INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2017) 1–7

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/he

Improving the combustion performance of a gasoline rotary engine by hydrogen enrichment at various conditions

Teng Su, Changwei Ji, Shuofeng Wang, Xiaoyu Cong, Lei Shi*

College of Environmental and Energy Engineering, Key Laboratory of Beijing on Regional Air Pollution Control and Collaborative Innovation Center of Electric Vehicles in Beijing, Beijing University of Technology, Beijing, 100124, China

A R T I C L E I N F O

Article history:
Received 15 September 2017
Received in revised form
23 November 2017
Accepted 30 November 2017
Available online xxx

Keywords:
Combustion
Hydrogen
Gasoline
Rotary engine

A B S T R A C T

The combustion process within the cylinder directly influences the thermal efficiency and performance of the engines. As for the rotary engine, the long-narrow combustion chamber prevents the mixture from fully burning, which worsens the performance of the rotary engine. As a fuel with excellent properties, hydrogen can improve the combustion of the original engine. In this paper, improvements in combustion of a gasoline rotary engine by hydrogen supplement under different operating conditions were experimentally investigated. The experiment was conducted on a modified hydrogen-gasoline dual-fuel rotary engine equipped with an electronically-controlled fuel injection system. An electronic control module was specially made to command the fuel injection, excess air ratio and hydrogen volumetric fraction. Integral heat release fraction (IHRF) was employed to evaluate the combustion of the tested engine. The tested engine was first run at the idle speed of 2400 rpm and then operated at 4500 rpm to investigate the combustion of the hydrogen-blended gasoline rotary engine under different hydrogen volume fractions, excess air ratios and spark timings. The testing results demonstrated that the combustion of the gasoline rotary engine were all improved when the hydrogen was blended into the chamber under all tested conditions.

Introduction

Differing from the conventional reciprocating engine, the rotary engine profiles are based on a two-lobed epitrochoid and its inside envelope, which become the housing bore and rotor profiles, respectively [1–3]. The rotor design has three apexes that maintains contact with the housing throughout the planetary rotation. The rotary engine is a promising alternative to the conventional reciprocating engine in general aviation aircraft, lawn mower, sporting car, various stationary and mobile applications [3–5] because of its high power-to-weight ratio, large specific power output at the high allowable engine speed, simple and compact design [6–10] resulting from less moving parts, multifuel applicability, and low noise and vibration levels [11–14]. However, the compressed and irregular working chamber of the rotary engine and the low burning velocity of fossil fuel result in poor combustion and high unburnt hydrocarbon [15,16]. This indicates that the combustion within the chamber of the rotary engine starves for further improvement. Therefore, the exploration aiming at improving the combustion efficiency of the rotary engine has significant practical value and theoretical significance.

* *Corresponding author.*
E-mail address: chwji@bjut.edu.cn (C. Ji).
https://doi.org/10.1016/j.ijhydene.2017.11.175

Please cite this article in press as: Su T, et al., Improving the combustion performance of a gasoline rotary engine by hydrogen enrichment at various conditions, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.11.175

Nomenclature

CFD	Computational fluid dynamics
IHRF	Integral heat release fraction
IECM	Integrated electronic control module
AC	Alternating current
RON	research octane number
MAP	Manifolds absolute pressure (kPa)
CA	Crank angle
BTDC	Before top dead center
α_{H_2}	Hydrogen volume fraction (%)
λ	Excess air ratio
V_{H_2}	Hydrogen volume flow rate (L/min)
V_{air}	Air volume flow rate (L/min)
ρ_{H_2}	Density of hydrogen at standard state (g/L)
ρ_{air}	Density of air at standard state (g/L)
$AF_{st,gasoline}$	Stoichiometric air-to-fuel ratio of gasoline ($AF_{st,gasoline} = 14.6$)
AF_{st,H_2}	Stoichiometric air-to-fuel ratio of hydrogen ($AF_{st,H_2} = 34.3$)
$m_{gasoline}$	Gasoline mass flow rate (g/L)

Recently, a lot of attempts have been done to improve the combustion of the rotary engine. Hasegawa et al. [17] used laser light sheet method with Schlieren method to explore the air-fuel mixture formation inside the combustion chamber of a rotary engine. The results indicated that the airflow inside combustion chambers of the rotary engine was affected by the intake pressure. Setting the recess close to the L-side induced the counter clockwise vortex on the L-side instead of the clockwise vortex dominating the center of the combustion chamber. The combustion lean limit was improved with the state of the L-side stratification. The combustion chamber pressure computed with a three-dimensional model was compared with the measured one in a natural gas rotary engine by Abraham et al. [18,19]. It was found that the pre-combustion spatial distribution of the turbulence diffusivity strongly influenced the entire combustion event. It was also shown that the laminar conversion time became dominant as flames approach walls, thus slowing down their propagation rate. Kawahara et al. [20] used the *in situ* laser infrared absorption method with a newly developed optical spark plug sensor to investigate the fuel concentration near the spark plug in a commercial rotary engine. The developed infrared spark plug sensor measured the fuel concentration around a spark plug in a commercial rotary engine quantitatively with high temporal resolution. The magnitude of the inhomogeneity decreased throughout the compression stroke. A strong correlation between the fuel concentration measured with the spark plug sensor and the combustion characteristics during the initial combustion period was observed. The initial combustion was faster when the conditions was slightly richer than stoichiometric near the spark plug. Yamada et al. [21] developed a multi-dimensional simulation inside the combustion chamber to improve the combustion efficiency, gas exchange and stable ignition. A commercial computational fluid dynamics (CFD) software, FLUENT, was applied by Jeng et al. [22] and a two-dimensional model was constructed to investigate the influence of fuel type and recess size on the performance of a rotary engine. The outcomes manifested that decreasing the recess size was beneficial to building up the pressure in the working chamber before ignition, and thus higher pressure in the burning stage resulted in higher power output. In addition, Pan and Fan [10–13] investigated ignition position and ignition timing, injection strategy, pocket shape and ignition slot locations on mixture formation and combustion process in a port injection natural gas rotary engine using multi-dimensional software ANASYS Fluent. They found that the proper ignition position and timing, optimized pocket shape and ignition slot location and the appropriate injection strategy can help the natural gas rotary engine gain the improved combustion and engine performance. Pan and Fan [14] also declared that hydrogen addition can significantly increase the intermediate OH and the peak pressure of the natural gas rotary engine, which meant that the combustion was improved by supplying hydrogen. It was told that adding hydrogen into the original engine as additive can effectively improve combustion within the chamber.

Beyond those have been mentioned above, another feasible way for improving the combustion is to improve the physicochemical properties of fed fuel of the engine [23–26], which needs few modifications in engine configuration. The correlational studies have been widely conducted, especially those focusing on adding hydrogen into the original fuel to improve the fuel characteristic [24–29]. This is because hydrogen has many outstanding fuel properties [30–34] that can enhance the mixture homogeneity and turbulent flow. The flame position and structure of hydrogen at initial combustion stage is more stable than those of the traditional fossil fuels [18,23,35–40]. Huang et al. [41–44] conducted a series of experiments to study the effect of hydrogen enrichment on combustion of the natural gas. He found that hydrogen enrichment could improve the combustion of the original natural gas-air mixture in the spark ignition engine or constant volume vessel.

However, although there have been some literatures focusing on the combustion process and characteristic of the conventional reciprocating engines, publications concentrated on combustion (especially IHRF) of the hydrogen-blended gasoline rotary engine have not been publicly reported. As the chamber design and operating cycle of the rotary engine are different from reciprocating engine, hydrogen addition could differently affect the heat release and combustion process of the gasoline rotary engine. And combustion process highly affects the engine efficiency and emissions of the rotary engine. Therefore, there is a need to experimentally study the combustion characteristic of the hydrogen-gasoline rotary engine. The present paper aims to explore the combustion of a hydrogen-gasoline rotary engine under various testing conditions.

Experimental setup and procedure

Experimental setup

A naturally aspirated, port fuel injection, side-ported rotary engine is employed as the research object. The schematic diagram of rotary engine can be found in Fig. 1 in References

Please cite this article in press as: Su T, et al., Improving the combustion performance of a gasoline rotary engine by hydrogen enrichment at various conditions, International Journal of Hydrogen Energy (2017), https://doi.org/10.1016/j.ijhydene.2017.11.175