion for future research.

reduced operational cost on the vehicle. As much of RM 4,306 per year can be saved through implementation of the CNG system.

In the overall, the study has provided a simpler, cheaper and effective alternative to improve the CNG engine performance.

8.2 Recommendations

The advanced intake system in this study can be further improved by focusing on the swirl device that can create turbulent without blocking the air passage into the combustion chamber. A combination studies on intake and combustion system in the CNG engine is a possible option that has potential to further improve CNG engine performance.

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