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A preliminary experimental study on a free-piston engine generator prototype#

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ABSTRACT

As an emerging micro- or small-scale energy conversion technology, free-piston engine generator (FPEG) features the advantages of high efficiency, high volumetric power density, and multi-fuel adaptability potential. To solve the issues that the previous FPEG prototype (developed in the authors' group) had, in this work, we developed a new FPEG prototype with a compact structure that is capable of operating at a higher frequency. Some preliminary experimental results are obtained from the new prototype. The results indicate that there is no significant operation inconsistency between the two free-piston engines, and achieving continuous combustion in both of the engines will be the subject of future research.

Keywords: energy conversion, free-piston engine, linear generator, experimental study

NONMENCLATURE

Abbreviations	
BDC	bottom dead centre
EVC	exhaust valve close
EVO	exhaust valve open
FPEG	free-piston engine generator
IVC	inlet valve close
IVO	inlet valve open
LH	left-hand
RH	right-hand
TDC	top dead centre

1. INTRODUCTION

Free-piston engine generator (FPEG) is a new class of energy conversion devices that integrates a linear combustion engine and a linear generator into a single unit. It has the advantages of high efficiency, high volumetric power density, and multi-fuel adaptability potential [1], and it can be applied in on-board vehicle range-extender, emergency power systems, micro-combined heat and power systems, and so on [2].

Our group has developed an FPEG prototype with a dual-piston configuration before, and the prototype is comprised of two opposing internal combustion free-piston engines and a linear generator [3]. The combustion chamber of each free-piston engine is comprised of a spark electrode, a piston, and a set of poppet valves. The linear generator is a cylindrical linear generator, and it is located at the central of the two cylinders/pistons and keeps in line with them. In experiments, the FPEG prototype operated successfully in two-stroke combustion mode and achieved a 0.7 kW indicated power per cylinder with an indicated efficiency of 26%, when using gasoline as fuel [4]. The results also indicate that further increasing compression ratio and operating frequency are expected to achieve higher efficiency. It should be noted that due to the long response time of the pneumatic system (which is used to activate the opening and closing of the overhead intake and exhaust valves) [4], this FPEG prototype is not suitable for high-frequency operation. Besides, the placement of the linear generator between the two cylinders/pistons weakens the compactness of the system.

To solve these issues, we developed a new FPEG prototype with a dual-piston configuration, as shown in Fig. 1. The new prototype incorporates two internal combustion free-piston engines with higher output power than the former prototype. Each of the two free-piston engines has a combustion chamber comprised of a spark plug, piston, and set of poppet valves. The two pistons are linked together using a shared piston rod, which is connected with the mover of the linear generator and this component as a whole represents the only significant

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moving part of the system. In comparison with the former prototype [4], the opening and closing of the overhead intake and exhaust valves of each free-piston engine are activated by two cam motors to meet the high-frequency operation requirements. In addition, a flat-plate linear generator with a power capacity of 24 kWe is deployed at the bottom of the two free-piston engines. The linear generator is employed to convert the mechanical power into electric power, and its mover is connected with the two pistons but not keeps in line with them: the linear generator mover is parallel to the piston rod. Such a configuration can shorten the axial length of the FPEG prototype greatly.

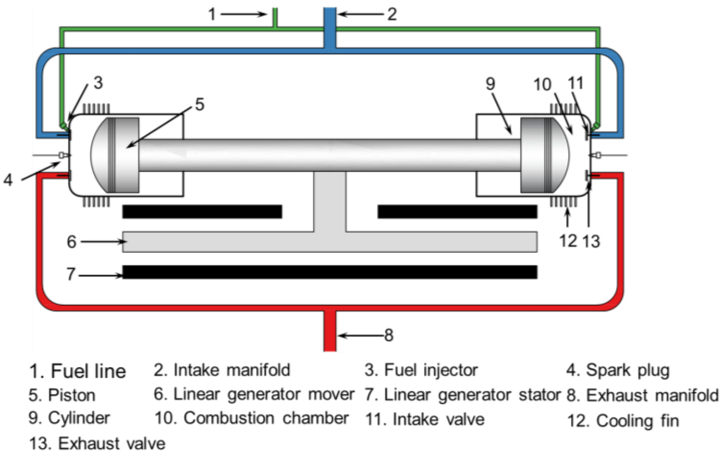


Fig. 1 Schematic configuration of the new FPEG prototype.

2. METHDOLOGY

Fig. 2 shows the photograph of the new FPEG prototype, and the specifications of the new FPEG prototype are given in Table 1. A flat-plate linear motor from Hiwin (model: LMFA62L) was used for the linear generator, and it is driven by a Parker C3T40 controller in experiments. In addition, two cam motors from Hiwin (driven by two matching Hiwin E1 controllers) are used to control the opening and closing of the overhead intake and exhaust valves of the two free-piston engines. Two AVL (model: ZI21) piezoelectric transducer sensors which are mounted in the two spark plugs, respectively, are employed to measure the dynamic in-cylinder combustion chamber pressures. In experiments, we use propane as fuel.

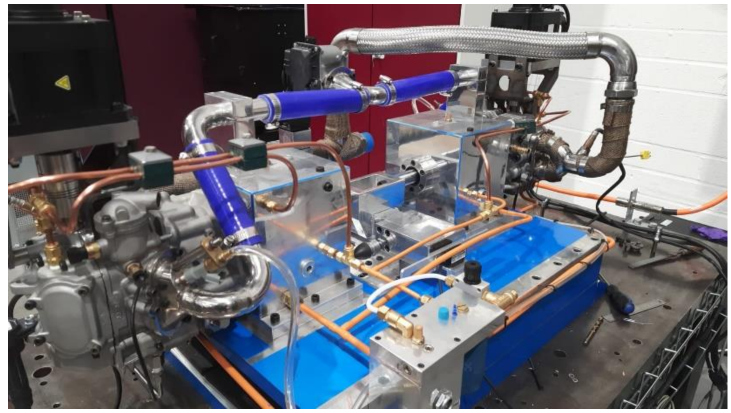


Fig. 2 Photograph of the new FPEG prototype at Durham University.

Table 1. FPEG prototype specifications.

Parameters	Unit	Value
Maximum stroke	mm	42
Effective bore	mm	102
Intake valve clearance	mm	0.15
Exhaust valve clearance	mm	0.20
Valve lift	mm	9
Number of cylinders	-	2
Power capacity of linear generator	kWe	24

Since the linear generator can be either operated as a motor or a generator, so during the start process of the FPEG prototype, the linear generator first runs as a motor, driving the piston-mover assembly moves back and forth, to make air-fuel mixture in combustion chambers to achieve the required spark-ignition conditions. Once a stable motor-mode operation of the FPEG prototype is achieved, the system will be switched to a "generator" mode by running the linear generator as a generator.

3. RESULTS AND DISCUSSION

When the FPEG prototype operates in a two-stroke model, the supply mass flow rate of propane is 0.057 kg/s, the stroke of the piston is set to be 34 mm, and the operating frequency of the linear motor is 4 Hz, the in-cylinder pressure development, piston position and control signals for the two free-piston engines during a complete cycle are shown in Fig. 3. From Fig. 3, we can see that the right-hand (RH) cylinder injection starts following the start of the compression stroke. Before the RH piston reaches its top dead centre, the RH cylinder ignition is triggered. The maximum in-cylinder pressure achieved by the RH free-piston engine is around 10 bar. The operation process of the left-hand (LH) free-piston engine is similar and there is no big difference in the maximum in-cylinder pressure achieved by the two cylinders.

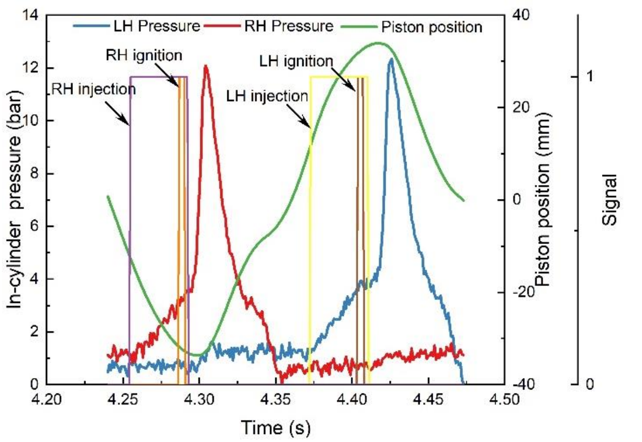


Fig.3 In-cylinder pressure development, piston position, and control signals for the two free-piston engines during a complete cycle.

Fig. 4 shows each in-cylinder pressure profile against the piston position during a complete cycle. One can see that the in-cylinder pressure profiles of the two free-piston engines are similar, indicating there is no significant operation inconsistency between the two engines.

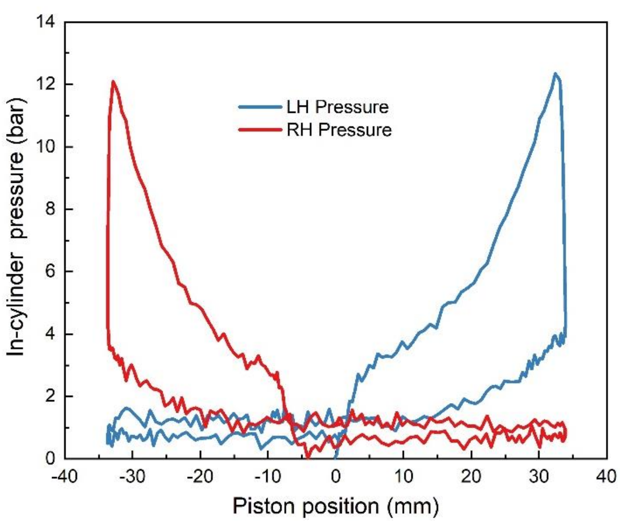
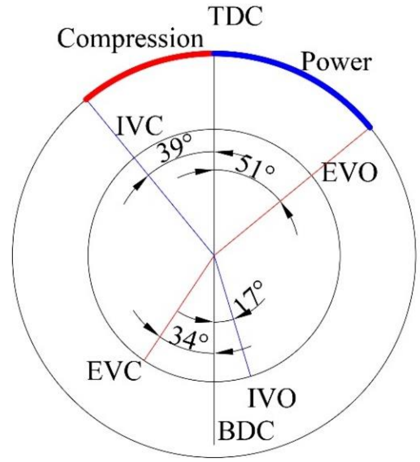
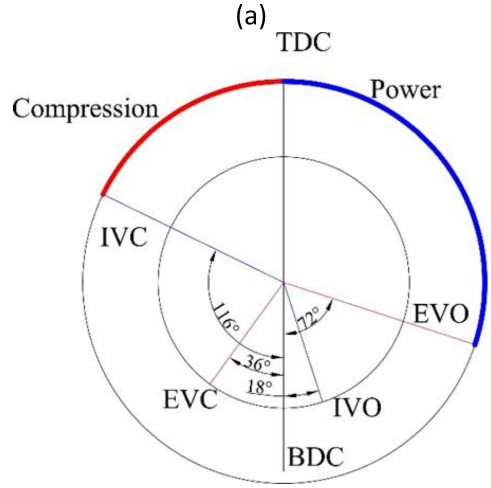


Fig.4 Each in-cylinder pressure profile against the piston position during a complete cycle.

However, the prototype's valve timing (Fig. 5a) was originally designed for low-carbon synthetic fuels with short ignition delays and combustion durations, such as hydrogen and methanol. It is currently being run on propane, which exhibits longer ignition delays and combustion durations. This choice is made to study the system with fewer safety concerns. The unsuitable valve timing explains the unsteady combustion observed in some runs. An FPEG model developed by the authors [5] suggests that the valve timing presented in Fig. 5b would achieve continuous combustion with propane. However, the current cam motor cannot achieve the valve timing shown in Fig. 5b, and therefore, it will need to be replaced to enable the required operation. Fixing the cam system and operating on suitable valve timing will be carried out subsequently in the future.



(a)



(b)

TDC: top dead centre; BDC: bottom dead centre; EVO: exhaust valve open; EVC: exhaust valve close; IVO: inlet valve open; IVC: inlet valve close.

Fig. 5 (a)Current prototype valve timing, and (b) improved valve timing.

4. CONCLUSION

To enhance the compactness of the previous FPEG prototype developed in our group, meanwhile making it suitable for high-frequency operation, in this work, we developed a new FPEG prototype with a bottom-positioned flat plate linear generator. In addition, the valves of each free-piston engine are driven by two cam motors to meet the high-frequency operation requirements. Some preliminary experimental results are obtained from the new prototype. The results indicate that there is no significant operation inconsistency between the two free-piston engines. However, currently, the new prototype cannot achieve continuous combustion in both of the free-piston engines when it operates in a motor mode, solving this issue will be the subject of future research.

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