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RESEARCH ON THE PISTON DYNYMICS OF A FREE PISTON GASOLINE ENGINE LINEAR GENERATOR UNDER VARIOUS IGNITION TIMINGS

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ABSTRACT

The free-piston engine linear generator (FPELG) has the high thermal efficiency and simply structure. Thus, it is investigated by many researcher groups. However, many researchers main focused on the FPELG characteristics from the simulation results. Therefore, in the paper, the piston dynamics and the combustion characteristics of the gasoline FPELG from the experimental results were investigated. The experimental results demonstrated that the piston TDC is 32.2mm, the peak velocity is 5.3m/s and the frequency is 32.8Hz. And it is found that the optimal ignition timing of the free-piston engine is between 27.5 mm and 28 mm.

Keywords: Free piston gasoline engine, linear generator, piston dynamics, various ignition timings

1. INTRODUCTION

Because the limited fossil energy reserves in the earth and the stringent the emission standard was carried out, the global researchers not only optimize the currently energy conversion device, but also develop the new equipment [1]. The free-piston engine linear generator (FPELG) is one of the typical representatives, which unique operation characteristics and great performances [2]. The FPELG combines the free-piston engine and the linear generator directly. The FPELG operation principle is that the high-temperature and high-pressure gas produce after the combustion and heat-release process in the cylinder of the free-piston engine, then they drives the piston assembly and the generator moving magnet rod (they are named the mover) to reciprocate, and then the linear generator converts parts of the moving magnet rod kinetic energy into electricity [3]. According to the operation principle, it is found that the FPELG has many advantages, such as the high thermal efficiency, the low energy conversion-chains, the multi-fuel and the combustion mode feasibility. Hence, the FPELG as a new energy conversion device is researched in the world, according to the previous literature.

Researchers at West Virginia University focused on the performances of the FPELG since the 1998. The experimental results showed the prototype during the generating process could achieve 316 W output power and the equivalent speed was 1426 rad/min [4]. Researchers at Czech Technical University in Prague developed the FPELG in 2003 and 2007 respectively. The results demonstrated that the prototype operation frequency was 27Hz, the maximum output power was 650W, and the system generating efficiency was only 10% [5]. Researchers studied the FPEC (Free piston Energy Converter) from 2002, based on the European Union energy project. The results showed that the fuel consumption of the FPEC was decreased 13%, compared with the conventional ICEs [6]. Siqing Chang at Nanjing University of Science & Technology developed a four-stroke spark-ignition FPELG. The results demonstrated that the FPELG prototype output was about 2.2kW, and the thermal efficiency was above 32% [7]. Toyota central R&D Labs Inc. started to carry out research on the FPELG since 2013. The results demonstrated that the output power of 10kW, and the engine thermal efficiency was up to 42% in the PCCI mode [8]. Roskilly and Boru Jia *et al*. at Newcastle University investigated the FPELG by the simulation model and experimental prototype. The results showed that the parameters of the FPELG were highly coupled and in a nonlinear relationship [9]. Compared with the conventional ICEs, the FPELG has many advantages, such as the thermal efficiency, the NOx emissions. Zhengxing Zuo at Beijing Institute of Technology have

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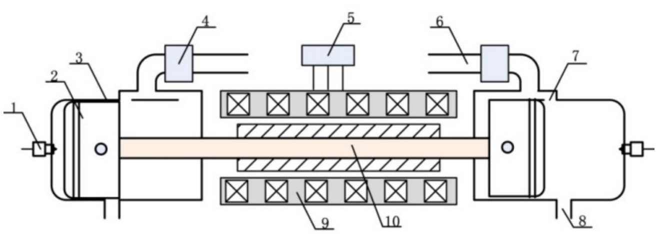
designed two types of the FPELG respectively, namely spark ignition FPELG and compression ignition FPELG [10]. The piston dynamics, the combustion characteristics, the performances and control strategies of the FPELG were researched by coupling the zero-dimensional model and the three-dimensional model.

According to the discussions above, it is found that many researchers had done much work of the PFELG. However, few researchers studied on the piston dynamics and the combustion characteristics of the FPELG by the experimental results. Therefore, this paper aims to research on the piston dynamics of the FPELG during the stable generating process from the experimental data. As for the spark ignition engine, the ignition timing is a key parameter. Thus, this paper focuses on the piston dynamics of the FPELG under various ignition timings during the stable generating process. And the results could provide a useful guidance for optimize the performances and the combustion characteristics.

2. FPELG SYSTEM

2.1 Prototype configuration

According to the previous literatures, it is found that the dual-piston dual-cylinder type FPELG has higher power to weight ratio and less mechanical components, compared with the other types [3]. Hence the dual-piston dual-cylinder type FPELG is applied in this paper. The main structure is shown in Figure 1, and the main parameters of the FPELG are summarized in Table 1.



1. Spark plug 2. Piston 3. Cylinder 4. Fuel injector 5. External load 6. Air-intake tube 7. Scavenging port 8. Exhaust port 9. Stator 10. The connecting rod

Fig 1. The main structure of the FPELG

Table 1 Main parameters of the prototype

Parameters	Values
Cylinder Bore (mm)	52.5
Equivalent Effective stroke (mm)	34.0
Piston and connecting rod mass (kg)	4.2
Thrust force constant (N/A)	89.9
Back EMF constant (V/m/s)	76.0
Coil resistance (ph-ph) (Ω)	7.0
External load resistance (Ω)	100.0

2.2 FPELG operation process

According to the FPELG principle, it is found that its operation process as following. Firstly, the linear motor/generator runs as a motor during the starting process [2]. When the in-cylinder mixed gas state meet the ignition condition, it means that the starting process was completed. Secondly, the conversion system, as shown in Figure 2, is enabled. At the same time, the linear motor/generator runs as a generator. And the ignition system and the injection system are enabled. The operation process of the FPELG prototype is illustrated in Figure 2.

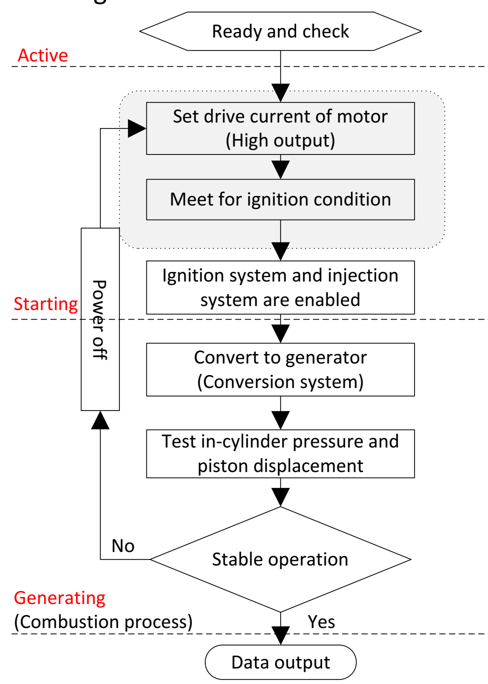


Fig 2. The FPELG operation process

2.2 Testing and controlling system

Based on the physical prototype of the FPELG, the testing and controlling system of the FPELG is designed, according to the previous paper [1]. As for the testing system, the real-time in-cylinder gas pressure and the mover displacement are collected. And the in-cylinder gas pressure sensors is selected to measure the in-cylinder gas pressure. The built-in encoder of the selected commercial linear generator is used to measure the piston displacement. The measuring range of encoder is from 0 to 318mm, and sensitivity is 0.01mm [11].

3. PISTON DYNAMICS AND ENGINE OPERATION PERFORMANCES

3.1 Piston dynamics

According to the FPELG prototype, the experimental results of the piston displacement and the in-cylinder gas pressure were showed in Figure 5. In the Figure, the time from 2.0s to 3.0s, the FPELG operated in the starting process (the linear generator run as a motor), and the FPLEG during the generating process when the time from 6.0s to 10.0s. It can be seen from Figure 5 that the peak in-cylinder gas pressure could reach to 35bar when the FPELG operated in the generating process. Compared with the peak in-cylinder gas pressure when the FPELG operated in the starting process, it was found that the FPELG could operate stably during the generating process. Meanwhile, the Figure 5 displayed that the piston TDC was changed in each cycle, due to the crankshaft of the FPELG was cancelled and the forces of the piston were depended on the in-cylinder gas pressure, the friction force and the electromagnetic force from the linear generator. And the results in the paper were the same as the previous paper [2].

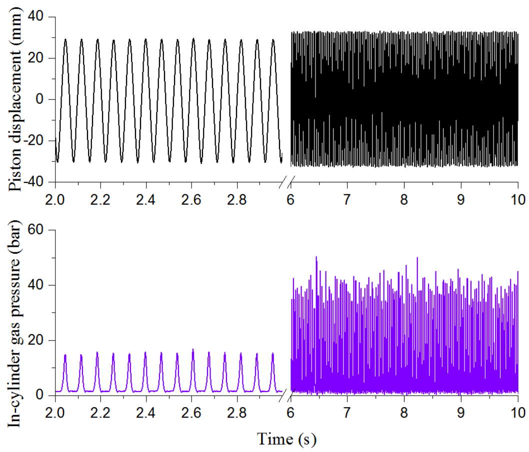


Fig 5. Experimental results of the piston displacement and in-cylinder gas pressure

Due to the FPELG has not the crankshaft, the piston movement is free. The piston TDC was various in each cycle during the generating process. In order to research accurately on the piston dynamics and the performances of the FEPLG during the generating process, the statistical analysis method and the weighted mean method were used in the paper. During the experimental process, the weighted average of 200 tested consecutive cycles is applied in order to eliminate the effects of the piston TDC cyclical variations. The processing results of the piston displacement versus velocity profile was showed in Figure 6. It was found that the piston TDC was 31.8 mm, the peak piston velocity was about 4.9 m/s, and the engine operation frequency was about 30.5 Hz when the FPELG operated in the generating process, according to the experimental results. While the engine operation frequency was only about 14 Hz when the FPELG during the starting process. The engine operation frequency during the generating process was increased, compared with that during the staring process. Because the input energy of the FPELG during the staring process was much less than that operated in the generating process.

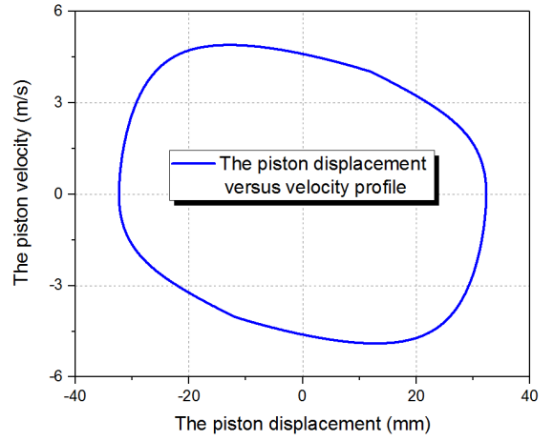


Fig 7. The processing results of the piston displacement versus velocity profile

Compared with the conventional ICEs, the FPELG has eliminated the crankshaft system. Thus, the ignition timing of the FPELG was depended on the piston displacement. In the paper, the ignition timing (ignition position) is defined as the distance from the ignition position to center of the two cylinder heads.

The experimental data was processed by the above methods, the piston operation parameters, such as the piston TDC, the peak piston velocity and the free-piston engine operation frequency profiles were showed in the Figure 8, when the engine under different igniting timing. It can be seen that the piston TDC was 32.3 mm and the peak piston velocity could reach to 5.3 m/s when the ignition timing was 27.5 mm. In addition, the operation frequency of the FPELG was about 32.8 Hz. The piston TDC and the peak velocity were both increased when the ignition timing from 26.5 mm to 27.5 mm. With the ignition timing continues to retarded, the piston TDC and the peak velocity were both decreased. And the peak in-cylinder gas pressure changed trend was the same as the piston TDC, it increased firstly and then decreased.

Meanwhile, it can be seen from the Figure 9 that the piston operation parameters profile was not monotone changed with the ignition timing increased. With the ignition timing retarded, a portion of in-cylinder mixed gas was combusted under the expansion process, then the piston TDC, the peak piston velocity and the operation frequency decreased, when the ignition timing was abled after the piston displacement was 27.5mm. Therefore, the optimal ignition timing of the free-piston engine is between 27.5 mm and 28 mm.

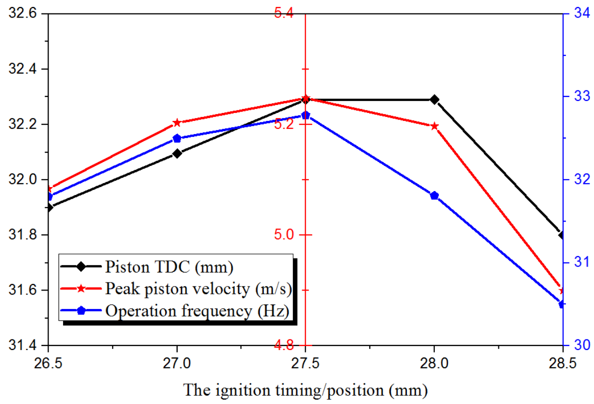


Figure 9. The piston operation parameters under various ignition timing from the experimental results

4. CONCLUSIONS

This paper focused on the piston dynamics of the FPELG with different ignition timings during the generating process. The FPELG prototype was established, and it could run continuously during each operating process. The experimental results indicate that:

It was observed that the piston TDC, the peak piston velocity and the peak piston velocity were changed in each cycle, and those parameters value during the generating process were much larger than that during the staring process. Meanwhile, it can be seen that the optimal ignition timing of the free-piston engine is between 27.5 mm and 28 mm.

ACKNOWLEDGEMENT

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