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An Investigation about Generating Electric Power on Operated Parameters of Powerpack Utilizing Linear Engine

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Abstract

The research shows the experimental results for a free piston linear engine according to operation conditions of the linear engine and the structure of linear generator for generating electric power. Each parameter such as input calories value, equivalence ratio, spark timing delay, electrical resistance and air gap length were settled for identifying the combustion characteristics of the linear engine. As a result, the piston frequency was 57.2 Hz and the maximum generating power was 111.3 W where the operation conditions were as follows: 1.0 of equivalency ratio, 1.5ms of spark timing delay.

Keywords: Linear engine, Linear alternator, Powerpack

1 Introduction

Recently, researches on alternative high-efficiency internal combustion engines and hybrid electric vehicles are attracting great interest due to environmental pollution, energy depletion and selection of alternative energy. Numerous alternative engine configurations have been proposed with the aim of improving fuel efficiency and reducing exhaust emissions. To solve and overcome the problems mentioned previously, various new concepts of engines and combustion methods have been investigated. Among these, in this study, a linear generator applied the free piston linear engine was carried out.

Research on free-piston engines has been nearly stagnant since the mid-20th century after the first proposal of the free-piston-type engine configuration [1]. As a free piston linear engine is internal combustion engine with linear motion, some parts were not required such as crankshaft, camshaft and et al [2], the free-piston linear engine has some advantages. The main advantages of the free-piston engine are simplicity in mechanical structure with a few moving parts, low friction losses and high operational flexibility. As you know already, the lack of a crankshaft mechanism allows the piston move freely as well as reduced the frictional losses when delivering the combustion energy to the final shaft [3]. Also, unlike conventional engine with crankshaft mechanism, the free- piston linear engine could optimize the combustion process through the variable compression ratio. In this regard, the variation of compression ratio in free-piston linear engine also allows the engine to operate with multi-fuel such as diesel, hydrogen, gasoline and natural gas. [4]

To investigate some previous researches performed by West Virginia University, there were various results and demonstrations of reliable operation that was used a SI linear engine equipped spark device. It follows that linear engine combined with linear generator was successfully operated, although it was not suitable for the propulsion of hybrid vehicle, appropriate electricity output was stably generated [5]~[9]. However, previous researches about experiment of free piston linear engine and the generating power associated with any operation conditions of linear engine were highly insufficient. Because of these reasons, in this experimental research, not only the generating power of powerpack utilizing linear engine but also the effective main parameters which are related to generating power were investigated. For that the linear engine performance test was conducted by varying main parameters such as input calories value, equivalence ratio, electrical resistance, spark timing delay and air gap length (L_{air_gap}).

2 Experimental system

2.1 Experimental apparatus

In this study, experimental apparatus largely consists of the free piston linear engine, linear generators, ignition device, sensor parts, engine control part and data acquisition part. As you can see, Figure 1 and Figure 2 shows the photography and schematic diagram of experimental system.

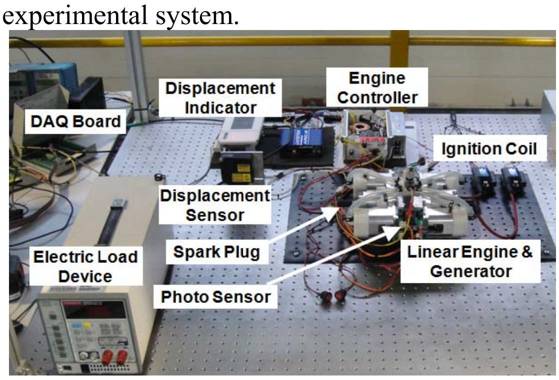

Figure1: A photograph for experimental system

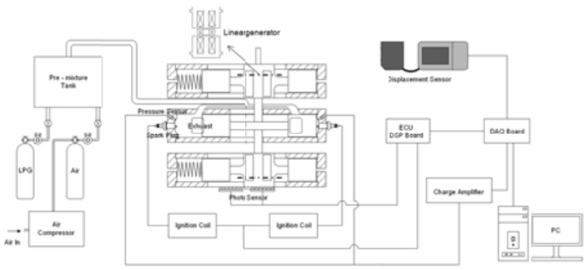

Figure2: A schematic diagram of the experimental system

2.2 Free piston linear engine

Table 1 show the specification of the linear engine. The piston of the linear engine was combined with translator of linear generator part and it was controlled by the engine control unit(ECU).

Table1: The specifications of linear engine

Parameters	Value
Engine type	Two-stroke linear engine
Bore [mm]	30
Maximum stroke [mm]	31
Effective max. stroke [mm]	18
Translator mass [kg]	0.8
Scavenging type	Cross-scavenged type
Compression ratio	varied

2.3 Experimental methods

In this experimental research, the generating power as well as the combustion characteristics of the linear engine was investigated. For this purpose, the parameters such as input calories value, equivalence ratio, electrical resistance, spark timing delay and L_{air_gap} were varied. Following that, engine performance test for confirming the optimized generating power was conducted in the various conditions. The overall conditions appeared Table2.

Table2: Experimental conditions

Parameters	Value
Fuel type	Propane
Input calories value [kJ/s]	4.56, 5.21, 5.88, 6.53
Spark timing delay [ms]	0.5, 1.0, 1.5, 2.0
Equivalence ratio	0.8, 0.9, 1.0, 1.1, 1.2
Air gap length [mm]	1.0, 2.0

Electric load [Ω]	5, 10, 15, 25, 30, 40

When the combustion was occurred, the translator combined with piston was reciprocated. At this time, a role of the linear generator was changed from the starting motor to the AC generator. Eventually, the voltage was induced by the reciprocation of translator based on Faraday's law; thereby the electric power was generated. In this paper, the experiment was performed to investigate the generating power of the free piston linear engine according to operation conditions of the linear engine and the structure of linear generator for generating electric power. The generating power was calculated by multiplying Vrms and Arms which were obtained from the scope meter (Fluke; Scope meter 199c) connected with the linear generators.

3 Experimental results

3.1 The changing input calories value

So as to investigate the generating power in accordance with input calories value and electrical resistance, the linear engine performance test was conducted. At this, the equivalency ratio and spark timing delay and Lair_gap was fixed as 1.0, 1.5 ms and 2.0 mm respectively. The results were shown in Figure 3. The electrical resistance was varied from 5 to 40 Ω in incremental 5 Ω and was directly applied to linear generators using the electronic load device. Air flow ratio was changed by using the mass flow meter and input calories value was varied as 4.56, 5.21, 5.88, 6.53 kJ/s respectively. Input calories value was calculated through multiplication among fuel flow rate and density and lower heating value of fuel. The unit of input calories value is defined as kJ/s instead of kJ/cycle because there was variation of each cycle. Also, the intake flow rate was varied as 70, 80, 90, 100 lpm under the constant pressure of intake in order to fix the equivalency ratio as 1.0.

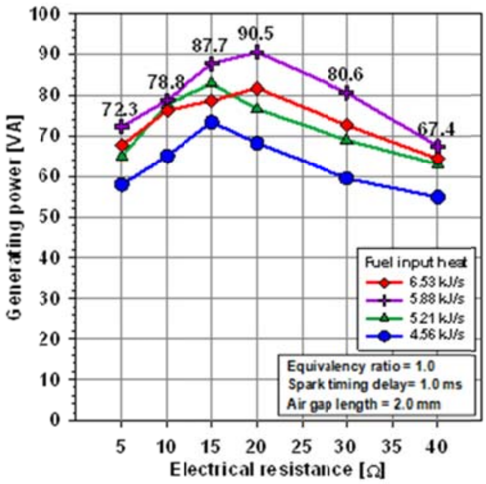

Figure3: The effects of input calories value on generating power at varied electrical resistance

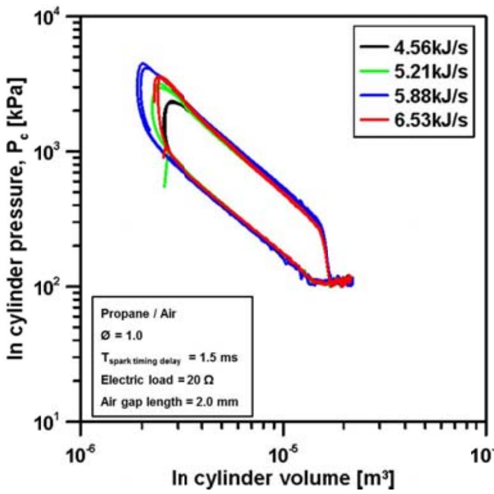

Figure4: The effects of input calories value on P-V diagram

As can be seen in Figure 4, when 5.88 kJ/s of input calories value, 90 lpm of air flow, 20 Ω of electrical resistance was fixed, Vrms was 43.5V and Arms was 2.08. Thus, the highest generating power was calculated as 90.48 W. In addition, although the generating power was climbed when the electrical resistance was increased from 5 to 20 Ω, the generating power was declined when the electrical resistance was increased from 20 to 40 Ω.

3.2 The changing spark timing delay

In this experiment, the definition of the spark timing delay is as follows. When the translator combined with piston was reciprocated, and it was passed by the photo interrupter sensor; and then the 5V digital signal was caused. That was delivered to ECU and delayed from 0.5 to 2.0 ms in incremental 0.5 ms by using the Matlab/Simulink.

The results for the generating power according to the spark timing delay could be seen in Figure 4.a. Except the spark timing delay, the other conditions mentioned in the previous section such as electrical resistance, input calories value and et al were same when the generating power was the peak value.

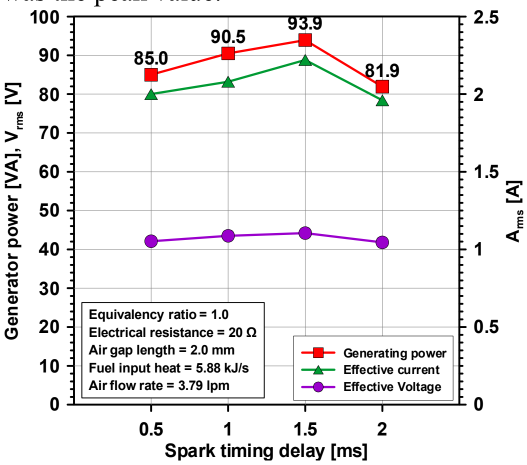

Figure5: The effects of spark timing delay on generating power at varied electrical resistance

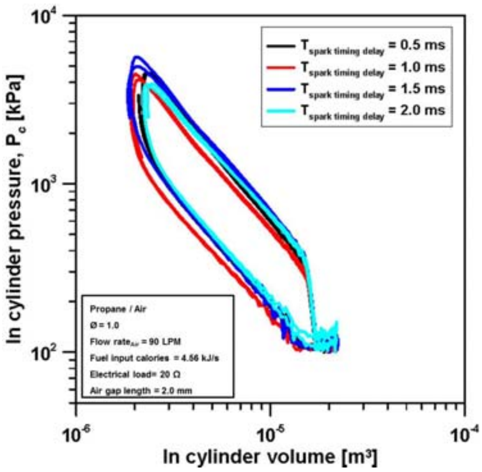

Figure6: The effects of spark timing delay on P-V diagram

In the Figure 5, there are the inflection points in the graph. The generating power was gradually increased and then decreased by 1.5 ms of spark timing delay. In addition, the highest generating power was 93.9 VA when the spark timing delay was 1.5 ms.

3.3 The changing equivalence ratio

The results for the generating power on the equivalency ratio were shown in Figure 5.a. In order to vary the equivalency ratio, the air flow was fixed as 90.0 lpm and then input calories value was varied as 4.70, 5.29, 5.88, 6.46, 7.05 kJ/s respectively. It follows that the equivalency ratio varied from 0.8 ~ 1.2 in incremental 0.1. In this condition, the electrical resistance, L_{air_gap} and the spark timing delay were fixed as 30 Ω, 1.0 mm and 1.5 ms respectively.

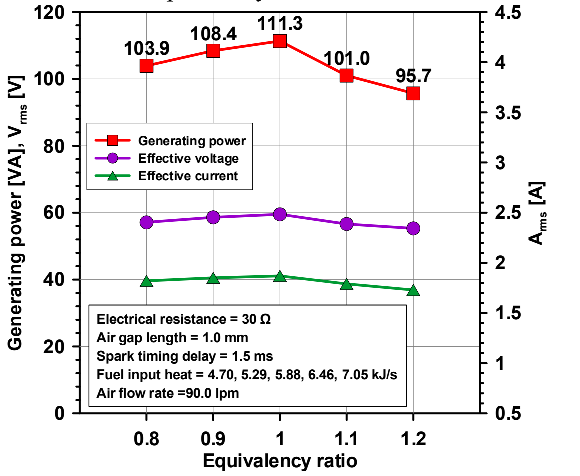

Figure7: The effects of equivalence ratio on generating power at varied electrical resistance

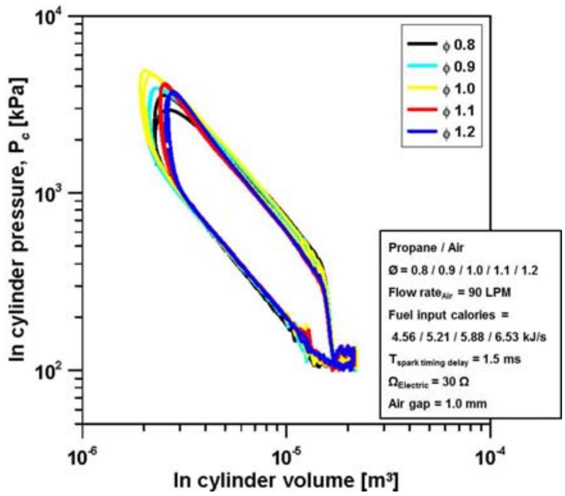

Figure8: The effects of equivalence ratio on P-V diagram

As can be seen in Figure 7, the equivalency ratios from 0.8 to 0.9 show tendencies that the V_{rms} and A_{rms} were increased. Because of that, the generating power was also increased. However, the generating power was decreased when equivalency ratio was richer than 1.0.

3.4 The changing air gap length

The experiment was performed to investigate the generation power of the linear engine depending on the L_{air_gap} varied 1.0, 2.0 mm and electrical resistance varied as 5, 10, 15, 20, 30 and 40 Ω. The equivalency ratio was fixed as 1.0 by fixing the air flow and input calories value as 90.0 lpm and 5.88 kJ/s and ignition timing delay was fixed as 1.5 ms.

Next, V_{rms} and A_{rms} were measured by varying the electrical resistance from 5 to 40 Ω in incremental 5 Ω at each condition of L_{air_gap}. And then the generating power was calculated through multiplication between V_{rms} and A_{rms}.

As can be seen in Figure 6, the generating power was generally higher at 1.0 mm than at 2.0 mm for L_{air_gap}. The highest generating power was shown under the conditions that L_{air_gap} was 1.0 and the resistance was 30 Ω. Since the electrical resistance was higher than 30 Ω, the generation power was declined. Unlike this, when L_{air_gap} was 2.0 mm, even if the generation power was increased rapidly until 20 Ω, since that it was decreased.

In summary, the maximum generation power was 111.3 VA when the experimental conditions were that L_{air_gap}, the electrical resistance, equivalency ratio and spark timing delay was 1.0, 30 Ω, 1.0 and 1.5 ms respectively.

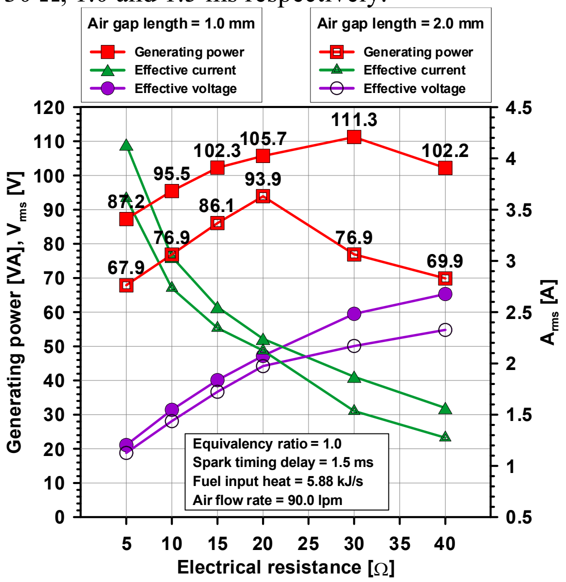

Figure9: The effects of air gap length on generating power

4 Conclusions

The In this experimental research, not only generating power but also the effects of operating conditions of powerpack utilizing linear engine for generating power were investigated. For this, linear engine performance test was conducted by changing a variety of operating parameters such as input calories value, equivalence ratio, electrical resistance, spark timing delay and air gap length.

1) As can be seen in Figure 3, when linear engine performance test conditions were constant such as 5.88 kJ/s of input calories value, 90 lpm of air flow and 20 Ω of electrical resistance, V_{rms} was 43.5V and A_{rms} was 2.08 A and the highest generating power was calculated as 90.48 VA. Although the generating power was climbed when the electrical resistance was increased from 5 to 20 Ω, the generating power was declined when the electrical resistance was increased from 20 to 40 Ω, It was supposed that more than certain electrical resistance has a negative effect on displacement and frequency of the translator.

2) In the Figure 4, there is an inflection point in the graph for the generating power. Also, the highest generating power is 93.9 VA when the spark timing delay was 1.5 ms. In case that the spark timing delay was 2.0 ms, the generating power was the lowest. It was thought that the combustion occurred from the nearest to bTDC when the spark timing delay was 1.5 ms. On the other hand, when the spark timing delay was 2.0 ms, it was regarded that the combustion occurred at aTDC.

3) As can be seen in Figure 5, the equivalency ratios from 0.8 to 0.9 show tendencies that the V_{rms} and A_{rms} were increased. Because of that, the generating power was also increased. However, the generating power was decreased when equivalency ratio was richer than 1.0. The highest generating power occurred at 1.0. It was supposed that when the equivalency ratio was increasing, simultaneously, the piston work per one cycle was increasing and frequency was peak value at 1.0.

4) As can be seen in Figure 6, the generating power was generally higher at 1.0mm than at 2.0mm for L_{air_gap}. And the maximum generation power was 111.3 VA when the experimental conditions were that L_{air_gap}, the electrical resistance, equivalency ratio and spark timing delay was 1.0, 30 Ω, 1.0 and 1.5 ms respectively. As can be seen in the result, L_{air_gap} has a sufficient effect on the generating power. It might be predictable fact that the generation power was increased when the distance between coil and permanent magnet was getting shorter. However, the power consumption was increased to initial operation of the linear engine because of increasing the magneto-resistance when L_{air_gap} was getting smaller. To consider that facts, some experimental test will be performed to find the appreciate conditions of L_{air_gap} additionally.

Current work is just focused on the generating power and finding the suitable conditions to optimize the linear engine. The next stage of testing is to investigate dynamic behavior of the module with combustion and to implement our previous test. At the final stage, the test will be performed for exhaust emission and fuel efficiency of the linear engine. Furthermore, the various fuels will be used in the linear engine such as diesel, DME and hydrogen et al.

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