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Realizing the part load control of a hydrogen-blended gasoline engine at the wide open throttle condition

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ABSTRACT

This paper proposed a way for realizing the load control of a hydrogen-blended gasoline engine running at the wide open throttle (WOT) condition through lean combustion. The engine performance of the original gasoline engine and a 3% hydrogen-blended gasoline engine running at the WOT and lean conditions under various loads at a constant engine speed of 1400 rpm was compared. The experimental results showed that because of the reduced residual gas fraction and throttling loss, brake thermal efficiency of the 3% hydrogen-blended gasoline engine running at the WOT and lean conditions was obviously higher than that of the pure gasoline engine. The 3% hydrogen-blended gasoline engine running at the WOT and lean conditions produced much lower particulate and CO emissions than the original gasoline engine. Besides, NOx emissions at part load conditions were also reduced for the 3% hydrogen-blended gasoline engine running at the WOT and lean conditions.

Introduction

With concerns on the nation energy safety and environmental protection, researches on alternative fuels for internal combustion engines have gained more and more attentions. Compared with fossil fuels, hydrogen is demonstrated to be a good energy carrier that can be produced by kinds of ways [1–3]. Since the hydrogen can be produced from water electrolysis and the combustion of hydrogen generates water, the hydrogen is also seen as a clean and renewable fuel for internal combustion engines. Thus, many investigations have been dedicated to study the performance of hydrogen engine engines [4–6]. According to Vancoillie [7], the highest brake thermal efficiency of hydrogen engines could reach 45%, which is 40% higher than that of the gasoline engines. Moreover, as the hydrogen has a wide flammability, the pure hydrogen engines could run with lean mixtures to obtain higher thermal efficiency even at the idle condition [8]. However, because of the high flame temperature, the pure hydrogen engines tend to exhaust more NOx emissions than the gasoline engines [9]. Besides, the high flame temperature, low activation energy and wide flammability of hydrogen also elevate the possibility of the occurrence of abnormal combustion in pure hydrogen engines [10–14], such as backfire, pre-ignition and knocking. Furthermore, the high hydrogen

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consumption rate of hydrogen engines is also an enemy to the limited hydrogen infrastructure distribution. Thus, these problems have to be shot before the pure hydrogen engine meets the market.

Compared with the pure hydrogen engine, adding small amount of hydrogen to the fossil fuel-powered engines is also capable of improving the engine fuel economy and reducing harmful emissions from vehicles [15–17]. Besides, since the hydrogen consumption of hydrogen-blended engines is obviously lower than that of the pure hydrogen engines, an onboard hydrogen electrolysis generator is generally able to produce enough hydrogen for engine application [18,19]. Thus, the hydrogen-blended engines seem to be a feasible way for improving the engine combustion and emissions performance at present. Huang et al. [20–25] conducted a series of investigations to learn the effect of hydrogen addition on the combustion characteristics of natural gas. The results confirmed that the fuel burning speed could be effectively enhanced by hydrogen addition. Besides, the photos taken in the constant combustion vessel showed that the flame structure and position became more stable after the hydrogen blending. It was also demonstrated that the addition of hydrogen availed stimulating the formations of O, H and OH radicals which benefited the complete combustion of the fuel-air mixtures. Simio et al. [26] converted an engine used on bus to be fueled with hydrogen–natural gas blends. The results demonstrated that the well-to-wheel CO_2 emission was reduced for the hydrogen-blended natural gas engine, but the engine torque output was slightly decreased after the hydrogen addition due to the low volume energy density of hydrogen. Ma et al. [27–31] investigated the performance of a hydrogen-blended natural gas engine at lean conditions. The test results indicated that the addition of hydrogen resulted in the enhanced engine thermal efficiency, reduced cyclic variation, extended flammability and shortened combustion duration for the natural gas engines at lean conditions. Park et al. [32–34] conducted investigations on heavy-duty spark-ignition engines to explore the effect of hydrogen addition on the combustion and emissions characteristics of compressed natural gas engines. The results confirmed that the relevant excess air ratio of the engine lean burn limit could be extended to 1.8 by adding a supercharging system. Their experiments also demonstrated that increasing compression ratio and adopting rich mixture may reduce the effect of hydrogen addition on improving the engine thermal efficiency. There are also some investigations reported the effect of hydrogen addition on the performance of liquid fossil fuel engines. Ji and Zhang et al. [35] found that the addition of hydrogen also benefitted improving thermal efficiency of methanol engines. Besides, the constant volume combustion efficiency and brake mean effective pressure of the methanol engine at lean conditions were improved with the hydrogen blending. Ji and Wang et al. [18,36–39] proposed an optimal control strategy for the hydrogen-blended gasoline engine. According to the strategy, the engine overall HC, CO and NOx emissions during the driving cycle were reduced obviously. Besides, their investigations also showed that the engine NOx emissions during the idle condition could be reduced after the hydrogen addition.

All in all, there are many investigations demonstrating that the addition of hydrogen avails improving the engine fuel economy and reducing toxic emissions through enhancing the combustions process. Besides improving the fuel combustion quality, reducing the engine pumping loss is also a feasible way for further enhancing the engine performance. Generally, the engine pumping loss can be decreased through charging the engine or running a natural-aspirated engine at the wide open throttle (WOT) condition. Fontana et al. [40] found that the engine thermal efficiency of the spark-ignition engines can be improved significantly by running the engine at WOT condition. However, for the traditional gasoline engines, because of the adoption of stoichiometric fuel–air mixtures, the engine load is hard to be adjusted at the WOT condition. Thus, ways for adjusting the engine load at the WOT condition has to be proposed. Xie et al. [41] tried to control the load of a methanol engine by changing the exhaust gas recirculation (EGR) ratio and spark timing at the WOT condition. The test results showed that the engine performance at high loads can be improved through this strategy, but the adoption of EGR tends to cause the increased brake specific fuel consumption at low loads. Ma et al. [42] investigated the performance of a hydrogen-blended CNG engine at the WOT condition. It was found that the addition of hydrogen could improve the engine indicated thermal efficiency at the lean and WOT conditions. Besides, because of the wide flammability, low ignition energy and high burning velocity of hydrogen, the heat release rate was enhanced with the addition of hydrogen.

However, controlling the load of a hydrogen-blended gasoline engine at the WOT condition has never been reported publicly before. This paper compares the load characteristic of a typical gasoline engine with the throttle controlled load and a hydrogen-blended gasoline running at the WOT condition with lean combustion controlled load. Since the application of EGR could result in the decreased thermal efficiency [41], lean combustion is used to control the load of a hydrogen-blended gasoline engine at the WOT condition. Compared with EGR, the adoption of lean combustion avails increasing the oxygen content in the cylinder. This benefits the combustion of the fuel–air mixtures and improves the post oxidation of HC and CO emissions. Besides, for the engines which are not equipped with an EGR system, the application of lean combustion can be simply realized by reprogramming the engine electronic control unit without modifications on the engine intake and exhaust systems. During the test, the engine was run at a constant speed of 1400 rpm with various loads. The combustion and emissions characteristics of a traditional gasoline engine fueled with the stoichiometric fuel–air mixtures at the throttled conditions and a hydrogen-blended gasoline engine fueled with lean hydrogen–gasoline–air blends at the WOT condition were compared.

Experimental setup and procedure

Experimental setup

The engine used in this test is a naturally-aspirated commercial gasoline engine manufactured by Beijing Hyundai Motors. The engine has a displacement of 1.6 L, a rated torque of 143.28 Nm at 4500 rpm and a rated power of 82.32 kW at