EVS24
Stavanger, Norway, May 13 - 16, 2009

Small Scale Linear Ceramic Engine Generator for Neighborhood Electric Vehicle

Gangchul Kim*, Namyuer Kim, Chongpyo Cho
Automobile Energy & Environmental Research Center, Korea Institute of Energy Research, 305-343, Jang-Dong, Yuseong-Gu, Daejeon, Korea, kimgc@kier.re.kr

Abstract

In the realm of small electric vehicles (neighborhood electric vehicles or personal electric vehicles such as electric wheelchairs, electric scooters etc.), there's a power struggle brewing. They demand lots of electrical power and long operation, but current rechargeable battery cannot provide the operational durations required. Also short lifetimes of batteries impose a fundamental limitation. Due to these reasons, a small linear reciprocating engine and linear electric generator are designed in this paper. If an engine is used solely to produce electrical power, it is not necessary to convert the reciprocating linear motion of the piston to rotary motion by crank. Instead, a linear electrical generator may be coupled directly to the piston for a conversion of mechanical energy into electrical energy. Such a design has many advantages such as mechanical simplicity and low friction and it can make possible a small engine having high efficiency. In other words, linear engines give power output more efficiently compared to conventional reciprocating piston engine, because it doesn't have a crank mechanism, hence there is less mechanical loss. In this study, we developed a small sized linear engine generator for the electrical power generation. To increase the efficiency and endurance, we made a piston and cylinder sleeve by ceramic materials.

Key words: Linear Engine, Linear Generator, Ceramic Engine, NEV(Neighborhood Electric Vehicle)

1. Introduction

With an awareness of high oil prices and the environment raised, much more researches are conducted on eco-friendly vehicles including Hybrid Vehicles or Plug-in Hybrid Vehicles rather than the traditional internal combustion engines. Along with this trend, vehicles with new concept, for example, vehicles without internal combustion engine, including fuel cell vehicles, electric-powered vehicles or solar-powered vehicles are also being developed.

These demonstrate that the main power of a vehicle changes from mechanical energy into electrical energy. However, major car manufacturers don't sell vehicles powered only by battery yet. This is because their battery prices, performance(trip length), and duration haven't reached to the satisfying level. Also it would take a long time to establish the infrastructure for charging electric-powered vehicles.

Thus, it is expected that a variety of vehicles with various trip pattern or purposes would appear in the future of the car market. Vehicles with the traditional internal combustion engine would be preferred to Hybrid vehicles in the suburban areas not with serious traffic jam, while Neighborhood Electric Vehicle(NEV) would be better when one drives a short distance for commuting or shopping in urban areas. Also when the combination of the two trip patterns is used, Hybrid Vehicles are recommendable. Meanwhile, Segway, electric-powered scooters and Personal Electric Vehicle(PEV) are useful when one moves a short distance alone.

2. NEV with On-board Generator

While many types of electric-powered vehicles have been developed, they are not yet getting popularity in the market due to their price(battery price), performance(trip length) and lack of duration. Researches are being conducted on Plug-in Hybrid Vehicles that use internal engine and battery together to reduce more exhaust gas than pure electric vehicles and the use of fossil fuel.

Developing 500W on-board generator, this paper develops NEV and PEV, shown in Fig. 1 and Fig. 2, which would be popular in urban areas with slow vehicle speed, short trip length, and dense population (Seoul, Tokyo, London, etc.) into Plug-in Hybrid Vehicles.

Fig. 1 Neighborhood Electric Vehicles(NEVs)
http://www.gemcar.com, http://www.bugev.net

Fig. 2 Personal Electric Vehicles(PEVs)

A Vehicle with on-board generator charges its battery using cheap mid-night electric power through an outer charging port, as shown in Fig. 3. Also it can charge its battery through on-board generator when it is impossible to use charging facilities during its operation or stop(places without charging facilities, breakdown etc.). As shown in Fig. 4, energy density of lead acid battery that is used a lot thanks to its low price is lower than 50 Wh/kg. In case of Lithium developed a lot recently, energy density per unit cell is relatively high, while the density of it actually applied is less than 100 Wh/kg and the price is very high. Meanwhile, energy density of liquid fuel is 100 times higher than that of Lithium cell. So if on-board generator with the efficiency of more than 20% is developed, its energy density would be 20 times higher than that of Lithium cell.

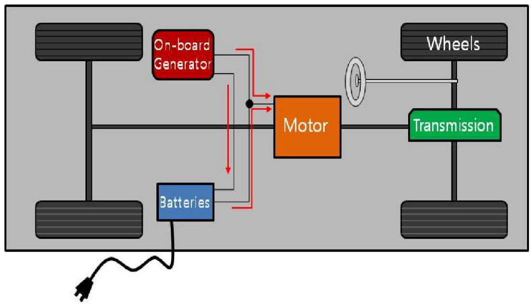

Fig. 3 NEV schematic with on-board generator

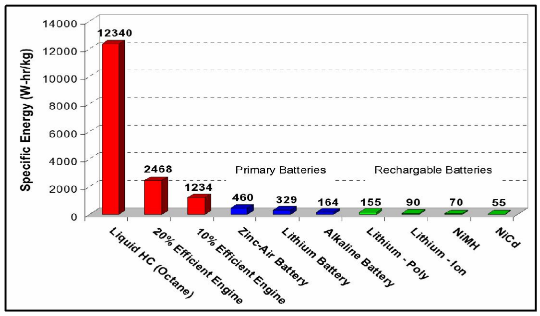

Fig. 4 Specific energy density
(Reference : Miniature and microscale energy systems, Richard B. Peterson)

Applying 500W on-board generator to NEV can not only reduce the price of a vehicle by reducing battery capacity required but also improve the energy efficiency by reducing the vehicle weight. As battery charging is possible while driving, the movability(capability) of a vehicle considerably improves. Lastly, charge equalization and prevention of deep cycle by on-board generator makes the efficient use of battery possible, leading to the improvement of its lifespan and efficiency.

on-board generator can also have good environmental performance because it uses a variety of clean fuel including hydrogen, bio fuel, DME, and etc.

3. NEV Performance Estimates depending on Battery Weight

One of the major advantages of NEV with on-board generator is to reduce the price of a vehicle by reducing battery capacity required and to improve the efficiency by reducing vehicle weight. While some batteries applied to NEV use Lithium cell, most of vehicles use lead acid battery with excellent prices and stability. In order to evaluate the effect of battery weight on NEV performance, trip length and efficiency were calculated under the condition of steady speed and driving pattern in the Metropolitan area(Mode: Manhattan Driving Cycle) with the specifications of NEV shown in Table 1.

In case of lead acid battery, energy density is very low with 30 Wh/kg. So as shown in Fig. 5, its trip length is about 60 km with stead speed of 30 km/h when 200kg of battery is installed, but the actual driving pattern in the Metropolitan area is as short as about 10 km. This means that the battery capacity shall increase in order to extend trip length. As shown in Fig. 6, the loss caused by the increase in battery weight reduces the increase range of trip length. The efficiency also reduces shown in Fig. 7.

Table 1. Specifications of NEV

Vehicle Weight(kg)	400
C_D	0.5
A(m²)	2.044
motor	AC motor 8kw
battery	72V 85Ah Lead acid
Weight of modules	32.833kg
Passenger	2(120kg)
Wheel	13 inch

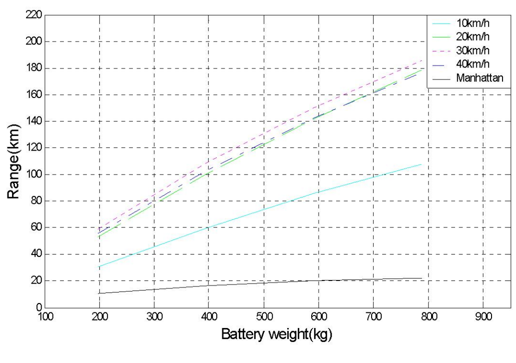

Fig. 5 NEV Trip Length Depending on the Battery Weight

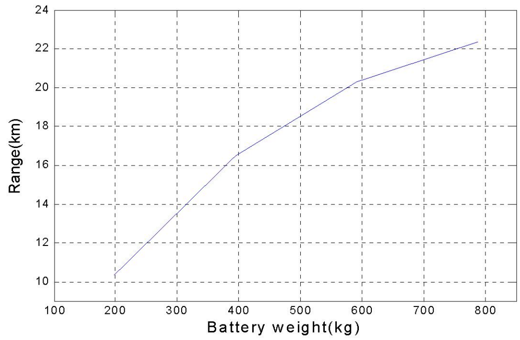

Fig. 6 Range of NEV on Manhattan Driving Cycle

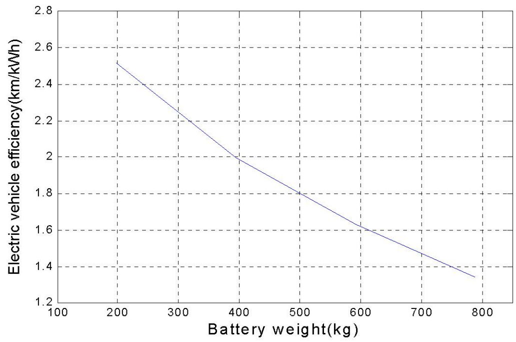

Fig. 7 Efficiency of NEV on Manhattan Driving Cycle

In case of NEV with Plug-in Hybrid method, weight of on-board generator with fuel included is about one fiftieth of lead acid battery, improving its efficiency a lot. Though the deep cycle lifespan of load storage battery is very short, on-board generator can control SOC, leading to the improvement of the lifespan and efficiency of battery and then considerably reducing the maintenance cost for NEV.

4. Development of On-board Generator using a Ceramic Linear Engine

4.1 Concept and advantages of linear Engine

The traditional small scale engine is a two-stroke reciprocating engine and converts the reciprocating linear motion of the piston to rotary motion by crank and flywheel as shown in Fig. 8. On the other hand, the linear engine is the linear reciprocating engine which uses the linear motion of the piston directly without any conversion of it as shown in Fig. 9. While an engine-powered vehicle needs rotary motion, a generator-powered vehicle can directly get electric output using its linear generator without any rotation and conversion. A linear engine can be produced in a small size because it doesn't need any crank and flywheel. Also the efficiency and duration improves while the frictional resistance on the side of the piston is considerably reduced.

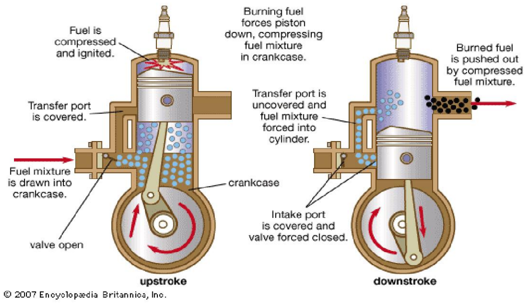

Fig. 8 Conventional 2 stroke engine (http://www.britannica.com)

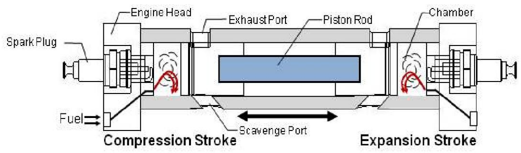

Fig. 9 Schematic of Linear engine

4.2 Concept Design of 500W On-board Generator

As shown in Fig. 10 and Fig. 11, on 500W on-board generator this study develops, the linear engine is located in the center with linear generator and air compressure located symmetrically. Major specifications are shown in Table 2. As shown in the table, the size of 500W engine is as small as 14 ㏄, a meso-scale.

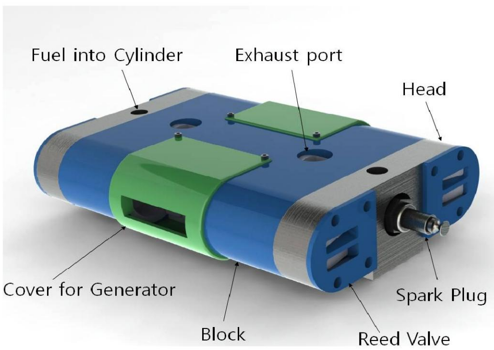

Fig. 10 Concept Design of On-board generator

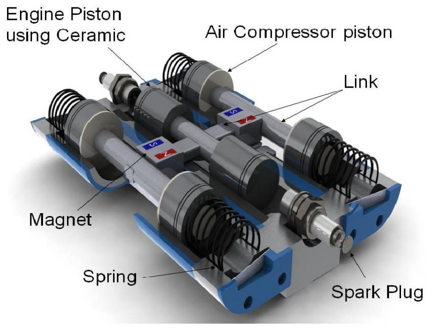

Fig. 11 Sectional view of On-board generator

Table 2. Specifications of linear engine

Description	value
Bore of combustion chamber (㎜)	20
Bore of Air chamber (㎜)	24
Max. Stroke (㎜)	23
Max. Swept Volume of combustion chamber (㏄)	14.5
Max. Swept Volume of Air chamber (㏄)	41.6

Traditional linear engines and generators are designed as a linear generator is located on the center of a linear engine. This makes the connecting road of a linear engine long, increasing the weight on the side due to the eccentricity by buckling and causing problems on its duration. Thus, this study minimizes the length of connecting road by setting linear engine, linear generator and air compressor in a parallel way and increases the capacity of air compressor , making it possible to supply air to the combustion chamber. Cylinder Sleeves of the both combustion chambers of linear engine are designed to be integrated, minimizing the weight on the side.

As a traditional small-scale two-stroke reciprocating engine mix lubricating oil to fuel , exhaust gas and efficiency deterioration caused by the combustion of lubricating oil have been a major problem. As shown in Fig. 12, in order to improve the duration and efficiency of the engine, this study designs cylinder sleeve and piston with ceramic, making the engine operate with low or no lubricating oil. As ceramic material has a high abrasion resistance and thermal property while has a weak brittleness, it is difficult to use it. However, this study designs it to be used with a Meso-scale size in linear reciprocating motion. In this regard, it is relatively easy to apply ceramic material.

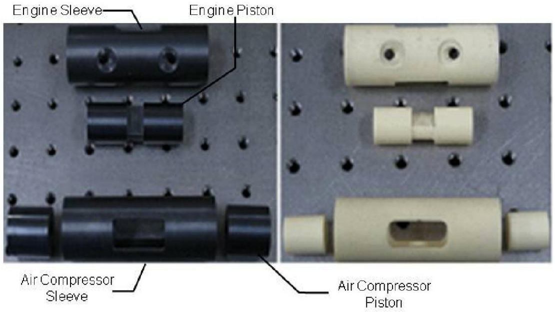

Fig. 12 Ceramic cylinder sleeve and piston (Left: SiC, Right: Alumina)

4.3 Scavenging System and Fuel Supply

As shown in Fig. 13, scavenging system of small-scale two-stroke reciprocating engine adopts various types. Uni-flow method in (c) has an excellent efficiency but has problems in costs and its structure due to valves. So in a small size, Cross in (a) and Loop in (b) are commonly used. When these methods are used, fuel and air are pre-mixed and flowed into the combustion chamber during the injection stroke. This causes the loss of fuel because injection and exhaust port open together, increasing the exhaust gas and decreasing the efficiency.

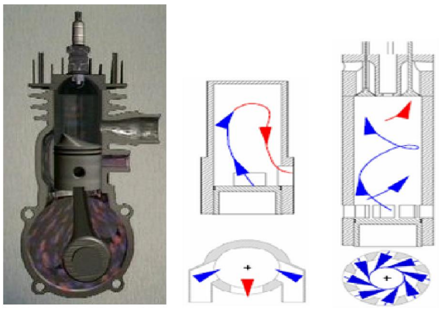

Fig. 13 Scavenging methods ((a) http://www.cdxetextbook.com, (b) and (c) S. Scott Goldsborough and Peter Van Blarigan)

As shown in Fig. 14, this study doesn't pre-mix fuel and air. Fuel is supplied to the combustion chamber through the injection hole located in the lower part of cylinder head. It is designed for air to be injected to the power part of cylinder with the angle of 45°, making smooth ventilation possible and minimizing the loss of fuel. When vaporized gas fuel is supplied through the small hole of cylinder, fuel supply is stopped during the explosion and expansion strokes due to the pressure difference between fuel supply and the combustion chamber, while it is continued during the scavenging and compression strokes.

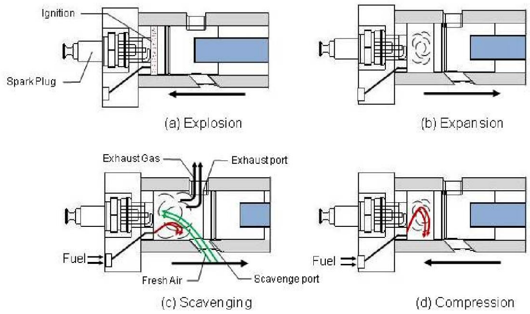

Fig.14 Fuel supply and scavenging system of linear engine

4.4 Air Injection and Supply System

In order to inject enough air and provide them to the engine, as shown in Fig. 15, this study installs air compressor on both sides of linear engines and sets an airway between the compressor and the combustion chamber at the bottom of engine block. In case of inject stroke, the chamber piston blocks the air entrance and reed valve located on a compressor head opens due to the pressure difference, making air come in. In case of compression stroke, reed valves blocks, making air compressed. Then as injection and exhaust port open during the scavenging stroke, air is supplied to the exhaust chamber.

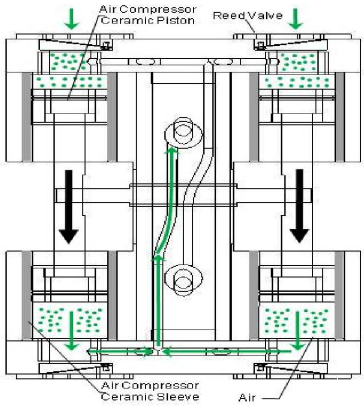

Fig. 15 Compressed air line in the cylinder

4.5 Design of Linear Generator

The traditional generating system connect generator and engine with a spindle, with a rotary generator used. However, this study designs linear generator integrated with linear engine, minimizing the system size and volume. There are two types of linear generator - cylinder and flat board. This study selects flat-board type generator with its structural consideration as shown in Fig. 16.

Permanent magnet is set as a mover, with coil and core arranged as stator located symmetrically on ups and downs of permanent magnet.

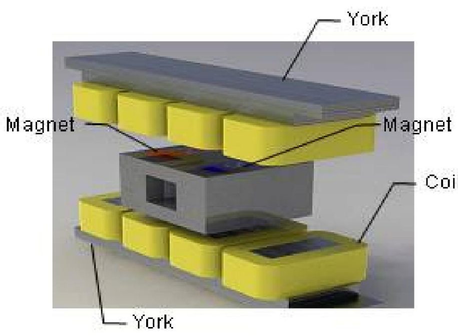

Fig.16 Schematic of linear generator

5. Experimental setup and Results

5.1. Experimental setup and Methods.

Fig. 18 and Fig. 19 describe a schematic diagram for experimental set and its photographs. For linear engine, the location of the piston is measured with the interval of 0.5ms by the displacement sensor(Model: optoNCDT 2200) in order to measure it instead of the angle of crank. The pressure in the combustion chamber is measured using the pressure sensor(Model : 6113AFD13Q02_spark plug M10) integrated into the ignition plug.

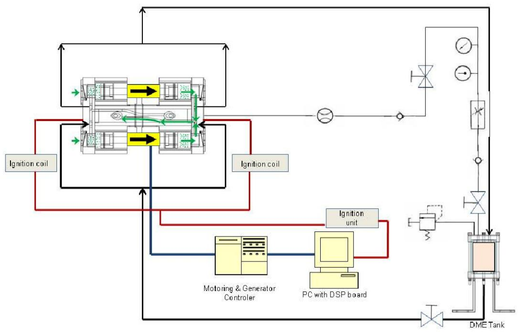

Fig. 18 Schematic diagram for experimental setup

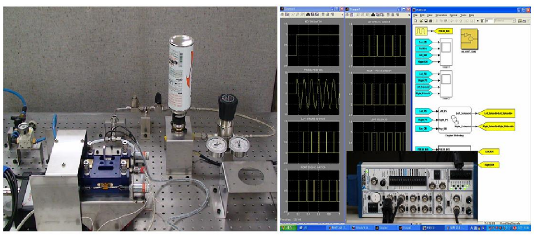

Fig. 19 Photographs for experimental setup(left) and control system(right)

5.2 Experiment Results and Analysis

Fig. 20 and Fig. 21 show a part of data under the condition of idling. Fig. 20 measures the location of piston versus time and Fig 21. demonstrates speed versus the location of piston. Idling frequency was about 50 Hz and its speed was 3 m/s.

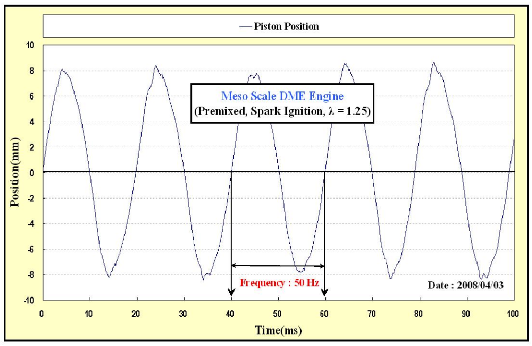

Fig. 20 Piston position versus time

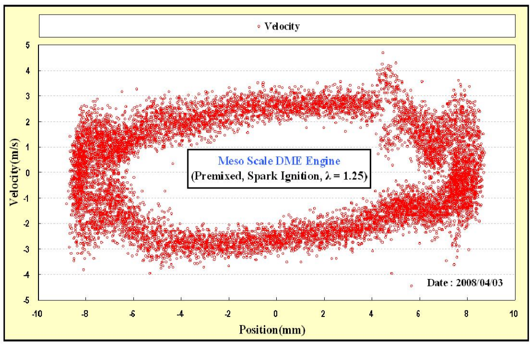

Fig. 21 Piston velocity versus piston position

6. Results and Future Plans

As shown in this study, if 500W NEV vehicles are generated with the efficiency of more than 20%, it can improve the performance and price of NEV vehicles, making better the environment and responding to high oil prices.

Currently 500W pilot generator using ceramic linear engine is manufactured. Experiments are being conducted on it, yet not to evaluate the performance and efficiency but to verify the operation and possibility of its structure and designing variants. If the development is finished, its efficiency and duration will be evaluated and then by applying them to the real NEV vehicles, the performance will be experimented.

References

1. Electric vehicle technology explained, James Larminie and John Lowry, John Wiley & Sons, Ltd.
2. Engineering fundamentals of the international combustion engine, Willard W. Pulkrabek, Pearson Education, Inc.
3. Design and simulation of two-stroke engines, Gordon P. Blair, Society of Automotive Engineers, Inc.
4. The two-stroke cycle engine, John B. Heywood and Eran Sher, Taylor & Francis.