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Investigation of cold-start emission control strategy for a bi-fuel hydrogen/gasoline engine

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ABSTRACT

For spark-ignited gasoline engine, cold start emission of hydrocarbon (HC) and carbon monoxide (CO) is a long-term concern due to a large portion of HC and CO emitted during cold start period. Starting by hydrogen or adding a fraction of hydrogen can greatly reduce the engine cold start emissions of HC and CO due to the carbonless and excellent combustion characteristics of hydrogen. However, the higher combustion speed and temperature of hydrogen tend to cause more NO_x emissions. Therefore the amount of hydrogen addition to conventional fuel should be optimized at different engine operating conditions. In this paper, a spark ignited gasoline engine was retrofitted to a hydrogen gasoline flexible fuel engine by adding a set of hydrogen injection system, and the engine can be fueled with gasoline, hydrogen or both. An electronic control system was developed and applied to control the injection timings and durations of hydrogen and gasoline. In order to reduce cold start emissions of HC and CO, the engine started with hydrogen and then changed to run on gasoline with hydrogen addition or on pure gasoline to avoid high NO_x generation. The basic composition of the control system was introduced and the cold-start emission control strategy for the hydrogen gasoline flexible fuel engine was investigated. And finally the emission of the vehicle running on the hybrid hydrogen and gasoline fuel mode was tested over the New European Driving Cycle (NEDC), and compared with that of the original gasoline car. The experimental results showed that the cold start emissions of HC and CO greatly decreased when the vehicle engine operating on hybrid hydrogen gasoline mode.

Introduction

In recent years, the toxic exhaust emissions from automobiles have drawn more and more attention due to their negative effects on humans' health and environment. For spark-ignited gasoline engines, the problem of cold start HC and CO emissions is a long-term concern due to a large portion of HC and CO pollution emitted during the cold start period. Dardiotis et al. [1] investigated the gaseous emission performance of thirteen late technology vehicles over the NEDC driving cycle, at 22 °C and −7 °C test cell temperatures. The test results showed that CO and HC emissions of gasoline vehicles

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increased from 2.3 to 11.3 times at −7 °C over the Urban Driving Cycle (UDC), but still remaining below the current legislative limits by 45% and 65% respectively. Weilenmann et al. [2] studied the cold-start emissions of modern passenger cars at different low ambient temperatures, and pointed out that during real-world driving, the majority of the CO and HC emissions of gasoline cars were discharged within cold-start phase. In low ambient temperature conditions, large amounts of regulated and unregulated gaseous pollutants will be emitted during a gasoline engine cold start, in particular within the initial minutes before the catalyst reaches its working temperature. Brigitte et al. [3] studied the effects of fuel metering on hydrocarbon emissions within the initial few cycles after cold-start, and found that the non-uniformity of air-fuel mixture and the deposit fuel in the cylinder during cranking greatly increases HC emissions. Besides, spark plug wetting would also result in misfire and heavier HC emissions. Quader [4] investigated the cold starting of one single cylinder engine and found that the fuel supply equivalence ratio for gasoline engine cold-start varied from 5.6 at −29 °C to 1.1 at 21 °C. Sampson and Heywood [5] studied the fuel behavior in the spark-ignition engine start-up process and also concluded that about more than five times of the fuel needed to be injected during the first one or two cycles comparing with a hot engine start. This means that nearly 80% of the injected fuel will deposit as the fuel film during the first one or two cycles, afterwards, the formation and evaporation of the fuel film exist at the same time, and make the precise control of fuel delivery very difficult during cold starting and warm-up. Due to poor evaporation of the injected fuel and the existence of fuel film, spray droplets is introduced into the cylinder in the first several cycles, a large portion of engine-out HC and CO will be emitted, especially within the initial several minutes before the catalyst reaches its optimal operating condition [6–8].

As a carbonless alternative fuel, hydrogen has shown a bright and promising future as internal combustion engine fuel due to its extremely good combustion characteristics, and can achieve very satisfactory performance in engine applications that may be superior in many aspects to those with conventional fuels [9–12]. However, the pure hydrogen engines are not practical due to the inconvenience of hydrogen storage, supply and their abnormal combustion tendency. For hydrogen engine, inlet manifold backfire and other abnormal combustion phenomena tend to occur because of the low ignition energy, wide flammability range and rapid combustion speed of hydrogen. Liu et al. [13] studied the effect of injection timing and equivalence ratio on mixture formation in a manifold injection hydrogen engine by Computational Fluid Dynamics (CFD) simulation and validated the simulation results by engine experiment, and concluded that the manifold injection hydrogen engine has limited injection end timing in order to prevent backfire in the inlet manifold. Szwaja et al. [14] examined the combustion knock characteristics in a port-injected, spark-ignited, single cylinder cooperative fuel research (CFR) engine fueled with hydrogen and gasoline, and found that knock detection techniques used for gasoline engines, can be applied to a hydrogen engine with appropriate modifications to improve the reliability of hydrogen engine while allowing the engine to be operated closer to combustion knock limits to increase engine performance. Ganesh et al. [15] experimentally studied the performance of a hydrogen engine and found that the power output of the hydrogen engine was 20% lower than that of the gasoline engine. Though HC and CO emissions of the pure hydrogen-fueled engine were negligible, NO_x emission was almost four times higher than that measured with gasoline fueling.

On the other hand, adding a portion of hydrogen to a traditional gasoline engine allows better in-cylinder combustion due to wider flammability, lower ignition temperature and higher burning speed of hydrogen, hence better performance of gasoline engines with hydrogen assistance was found in previous studies [16–18]. Du et al. [19] investigated the combustion and emission characteristics of a lean burn gasoline engine with hydrogen direct-injection under the conditions of the excessive air ratio from 1.0 to 1.5. With the increasing hydrogen addition fraction (0%–11.09%), the combustion speed increases, mean effective pressure and thermal efficiency were improved, while HC and CO emissions decreased and NO_x emissions increased. And the engine power performance improved because hydrogen direct injection does not reduce volumetric efficiency. Mohammed and Rahman [20] compared the performance of hydrogen fuel with other fuels and investigated the power and performance penalty when adding different fractions of hydrogen fuel to the other fuels by the prediction model, and found that adding small controllable mass factions of hydrogen (<10%) to gasoline enhances the burning velocity and combustion process in the low speed range. However, a small reduction in the output power (<6%) was documented. Zhou et al. [21] investigated the combustion, performance, regulated and unregulated emissions of a diesel engine with naturally aspirated hydrogen addition at the engine speed of 1800 rev min^{-1} under five engine loads. Hydrogen was added to provide 10%, 20%, 30% and 40% of the total fuel energy. Experimental results showed that engine performance can be improved from medium to high loads, the peak heat release rate increased, leading to improvement in the brake thermal efficiency and the brake specific fuel consumption. Hydrogen addition has the potential to reduce the HC, CO, CO_2, PM emissions (mass and number) and unregulated emissions. The effect of hydrogen addition on NO_x emission is positive at low engine load and negative at high engine load. Saravanan and Nagarajan [22] also carried out an experimental investigation on using hydrogen in the dual fuel mode in a diesel engine system by using electronic control unit (ECU) to control the injection timings and injection durations of hydrogen injection. Compared to diesel operation, experimental results showed that the brake thermal efficiency increased by 15% at 75% load, the NO_x emission was only increased by 1–2% at full load, and the emissions of CO, CO_2 and smoke decreased in dual fuel operation.

As mentioned above, hydrogen addition is one of the most promising methods to utilize hydrogen energy for the internal combustion engine to improve the combustion and emission performances. Most of the researches focus on the optimal control of the proportion of hydrogen addition, the main part of the blended fuel is still gasoline or diesel. For a port-injection gasoline engine with hydrogen addition, a rich air fuel mixture must be supplied during cold start to compensate