Hybrid Engine Model Using a Stirling Engine and a DC Motor

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The purpose of this paper is to present the possibility to combine a Stirling engine and a DC motor as a hybrid system. The Stirling engine is a heat engine that can be used with various kinds of fuel. The main disadvantages of the engine are the low starting torque and the low engine power. This make the engine cannot start by itself. In this paper we propose how to combine the Stirling engine with a DC motor to solve the problem. Then, we use the DC motor at the starting phase or in the situation that the Stirling engine cannot work properly. This hybrid system consists of a Stirling engine, a DC motor, a driving gear box, a power transmission unit, a battery and a microcontroller. The driving engine can be switched by the microcontroller on the power transmission unit. The hybrid system is tested in a real small train system model. The results show that the system has the maximum speed of 20.4 rpm and the efficiency is about 21.22 % of the injection power.

Keywords: hybrid modelling, Stirling engine, DC motor, cooperative, power transmission.

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1. Introduction

Nowadays, the widely use engines are internal combustion, which consumes fossil fuel, but the fossil fuel will run out someday. Due to the oil crisis in 1970, the development of engine systems that use bio-fuel like ethanol alcohol or biogas can be used to solve this problem. In this case, some kinds of heat engines like Stirling engines can use with various kinds of fuel. In 1970’s, Ford Motor even built a Stirling engine that could drive a car with relatively low power. Many prototypes were built and tested [1]. In 1979 AMC Spirit was equipped with an experimental Stirling engine called the "P-40". The Spirit was capable of burning gasoline, diesel, or gasohol. The P-40 Stirling engine promised less pollution, 30% better mileage, and the same level of performance as the car’s standard internal combustion engine [1]. However, the disadvantages of these engines are low starting torque and low power, which cripples these engines, cannot start by themselves. This problem can be solved by using a DC motor as a power source at the beginning of the starting phase, and then use the Sterling engine at the operating phase. When the oil prices came down in the 1980’s, there were no compelling reasons to build such engines that were substantially more efficient than the internal combustion engine. The hybrid engines have been forgot since then.

In this paper, we present the possibility to combine a Stirling engine with a DC motor as a hybrid system. This combination allows us to get better performance than the normal injection engine.

2. Theory

2.1 Hybrid Engines

A hybrid engine is an engine system that has two or more major sources of propulsion power. The ordinary hybrid engines currently marketed to consumers have mostly combine with combustion engines and electric motors. The system can generate power to the vehicle by either one source independently or in tandem. The hybrid engines normally have 3 structure types; series hybrid, parallel hybrid and combined hybrid. An example of hybrid system is shown in Fig.1.

![Fig. 1. An example of hybrid system](image)

The 2.1.1 Series Hybrid

In a series type, the hybrid system uses a combustion engine to drive an electric generator instead of directly driving the wheels. The electric motor is the only means of providing power to the wheels. The generator both charges a storage battery and generates power an electric motor that moves the vehicle. When a large amount of power is required, the motor draws electricity...
from both the battery and the generator. Thus the power
from the combustion engine has to run through both the
generator and electric motor. As a result, the total
efficiency is inferior to a conventional transmission, due
to the several energy conversions. The block diagram of
series hybrid type is shown in Fig. 1.

2.1.2 Parallel Hybrid

Parallel hybrid engine has combined an internal
combustion engine and an electric motor in parallel
connected to a mechanical transmission. Most designs
they combine large electric generators and motors into
one unit. This unit is often located between the combus-
tion engine and the transmission part by replacing both
the conventional starter motor and the alternator. This
configuration, the battery can be recharged during regen-
erative breaking period. However there is a fixed
mechanical link between the wheels and the motor, the
battery cannot be charged when the car is stand still.
The block diagram of parallel hybrid type is shown in
Fig.2.

![Fig. 2. Parallel hybrid engine](image1)

2.1.3 Combined hybrid

Combined hybrid engine has features of both series
and parallel hybrids. There is a double connection
between the engine and the drive shaft of mechanical
and electrical engine. This split power path allows
interconnecting mechanical and electrical power. The
power to the wheels can be either mechanical or elec-
trical or both. This is also the case in parallel hybrids. But
the main principle behind the combined system is the
decoupling of the power supplied by the engine from the
power demanded by the driver. The efficiency of the
power train transmission is dependent on the amount of
power being transmitted over the electrical path, as
multiple conversions, each with their own efficiency;
lead to a lower efficiency of about 70% compared with
the purely mechanical is 98%. The block diagram of
combined hybrid type is shown in Fig. 3.

![Fig. 3. Combined hybrid engine](image2)

2.2 Stirling engines

The Stirling engine is a heat engine that was invent-
ed by Robert Stirling in 1816. This engine is based on
the Stirling cycle, which uses cyclic compression and
expansion of air or other gas. The Stirling engine has a
sealed cylinder consisted of hot and cold part at the end
of each side. The working gas inside the cylinder is
moved by a mechanism from the hot side to the cold
side. When the gas is on the hot side, it expands and
pushes up on a piston. When it moves back to the cold
side it contracts. The Stirling engine can directly use
concentrated solar energy or it can use burnt alcohol,
coal or any fuel that can produce adequate heat to make
the Stirling engine run. This engine is known as one of
the cleanest heat engines. In theory, efficiency of the
Stirling engine \( \eta \) is given by Carnot’s Law [3] as:

\[
\eta = \frac{Th - Tc}{Th} \quad \text{or} \quad \eta = 1 - \frac{Tc}{Th},
\]

(1)

Where

\( Tc \) = the temperature of the gas when it is cold.

\( Th \) = the temperature of the gas when it is hot.

In this paper, a practical Stirling engine with effi-
ciencies of 50% has been produced. This doubles the
typical efficiency of an internal combustion engine,
which has greater pumping and air flow losses in the
engine and heat losses through the exhaust gas and
cooling system. The structure of a Stirling engine [4] is
shown in Fig. 4.

![Fig. 4. The structure of a Stirling engine](image3)
3. Designed System

The proposed system uses a Stirling engine and a DC motor connected in combined hybrid type. In this case, the driving power can come from either a Stirling engine or a DC motor or both engines. A transmission control unit is controlled by a microcontroller to switch the driving power source.

The DC motor is used to start the Stirling engine and turning together at the beginning phase, because the Stirling engine cannot move by itself. The Stirling engine must use some external forces to start the engine until the temperature at the cylinder is high enough. When the Stirling engine is running properly, the DC motor will stop and the transmission control unit will transfer all driving powers to the Stirling engine. If the turning revolution speed drops below 700 RPM (revolution speed of a vehicle wheel is of 7 RPM) then the driving transfer set will change to the driving mode with the 5 V DC motor again.

Table 1 The Stirling engine specifications

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cylinder bore</td>
<td>2.1 cm</td>
</tr>
<tr>
<td>Cylinder stroke</td>
<td>0.7 cm</td>
</tr>
<tr>
<td>Maximum Volume</td>
<td>15.125 cm³</td>
</tr>
<tr>
<td>Minimum Volume</td>
<td>14.109 cm³</td>
</tr>
<tr>
<td>Max. engine power</td>
<td>64 mW at 3500 RPM</td>
</tr>
</tbody>
</table>

Table 2 The DC motor specifications

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal Operating voltage</td>
<td>5 V</td>
</tr>
<tr>
<td>No load speed</td>
<td>13600 rpm</td>
</tr>
<tr>
<td>No load current</td>
<td>0.27 A</td>
</tr>
<tr>
<td>Maximum current</td>
<td>2.92 A</td>
</tr>
<tr>
<td>Maximum torque</td>
<td>2.92 mN-m</td>
</tr>
</tbody>
</table>

The operation of the system can be concluded as the flow chart shown in Fig. 5.

3.1 Designed System Block Diagram

To make explanation more clearly, the system block diagram is shown in Fig. 6. The system consists of a Stirling engine, a DC motor, a transmission control unit, a gear box, a battery set and a microcontroller installed on a train model that can be moved along the tracks as shown in Fig. 7. The train model is 0.634 kg and considered as a full load of the system.
4. Experimental Results

The system is tested in two types of experiment: The Stirling engine with no load test and the hybrid model speed test.

4.1 The Stirling engine with no load test

This test is done by giving the difference temperature between hot and cool sides of The Stirling cylinder. The average of 3 times experiment is shown in Table 3. Without load, the cold temperature size is tested at 298 K (25 °C) and 308 K (35 °C) while the hot temperature size is tested at 318 K (45 °C) and 573 K (300 °C). It can be seen that with 10 degree different the Stirling engine can run at 1800 rpm and 255 degree it can run at 3500 rpm. The efficiencies of both tests calculated with (1) are quite low at 6.29% and 46.25% respectively. However we can use the system instead of fossil fuel engine with a reasonable speed.

Table 3 The Stirling engine no load test

<table>
<thead>
<tr>
<th>No.</th>
<th>Tc (K)</th>
<th>Th (K)</th>
<th>Speed (rpm)</th>
<th>η (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>298</td>
<td>318</td>
<td>1800</td>
<td>6.29</td>
</tr>
<tr>
<td>2</td>
<td>308</td>
<td>573</td>
<td>3500</td>
<td>46.25</td>
</tr>
</tbody>
</table>

4.2 The hybrid model speed test

In this experiment, the hybrid model is tested as the running of the train model on the tracks by giving the difference temperature between hot and cold sides of the Stirling engine. The train is started with DC motor and switch to the Stirling engine when the torque is enough. The average temperature of the Stirling system is 30 °C at the cold side and the temperature at the hot side is varied from 45 to 300 °C. The result is shown in Fig. 8.

5. Conclusion

The hybrid system combining the Stirling engine and a DC motor is presented. In this paper we propose how to combine the Stirling engine with a DC motor to solve the problem of the starting phase of the hybrid system. We can use the DC motor at the starting phase or in the situation that the Stirling engine cannot work properly. The hybrid model can run by using only the Stirling engine after started by DC motor and has the maximum speed of 20.4 RPM and the maximum efficiency of 21.22 %.

References