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Effect of spark timing on performance of a hydrogen-gasoline rotary engine

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This paper aimed to study the effect of spark timing on performance of a hydrogen-gasoline dual-fuel rotary engine. For this aim, a modified rotary engine equipped with a dual-fuel port injection system was developed. An electronic management module (ECM) was specially made to command the fuel injection, excess air ratio and hydrogen volumetric fraction. In this study, the engine was operated at 4500 rpm with a manifold absolute pressure (MAP) of 35 kPa. Hydrogen volumetric percentage of total intake was kept at 0%, 3% and 6%, severally. When the hydrogen volumetric percentage was changed, the gasoline fraction was also adjusted to keep the mixture at the stoichiometric. For a specified hydrogen volumetric fraction, the ignition timing was varied from 24 to 42 °CA BTDC (before top dead center) with a fixed interval of 2 °CA. Experimental results showed that for a specific hydrogen volumetric percentage, the peak combustion pressure and chamber temperature were increased, brake thermal efficiency was first increased and then decreased with the increase of spark advance. Advancing spark timing caused the increased flame development period, the decreased flame propagation period and exhaust temperature. Cyclic variation was initially weaken and then deteriorated after raising spark advance. HC and NOx emissions were reduced after retarding spark timing. Spark timing had little effect on CO emission.

1. Introduction

With the energy crisis and environmental pollution, developing more efficient and environmental-friendly vehicles such as hybrid vehicles and pure electric vehicles have been a target for almost all automobile manufacturers [1–3]. However, the application of hybrid and pure electric vehicles are still unsatisfactory because of the limited range [2–6]. Range extender for battery electric vehicles is a feasible means to extend the vehicles range. Since modern vehicles are generally compact and comfortable, the extender should be light, simple and high power-density. Possessing advantages of higher power-weight density, more compact and less vibration when compared to reciprocating engines, gasoline rotary engines (GREs) are applied in hybrid vehicles powerplant or prospectively as a range extender for pure electric vehicles [6,7]. However, the operation and combustion geometry of GRE are different from the reciprocating engines [7–9]. The crescent-shaped combustion chamber makes the GRE endure high ratio of surface-to-volume (S/V). The excessively high S/V ratio would increase the quenching effect as well as the heat transfer from combustion chambers to rotors and walls [9,10]. Besides, the combustion chamber of GRE is divided into leading and trailing sides, which is bounded by the top dead center (TDC) position. Flame propagation is accelerated more usefully for the leading sides than for the trailing sides, due to the rotors rotating and squish flow [7]. Moreover, the small quenching distance and low combustion velocity of gasoline deteriorate the combustion process of GRE. The lower efficiency and high emissions of GRE are mainly attributed to the above-mentioned factors. GRE fuel consumption and emissions hardly meet the related standards regulations and these would limit its use in vehicles today. These drawbacks are confirmed to be eased by improving the combustion process [7,11]. Improvement in fuel economy and emissions could be realized by means of improving fuel properties for spark-ignited (SI) engines. Since hydrogen has many outstanding properties and characteristics [12–15], excellent performance of hydrogen engine was obtained by Yang et al. [16,17]. On the other hand, adding hydrogen into the fossil fuel could improve the combustion of basic fuel. Huang et al. [18–21] studied the effect of hydrogen addition on the laminar characteristics of hydrogen-enriched natural gas mixture flame in a constant-volume vessel. PREMIX code of CHEMKIN II program with GRI 3.0 mechanism was also used corporately in the study. They found that supplying hydrogen into natural gas

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effectively increased the mixture laminar burning velocity. Initial and main combustion durations were simultaneously reduced when hydrogen was added into natural gas. And the ascended concentrations of radicals, such as O, H and OH was found in the mixture flame. Huang et al. [22,23] also studied the characteristics of laminar premixed mixture of methane-hydrogen-air. Laminar burning velocity and mixture flame temperature as well as chemical reaction velocity were increased with the increase of hydrogen fraction, due to the increased concentrations of O, H and OH. Beyond that, Huang et al. [24–29] carried out a series of experimental studies on a SI engine fueled with natural gas-hydrogen blends. The outcomes showed that performance of natural gas SI engine was improved when hydrogen was introduced into natural gas.

As hydrogen enrichment could improve the combustion process of original fuel, some investigators also added hydrogen into the basic fuel to study the performance of SI engines fueled with hydrogen-blended mixture. Park et al. [30–32] carried out experiments to explore hydrogen enrichment on performance of methane engines. The test results showed that hydrogen addition contributed to the improved engine performance. Ji and Wang [33,34] experimentally studied the impact of hydrogen enrichment on combustion and emission characteristics of a hydrogen-gasoline SI engine. The investigations demonstrated that hydrogen enrichment was useful in raising thermal efficiency and peak temperature, reducing combustion duration and engine cycle-by-cycle variation. Carbon-based emissions were mitigated after enriching hydrogen.

The spark timing, a very important operating parameter for SI engines, determines the initial combustion and thermal condition during the combustion [35,36]. If the spark event occurs too late, the work done by the burned mixture on the piston during the expansion stroke is reduced. Furthermore, incomplete combustion mixture is increased when the exhaust stroke begins [35,36]. Conversely, if the mixture is ignited too early, the pressure rise and work done before the end of compression stroke will be increased. Also, knocking tends to occur more easily with early ignition. Therefore, the sparking timing becomes a critical factor of obtaining enhanced fuel efficiency and decreased emissions [35,36]. According to Ji and Wang's experimental investigation about the relationship between spark timing and performance of a hydrogen-gasoline dual-fuel engine [37], it could be found that indicated mean effective pressure (IMEP) first increased and then decreased when spark was advanced. Flame development period increased, however, flame propagation period decreased with the increase of spark advance. Furthermore, spark timing had little influence on CO emission. HC and NOx emissions were both reduced after retarding spark timing, due to the increased post oxidation and dropped peak chamber temperature, respectively. Ma et al. [38] carried out experiment on a SI engine fueled with hydrogen-compressed natural gas (HCNG), the results showed that indicated thermal efficiency was dropped when ignition timing was changed from the maximum braking torque spark timing.

The above descriptions provide a detailed review on the impact of hydrogen enrichment on performance of various fuels engines, such as hydrogen-gasoline [36,37], hydrogen-natural gas [38] and hydrogen-ethanol engines. However, limited publications have concentrated on the effect of spark timing and hydrogen enrichment on the performance of GRE. Thus, there is a strong motivation to investigate the effect of hydrogen enrichment on enhancing the performance of a GRE at different sparking timings. In this paper, an experiment was introduced to study the effect of spark timing on combustion and emissions characteristics of a hydrogen-gasoline rotary engine (HGRE) at part load and stoichiometric conditions.

2. Experimental setup and procedure

2.1. Experimental setup

A commercial single-rotor GRE with a displacement of 0.16 L is used as the tested engine, whose schematic diagram and basic specification are shown in Fig. 1 and Table 1, respectively. Before the research, the GRE was modified to be a HGRE through adding an electronic ignition module, a gasoline and hydrogen mixture supplying system and an ECM. Fig. 2 shows the intake pipe after modifying. The gasoline and hydrogen are injected independently according to the control signal supervised by the ECM, which is connected with a calibration computer. The real-time control of the excess air ratio (λ) and hydrogen volumetric percentage are realized by adjusting the injection flow of hydrogen and gasoline. The spark module is also governed by the ECM.

Fig. 3 demonstrates the sketch of experimental system. The GRE flywheel is connected with an AC electrical dynamometer to adjust and record the online speed and torque. A gasoline flow meter is used in the oil supply system to determine the gasoline mass flow rate. A thermal mass flow meter installed before the throttle is used to show the air flow rate. A high-accuracy thermal volumetric flow meter is applied to monitor the hydrogen flow rate. A high-accuracy pressure transducer cooperated with a spark plug is employed to capture the current time pressure. A self-made 23 (24–1) teeth trigger wheel mounted on the engine's output shaft and a photoelectric magnetic sensor inserted into the aluminum housing over against the trigger wheel are used cooperatively to obtain the crank angle signal. The crank angle signal is synchronized with the pressure trace. A combustion analyzer is used to record the pressures and crank angles, which are further processed

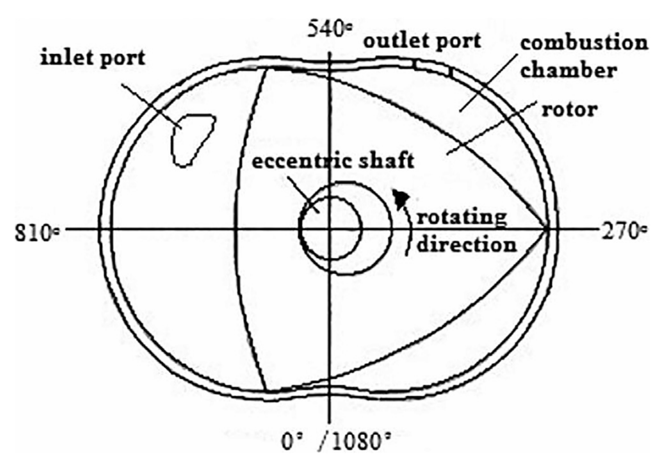

Fig. 1. Schematic of the tested rotary engine.

Table 1
Z160F gasoline rotary engine specifications.

Specifications	Value
Generating radius/mm	69
Width of rotor/mm	40
Displacement/L	0.16
Compression ratio	8.0
Eccentricity/mm	11
Power output	3.8 kW/4200 rpm
Intake timing/(°CA)	75 BTDC, 64 ABDC
Exhaust timing/(°CA)	62 BBDC, 70 ATDC