Design and Development of Natural Gas Injection System in IC Engine

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Abstract—As we are facing the lack of conventional fuels we have to use alternatives. Compressed Natural Gas (CNG) is regarded as one of the most promising alternative fuels, and may be the cleanest fuel for the spark ignited (SI) engine. Its high octane number permits a high compression ratio, thereby leading to higher thermal efficiency, and lower emissions could be released by using CNG. Today, we are using CNG kit for SI engine contains various types of injection systems with ECU (Electronic control unit). Among them direct injection system is latest fuel injection technique used in IC engine. In the SI engine, direct injection (DI) technology significantly increases the engine volumetric efficiency and decreases the need of throttle valve for control purposes. During low load and speed conditions, DI allows engine operation under ultra-lean conditions by realizing the stratified charge. This enables the use of extremely lean air–fuel mixtures, thereby reducing fuel consumption. In this work, the attempt will made to replace this ECU with mechanical devices thereby developing and designing a new direct injection system. After implementing the system with SI engine rate of fuel consumption, performance and emissions will be measured.

Key words: Engine Performance, Compressed natural gas(CNG), Spark ignition, Direct injection

I. INTRODUCTION

It is well known that the fossil-fuel reserves in the world are diminishing at an alarming rate and a lack of crude oil is expected at the early decades of this century. Gasoline and diesel fuel becomes scarce and most expensive. Alternative fuel becomes more conventional fuel in the coming decades for internal-combustion engines. Nowadays, the alternative fuel has been growing due to concerns that the reserves of fossil fuel all over the area are limited. Furthermore the world energy crisis made the fossil-fuel price increases.

Natural Gas (NG) has been found in various locations in oil and gas bearing sands strata located at different depths below the earth surface. NG is a gaseous form of NG was compressed. It has been recognized as one of the promising alternative fuels due to its significant benefits compared to gasoline fuel and diesel fuel. These include reduced fuel cost, cleaner exhaust gas emissions and higher octane number. Therefore, the numbers of engine vehicles powered by NG were growing rapidly. NG is safer than gasoline in many respects. The ignition temperature of NG is higher than gasoline fuel and diesel fuel. Additionally, NG lighter than air and dissipate upward rapidly. Gasoline fuel and diesel fuel will pool on the ground, increasing the risk of fire. NG is nontoxic and will not contaminate groundwater if failed. Advanced NG engines undertake significant advantages over the conventional gasoline engine and diesel engine. NG is a commonly available type of fossil energy. However, the investigation of applying NG as an alternative fuel in engines will be a beneficial activity, because the liquid fossil fuels will be finished and will become scarce and expensive. NG has some advantages compared to gasoline and diesel from the environmental perspective.

There are four methods to inject the NG into the engine cylinder. First type is gas mixer / carburetor injection, second type is the single point injection, third type is multi point injection and fourth type is direct injection.

II. WORKING PRINCIPLE

The existing metering and mixing of the fuel may be accomplished using either a mechanical gaseous fuel mixer or carburetor, or an electronically controlled gaseous fuel metering system. This approach strives to achieve a homogeneous mixture of air and fuel before the air flow splits in the intake manifold. Failure to obtain a homogeneous mixture at this point can cause significant cylinder-to-cylinder variations in the air-fuel ratio. This injection option can be increases emissions and the possibility of knock phenomena. Single point injection is use gaseous fuel injector to mix the gaseous fuel with the intake air in the manifold at one location for all cylinders of the engine. In this case, fuel is injected in a single location much like a gas mixer or carburetor. Single point electronic injection offers the advantage of more precise control of the amount of gaseous fuel entering the intake charge of the engine as well as the economy of using a minimum number of injectors. Multi point injection (MPI) is to inject the fuel into the each cylinder via intake port before intake valve. This system uses one or more fuel injectors for each cylinder intake port of an engine and allows the designer to remove the fuel supply from the air supply area of the intake manifold. Direct injection is to inject the gaseous fuel directly into each combustion chamber of the engine.

III. LITERATURE REVIEW

1) Lin lin et all [1] Shows Opportunities and challenges for biodiesel fuel. Fossil fuel resources
are decreasing daily. As a renewable energy, biodiesel has been receiving increasing attention because of the relevance it gains from the rising petroleum price and its environmental advantages. This review highlights some of the perspectives for the biodiesel industry to thrive as an alternative fuel, while discussing opportunities and challenges of biodiesel. Under the appropriate conditions, increasing biodiesel’s share of the energy mix can contribute to meet important global needs such as reducing GHG emissions, enhancing energy security and, particularly in developing countries, promoting sustainable rural development. As with any new technology or products, biodiesel will require continuous improvement especially in producing cleaner emissions and having less impact on the environment. Further development on the use of the by-product will enhance the economic viability of the overall biodiesel production process.

2) Enrico Mattarelli et al [2] Shows “CFD-3D analysis of a light duty Dual Fuel (Diesel/Natural Gas) combustion engine”. In this paper, a customized version of the KIVA-3V Computational Fluid Dynamic (CFD) code was adopted to analyze the combustion process of a 4-cylinder, 2.8 l, turbocharged HSDI Diesel engine, operating in both Diesel and DF (Diesel and Natural Gas) modes. It was found that DF combustion is soot-less, yields a strong reduction of CO and CO₂, but also an increase of NO. It was also observed that DF, in addition to the elimination of smoke, allows the reduction of CO₂ (about 20%) and CO (from 40 to 80%) emissions.

3) Meghan B. Peterson et al [3] Shows A parametric study of light-duty natural gas vehicle competitiveness in the United States through 2050. The model presented in this paper supported a parametric trade space analysis of the drivers and tradeoffs of NGV adoption and the broader impact of NGVs in the LDV stock. Since model conclusions are highly dependent on the assumption set used, he employed a parametric approach to understand the sensitivity of the model to these assumptions and explored a wide range of values rather than a few scenarios. The major driver of NGV adoption is low natural gas prices and correspondingly high oil prices.

4) M. Akif Ceviz et al [4] Shows Engine performance, exhaust emissions, and cyclic variations in a lean-burn SI engine fueled by gasoline hydrogen blends. The purpose of this study is to investigate the effect of adding small amounts of hydrogen to gasoline air mixtures on the performance and exhaust emission characteristics of a spark ignition engine. Four air fuel ratios are used ranging from stoichiometric to very lean. The amount of hydrogen added is varied from 0% to 2.14%, 5.28%, and 7.74% by volume. The test engine is operated at 2000 rpm, and measurements are made over 1000 consecutive engine cycles. From the experimental observations, the effect of hydrogen addition on (a) thermal efficiency, (b) specific fuel consumption, (c) cyclic variations of the indicated mean effective pressure (IMEP), and (d) emissions of CO, NO and unburned hydrocarbons are analyzed. It can be concluded from these experimental results that lean burn operation of a spark ignition engine using a small amount of hydrogen addition can offer some important advantages with regard to engine performance and exhaust emissions when the engine is carefully designed and air fuel mixture formation strategy is optimized.

5) A.K. Sen et al [5] Shows Analysis of pressure fluctuations in a natural gas engine under lean burn conditions. He have examined the dynamics of the indicated mean effective pressure (IMEP) variations for four different values of the equivalence ratio. For each equivalence ratio, he used a continuous wavelet transform to identify the dominant spectral modes and the number of cycles over which these modes may persist. His results reveal that when the mixture is not so lean, the IMEP undergoes persistent low frequency oscillations together with high-frequency intermittent fluctuations. For leaner mixtures, the low frequency periodicities tend to be less significant, but high-frequency intermittent oscillations continue to be present. When the mixture is made sufficiently lean, high-frequency oscillations become persistent, together with weak low frequency variations reflecting weak combustion.

6) Piotr Bielaczyce et al [6] Shows An assessment of regulated emissions and CO₂ emissions from a European light-duty CNG-fueled vehicle in the context of Euro 6 emissions regulations. Compressed natural gas is a promising fuel type for light-duty vehicles. Euro 5 and 6 emissions standards will reduce emissions to very low levels. A bi-fuel Euro 5 vehicle (CNG/gasoline) was tested on a chassis dynamometer. When operating on CNG the vehicle easily met Euro 6 limits. Carbon dioxide emissions were 24–25% lower when running on CNG.

7) Simona Silvia Merola et al [7] Shows Optical characterization of combustion processes in a DISI engine equipped with plasma-assisted ignition system. The aim of this paper is to improve the understanding of the processes related to the use of a plasma-assisted ignition system and its influence on combustion development. Experiments were performed in an optical spark ignition (SI) engine equipped with the cylinder head and injection system of a commercial gasoline turbocharged engine. The effects of spark plug geometry and different plasma configurations were investigated. UV visible digital imaging was applied; the optical data were correlated to in-cylinder pressure traces and exhaust emission measurements. Significantly higher stability, quantified through the coefficients of variation for the indicated mean effective pressure and flame radius, was obtained using the
alternative ignition system in stoichiometric and lean burn conditions. An improvement in engine performance and pollutant emissions was also achieved. Finally, PAI allowed an extension of lean burn limits inducing improvements in terms of combustion efficiency and stability and reduction of pollutant exhaust emissions.

8) Pradeep et al [8] Shows Scavenging port based injection strategies for an LPG fuelled two-stroke spark-ignition engine. With the optimum air injection timing (12°BTDC) the AI-LPGIND system improved the brake power at all operating conditions due to the increase in the overall air intake of the engine. The AI-LPG-IND system achieved significant reduction in HC emissions than LPG-MI (up to 40%) and LPG-BPI systems (up to 25%) at 25% throttle due to reduced short-circuiting losses. However, the thermal efficiency with AI-LPG-IND was similar to LPG-MI because of slower combustion due to charge stratification. Since the amount of secondary air injected was proportionally low at 100% throttle, improvements were not seen at this condition with AI-LPG-IND system. At 100% throttle, AI-LPG-IND was better than LPG-BPI in terms of thermal efficiency and brake power. The LPGBPI system reduced HC emissions at 100% throttle but the thermal efficiency was lower than other systems.

9) Kyunghyun Ryu [9] Shows Effects of pilot injection timing on the combustion and emissions characteristics in a diesel engine using biodiesel–CNG dual fuel. This experiment utilized a biodiesel pilot injection to ignite a main charge of compressed natural gas (CNG). It is concluded that Injection timing of pilot fuel in dual fuel combustion affects the engine power and exhaust emissions. BSEC of DFC improves with advanced pilot injection timing at low load and with delayed pilot injection timing at high loads. The ignition delay in DFC is 1.6–4.4 CAD longer than that of the diesel single fuel combustion. Smoke is decreased and NOx is increased with advanced pilot injection timing in the biodiesel–CNG dual fuel combustion.

10) Gharehghani et al [10] Shows Experimental investigation of thermal balance of a turbocharged SI engine operating on natural gas. In this study the thermal balance of a turbocharged SI engine operating on natural gas was investigated experimentally. From the results of this study, the following conclusions can be deduced by increasing load and coolant temperature, transferred energy to exhaust increased. Coolant energy percentage decreased by increasing the load and coolant temperature. Gaseous fuel and a turbocharger (TC) lead to 4.5% and 4% more thermal efficiency.

11) Yu Liu et al [11] Shows A study of spray development and combustion propagation processes of spark-ignited direct injection (SIDI) compressed natural gas (CNG). In this study, a visualization experiment system was designed and constructed to investigate the spray and combustion characteristics after the injection start of CNG. The ambient conditions were used to examine their effects on CNG’s spray development process, ignition probability and flame propagation process. The effects of ambient conditions on ignition probability were studied. It is found that high injection pressure leads to a high spray velocity that reduced the ignition probability because of quenching of the flame kernel. High ambient temperature increased the overall energy transferred to the mixture and increased the ignition probability. The effect of ambient pressure on the flame front position was significant, and the flame propagation became slow with increased ambient pressure.

12) Iman Chitsaz at all [12] Shows Experimental and numerical investigation on the jet characteristics of spark ignition direct injection gaseous injector. This paper presents an experimental and numerical study on the jet structure of gaseous fuel injector in spark ignition direct injection engine by Schlieren technique and numerical procedure. We provide the numerical and experimental work on the transient start of injector. Numerical simulation at the initial stage is not in exact agreement with the experiment. Non dimensional tip penetration is located between lines with slopes of 2.625 ± 0.875. Pressure drop at the initial stage is greater than its steady decrease.

13) K.A. Subramanian et al [13] Shows Comparative evaluation of emission and fuel economy of an automotive spark ignition vehicle fuelled with methane enriched biogas and CNG using chassis dynamometer. A vehicle’s emission and fuel economy for methane enriched biogas and CNG were evaluated. No significant change in the vehicle’s fuel economy is observed between both fuels. The vehicle’s emission with enriched biogas meets to BS-IV emission norms. The transient emissions are higher with UDC than EUDC. We found the enriched biogas gives comparable performance and emission like CNG.

14) Asok K. Sen et al [14] Shows Dynamics of cycle-to-cycle variations in a natural gas direct-injection spark-ignition engine. Results were obtained for four compression ratios: CR = 8, 10, 12 and 14, at two engine speeds of 1200 and 1800 rpm. The results reveal that the CCV exhibit multiscale dynamics with fluctuations occurring at different timescales. At the engine speed of 1200 rpm, the spectral power of CCV for CR = 12 was found to be significantly reduced at the different timescales compared to the CCV at other values of CR. At the higher engine speed of 1800 rpm, this reduction was less pronounced.

15) M.I. Jahirul et al [15] Shows Comparative engine performance and emission analysis of CNG and gasoline in a retrofitted car engine. Comparative analysis of the experimental results showed 19.25% and 10.86% reduction in brake power and 15.96% and 14.68% reduction in brake specific fuel
consumption (BSFC) at 50% and 80% throttle positions respectively while the engine was fueled with CNG compared to that with the gasoline. Whereas, the retrofitted engine produced 1.6% higher brake thermal efficiency and 24.21% higher exhaust gas temperature at 80% throttle had produced an average of 40.84% higher NOx emission over the speed range of 1500-5500 rpm at 80% throttle. Other emission contents (unburnt HC, CO, O2 and CO2) were significantly lower than those of the gasoline emissions.

16) Guo-xiu Li et all [16] Shows Nonlinear dynamics of cycle-to-cycle combustion variations in a lean-burn natural gas engine. Applying the nonlinear dynamical system theory methods, so-called phase space reconstruction, Poincare’ section and return map, different ways approaching the characteristics of cycle-to-cycle dynamics of the in-cylinder pressure evolution in the lean burn natural gas engine are investigated and the following conclusions can be drawn. The in-cylinder combustion process in the natural gas engine can be indicated explicitly by phase space, which spanned by derivative coordinates from the in-cylinder pressure series. Poincare’ sections calculated from the corresponding phase spaces of the in-cylinder pressure time series in the natural gas engine show a transition from simple zonal structure to bifurcation and to more erratic structure, which indicates stronger stochastic characteristics of the process as equivalence ratio decreases.

17) Ke Zeng, Zuohua Huang et all [17] Shows Combustion characteristics of a direct-injection natural gas engine under various fuel injection timings. The results showed that fuel injection timing had a large influence on the engine performance, combustion and emissions and these influences became largely in the case of late injection. Over-late injection would supply insufficient time for the fuel–air mixing of the late part of the injected fuel, bringing poor quality of mixture formation and subsequently resulting in the slow combustion rate, the long combustion duration and high HC concentration. However, early injection gave a slight influence on both engine combustion and emissions. There existed an optimum fuel injection timing where the maximum cylinder pressure, the maximum rate of pressure rise and the maximum rate of heat release would get their highest values along with the shortest combustion durations, the shortest heat release duration and more concentrated heat release process closing to the top-dead-centre while maintaining the low level of HC and CO emissions.

18) H.G. Zhang et all [18] Shows Study on the effect of engine operation parameters on cyclic combustion variations and correlation coefficient between the pressure-related parameters of a CNG engine. We test a CNG engine using two methods on setting ignition timing. Trends of COVIMEP versus operation parameters under the two kinds of ignition timing are different. The correlation coefficients are affected by operation conditions. R(pmax, θpmax) and R(pmax, (dp/θ)max) indicate stable, strong linear correlations. R(IMEP, pmax) and R(IMEP, (dp/θ)max) indicate obvious linear correlations in some cases.

19) Idris Cesur et all [19] Shows The effects of electronic controlled steam injection on spark ignition engine. In this study, the effects of steam injection at different injection rates on the evaluations of performance parameters and emissions of a gasoline engine have been investigated. Electronically controlled steam injection method has been used to inject the steam into the engine. The optimum steam ratio has been determined as 20% of fuel mass (S20) in terms of performance and emission parameters. Steam injected gasoline engine has been modeled by using zero-dimensional two-zone combustion model for optimum steam ratio at full load condition. The obtained results have been compared with conventional gasoline engine in terms of performance and NO, CO, CO2, HC emissions. The results of theoretical combustion model agree well with experimental data quite well. In the experimental results, it is seen that the engine torque and the effective power increase up to 4.65% at 3200 rpm, specific fuel consumption reduces up to 6.44% at 2000 rpm. There is 40% average reduction in NO emissions at 2800 rpm and it is 31.5% in HC emissions at 2000 rpm.

20) Mohand Said Lounici et all [20] Shows Investigation on heat transfer evaluation for a more efficient two-zone combustion model in the case of natural gas SI engines. The current study aims to investigate the effect of the choice of both the heat transfer correlation and burned zone heat transfer area calculation method and provide an optimized choice for a more efficient two-zone thermodynamic model, in the case of natural gas SI engines. For this purpose, a computer simulation is developed. Experimental measurements are carried out for comparison and validation. The effect of correlation choice has been first studied. The most known correlations have been tested and compared. Our experimental pressure results, supported for more general and reliable conclusions, by a literature survey of many other studies, based on measured heat transfer rates for several SI engines, are used for correlation selection. It is found that Hohenberg’s correlation is the best choice. However, the influence of the burned zone heat transfer area calculation method is negligible.

21) G. Dellino et all [21] Shows Kriging metamodel management in the design optimization of a CNG injection system. A comparative analysis of different metamodel management strategies has been conducted for a case study devoted to the design of a component of the injection system for CNG automotive engines. The performance assessment, conducted also with a DEA, is provided. On the basis of the computational results...
on the case study, we observe that all metamodel management schemes based on Kriging predictions are able to give accurate approximations. However, schemes with both adaptive or passive metamodel update mechanisms are more suitable to be integrated in the considered optimization process. These conclusions are based on an experimental campaign, in which these techniques have been applied comparing different strategies using different metrics for the accuracy evaluation. An adaptive update strategy based on the approximation error and adopting a best selection rule seems to be the scheme to prefer. This scheme presents a full DEA efficiency and seems more effective in the reduction of the number of calls of the original expensive function and in the overall computational costs saving, giving always accurate models.

IV. CONCLUSION
It is concluded that today Compressed natural gas (CNG) is regarded as one of the most promising alternative fuels, and may be the cleanest fuel for the spark-ignited (SI) engine. Its high octane number permits a high compression ratio, thereby leading to higher thermal efficiency, and lower emissions could be realized by using CNG. In the SI engine, direct injection (DI) technology significantly increases the engine volumetric efficiency and decreases the need of throttle valve for control purposes. During low load and speed conditions, DI allows engine operation under ultra-lean conditions by realizing the stratified charge. This enables the use of extremely lean air–fuel mixtures, thereby reducing fuel consumption. Most of the Light duty vehicles runs on CNG and most IC engines use ECU (electronic control unit) with latest CNG kit. It has some backlog like ECU is less. So, direct injection system is considered to be a performance and emissions. ECU is less. So, direct injection system is considered to be a

V. ACKNOWLEDGEMENT
A journey is easier when you travel together. Interdependence is certainly more valuable than independence. I would like to express our gratitude to all those who gave me the possibility to complete the work. I deeply indebted to my guide DR. VIKAS PATEL & MR. HIREN PATEL whose help, stimulation, suggestion and encouragement helped me in all the time and writing of this report.

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