Hybrid Engine (Stirling Engine + IC Engine + Electric Motor)

Swadhinpatnaik

I. Introduction
Hybrid engine is a combination of Stirling engine, IC engine and Electric motor. All these 3 are connected together to a single shaft. The power source of the Stirling engine will be a Solar Panel. The aim of this is to run the automobile using a Hybrid engine.

II. Construction Of A Hybrid Engine

III. Components Of A Hybrid Engine
1. IC ENGINE
2. STIRLING ENGINE
3. ELECTRIC MOTOR
4. SOLAR PANEL
5. 12V & 5V BATTERY
6. SPROCKETS [6 nos.]
7. PETROL TANK
8. SHAFT
9. TYRES
10. CHAIN [3 nos.]
11. RESISTOR [2 nos.]
12. THERMOSTAT
13. HEATING COIL
14. LIQUID NITROGEN
15. BEARINGS
IV. Working Of Hybrid Engine

- The 3 engines are connected to the main shaft such that IC engine is placed first followed by Stirling engine in the middle and then the Electric motor.
- The Solar Panel is connected to the 12 volt car battery through a Rectifier and the energy is sent to the battery.
- Then the energy travels to the smaller battery which is connected to the Stirling engine through a heating coil.
- The small battery gives energy to the coil to heat up the cylinder.
- A cooling gasket is fixed to the other cylinder to fill up liquid nitrogen in it for cooling.

V. IC Engine Specifications

- Diameter of piston – 0.050228 mm
- Radius of bore – 0.25114 mm
- Bore length – 46 mm
- Stroke length – 42 mm
- Cubic capacity – 69.9 CC
- Type – 2 stroke

VI. Calculations (IC Engine)

- Displacement = \( \frac{\pi}{4} \times 4.2^2 \times 4.6 \times 1 = 69.79 \) CC.
- Stroke = \( \frac{4D}{\pi \times B^2 \times N} = 4.21 \) cm.
- Bore = \( \frac{4D}{\pi \times S \times N} = 4.6 \) cm.
- Break mean effective pressure = \( 75.4 \times T / \text{Disp.} = 11.15 \) bar.
- Fuel consumption = \( V / T = 10.07 \) kg/hr
- Mass flow rate = \( (\text{Vol} \times \text{Spec gravity}) / (\text{Time} \times 1000) = 0.002803 \) kg/sec
- Efficiency = \( BP / \text{M.F.R} \times CV = 25\% \)
- Torque = \( [W \times S] / 1000 \) L = 5.6
- Power = 2.61KW @ 5000 RPM
- Angular speed = \( (2\pi N) / 60 \)
- Speed (N) = 4980 rpm
- Specific fuel consumption = \( \text{Wt. of fuel} / \text{Power} = 0.036 \) Kg/KW

![Graph showing engine speed vs. SFC, thermal efficiency, MEP, and air/fuel ratio for experimental results](image-url)
VII. Stirling Engine

CONSTRUCTION AND WORKING

VIII. Stirling Engine Heat Source

SOLAR PANEL

STIRLING ENGINE SPECIFICATION
5.1.5.1.2 Sample Engine Specifications

In order to check equations which look quite different, it was decided to specify a particular engine and then determine if the work integral checks. The specification decided upon was:

- \( M(R) = 10.518 \text{ J/K} \)
- \( TH = 600 \text{ K} \)
- \( TC = 300 \text{ K} \)
- \( VL = VK = VP = RD = 40 \text{ cm}^3 \)
- \( HD = CD = 0 \)
- \( AL = 90^\circ \)

TR is defined a number of ways, depending how it is defined in the analytical equation that is being checked. It may be:

1. Arithmetic mean (Walker)
   \[ TR = \frac{TH + TC}{2} = 450 \text{ K} \]
2. Log mean, most realistic
   \[ TR = \frac{TH - TC}{ln(TH/TC)} = 432.8 \text{ K} \]
3. Half volume hot, half volume cold (Mayer)
   \[ TR = \frac{1}{2} \frac{TH}{2} + \frac{1}{2} \frac{TC}{2} \]
   \[ TR = 400 \text{ K} \]

The above sample engine specification is for a gamma engine. For a beta engine assume in addition that \( VM = 0 \). Then:

- \( CD = 0 - 40(1 - \frac{RD}{2}) = -11.715 \text{ cm} \)

5.1.5.2 Dual Piston Engines

5.1.5.2.1 Engine Definition and Sample Engine Specifications

The nomenclature for engine internal volumes and motions are described in Figure 5-9. Also given in Figure 5-9 are the assumed values for the sample case. The following equations describe the volumes and pressures.

- **Hot Volume**
  \[ H(N) = \frac{VL}{2} \left[ 1 - \sin \left( F \right) \right] + HD \]  \hspace{1cm} (5-32)

- **Cold Volume**
  \[ C(N) = \frac{VK}{2} \left[ 1 - \sin \left( F - AL \right) \right] + CD \]  \hspace{1cm} (5-33)

- **Total Volume**
  \[ V(N) = H(N) + C(N) + RD \]  \hspace{1cm} (5-34)
Hybrid Engine (Stirling Engine + IC Engine + Electric Motor)

![Diagram of hybrid engine components]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
<th>Units</th>
<th>Assumed Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>HD</td>
<td>hot dead volume</td>
<td>cm³</td>
<td>0</td>
</tr>
<tr>
<td>RD</td>
<td>regenerator dead volume</td>
<td>cm³</td>
<td>40</td>
</tr>
<tr>
<td>CD</td>
<td>cold dead volume</td>
<td>cm³</td>
<td>0</td>
</tr>
<tr>
<td>VL</td>
<td>hot piston live volume</td>
<td>cm³</td>
<td>40</td>
</tr>
<tr>
<td>VK</td>
<td>cold piston live volume</td>
<td>cm³</td>
<td>40</td>
</tr>
<tr>
<td>TH</td>
<td>effective hot gas temperature</td>
<td>K</td>
<td>600</td>
</tr>
<tr>
<td>TC</td>
<td>effective cold gas temperature</td>
<td>K</td>
<td>300</td>
</tr>
<tr>
<td>TR</td>
<td>effective regenerator gas temp.</td>
<td>K</td>
<td>450</td>
</tr>
<tr>
<td>M</td>
<td>engine gas inventory</td>
<td>g mol⁻¹</td>
<td>1.265</td>
</tr>
<tr>
<td>R</td>
<td>gas constant</td>
<td>J (mol·K⁻¹)</td>
<td>8.314</td>
</tr>
<tr>
<td>M(R)</td>
<td>common gas pressure</td>
<td>MPa</td>
<td>10.518</td>
</tr>
<tr>
<td>P(N)</td>
<td>crank angles</td>
<td>degrees</td>
<td>(N₀⁺N) - 360</td>
</tr>
<tr>
<td>ND</td>
<td>crank angle increment</td>
<td>degrees</td>
<td>N = integer</td>
</tr>
<tr>
<td>AL</td>
<td>phase angle</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 5-9. Dual Piston Engine Nomenclature and Assumptions for Sample Case.

Engine Pressure

\[
P(N) = \frac{H(N) + C(N)}{TH + TC + TR}
\]  \hspace{5cm} (5-35)

5.1.5.2.2 Numerical Analysis

Using the assumed values given in Figure 5-9, Equations 5-32 to 5-35 were evaluated for \( F = 0, 30, 60 \ldots 360 \). The results were:

<table>
<thead>
<tr>
<th>F (Degrees)</th>
<th>V(N) (cm³)</th>
<th>P(N) (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100.0</td>
<td>41.2</td>
</tr>
<tr>
<td>30</td>
<td>87.3</td>
<td>45.7</td>
</tr>
<tr>
<td>60</td>
<td>72.7</td>
<td>54.4</td>
</tr>
<tr>
<td>90</td>
<td>60.0</td>
<td>67.6</td>
</tr>
<tr>
<td>120</td>
<td>52.7</td>
<td>83.0</td>
</tr>
<tr>
<td>150</td>
<td>52.7</td>
<td>91.9</td>
</tr>
<tr>
<td>180</td>
<td>60.0</td>
<td>86.1</td>
</tr>
<tr>
<td>210</td>
<td>72.7</td>
<td>71.2</td>
</tr>
<tr>
<td>240</td>
<td>87.3</td>
<td>57.0</td>
</tr>
<tr>
<td>270</td>
<td>100.0</td>
<td>47.3</td>
</tr>
<tr>
<td>300</td>
<td>107.3</td>
<td>41.9</td>
</tr>
<tr>
<td>330</td>
<td>107.3</td>
<td>39.9</td>
</tr>
<tr>
<td>360</td>
<td>100.0</td>
<td>41.2</td>
</tr>
</tbody>
</table>
5.2.2 Efficiency Prediction

Efficiency of a Stirling engine is related to the cycle efficiency of a Stirling engine which is the same as the Carnot efficiency, which of course is related to the heat source and heat sink temperatures specified. Section 4 gives all the information available on well-designed Stirling engines which have not been fully disclosed and shows how the quoted efficiencies of these engines relate to the Carnot efficiency.

Carlqvist, et. al (77 al) give the following formula for well optimized engines operating on hydrogen at their maximum efficiency points.

\[ \eta_{\text{eff}} = \frac{P_{\text{net}}}{E_F} = (1 - \frac{T_C}{T_H}) \cdot C \cdot \eta_H \cdot \eta_M \cdot f_A \]  \hspace{1cm} (5-42)

where

- \( \eta_{\text{eff}} \) = overall thermal or effective efficiency
- \( P_{\text{net}} \) = net shaft power with all auxiliaries driven
- \( E_F \) = fuel energy flow
- \( T_C, T_H \) = compression - expansion gas temperature, K
- \( C \) = Carnot efficiency ratio of indicated efficiency to Carnot efficiency, normally from 0.65 to 0.75. Under special conditions 0.80 can be reached.
- \( \eta_H \) = heater efficiency, ratio between the energy flow to the heater and the fuel energy flow. Normally between 0.85 and 0.90.
- \( \eta_M \) = mechanical efficiency, ratio of indicated to brake power. Now about 0.85 should go to 0.90.
- \( f_A \) = auxiliary ratio. At maximum efficiency point \( f_A = 0.95 \).

Thus the most optimistic figures:

\[ \eta_{\text{eff}} = (1 - \frac{T_C}{T_H})(0.75)(0.90)(0.90)(0.95) = (1 - \frac{T_C}{T_H})(0.58) \]
5.2.3 Power Estimation by First-Order Design Methods

Some attempts have been made to relate the power actually realized in a Stirling engine to the power calculated from the dimensions and operating conditions of the engine using the applicable Schmidt equation. Usually, the actual power realized has been quoted to be 30–40% of the Schmidt power (79 ad, p. 100).

However, the recommended way of estimating the Stirling engine power output is to use the Beale number method as described by Walker (79 y). To quote from Walker, “William Beale of Sunpower, Inc. in Athens, Ohio, observed several years ago that the power output of many Stirling engines conformed approximately to the simple equation:

\[ P = 0.015 p x f x V_0 \]

where:
- \( P \): engine power, watts
- \( p \): mean cycle pressure, bar
- \( f \): cycle frequency of engine speed, hertz
- \( V_0 \): displacement of power piston, cm³

“This can be rearranged as \( P/(pfV_0) \) = constant. The equation was found by Beale to be true approximately for all types and sizes of Stirling engines for which data were available including free piston machines and those with crank mechanisms. In most instances the engines operated with heater temperatures of 650°C and cooler temperatures of 60°C.

“The combination \( P/(pfV_0) \) is a dimensionless group that may be called the Beale number. It is self-evident that the Beale number will be a function of both heater and cooler temperatures. Recent work suggests the relationship of Beale number to heater temperature may be of the form shown in Figure 5-18 by the full line. Although for the sake of clarity the relationship is shown as a single line, it must of course be understood that the relationship is a gross approximation and particular examples of engines that depart widely may be cited. Nevertheless, a surprisingly large number of engines will be found to lie within the bounds of the confidence limits (broken lines) drawn on either side of the proposed relationship. Well designed, high efficiency units with low cooler temperatures will be concentrated near the upper bound. Less well designed units of moderate efficiency with high cooler temperatures will be located at the lower extremity.

“It should be carefully noted that the abcissa of Figure 5-18 is absolute temperature, degrees Kelvin; engines with the hot parts made of conventional stainless steels (say 18-8) will be confined to operate at temperatures limited to the region indicated by the line A-A. High alloy steels for the hot parts will permit the elevation of heater temperature to the limit of B-B. Above this temperature ceramic components would likely be used in the heater assembly.”

Figure 5-18 is the best information generated by Walker and his students based upon information available to them, both proprietary and non-proprietary.

Figure 5-18. Beale Number as a Function of Heater Temperature.
### IX. Electric Motor

#### Installation Concept And Overview

**Hybrid module operations**

- **Ready for start-stop operation:**
  - The electric motor is running, and can start up the combustion engine fractions of a second by engaging the start-up clutch.

- **Dynamic start:**
  - The start-up clutch is engaged, and the engine is brought to the right torque level in less than 0.7 seconds.

- **Recuperation:**
  - Brake energy is not wasted as heat, but rather stored as electric energy.

- **Boost:**
  - When starting up or accelerating, the combustion engine’s torque is boosted to torque from the electric motor. Especially at low rpm levels, this can fill gaps in the combustion engine’s torque curve.

- **Coasting mode:**
  - For full use of roll energy, e.g., on downhill gradients. Touching the gas pedal alleviates full engine function.

- **Purely electric drive:**
  - For example, diving in noisy protected or non-emission zones, or when maneuvering in tight spaces.

#### Specifications

<table>
<thead>
<tr>
<th>Mild hybrid</th>
<th>Full hybrid</th>
<th>Plug-in hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power [kW]</td>
<td>4–20</td>
<td>20–70</td>
</tr>
<tr>
<td>Torque [Nm]</td>
<td>100–250</td>
<td>100–500</td>
</tr>
<tr>
<td>Voltage [V]</td>
<td>42–450</td>
<td>120–650</td>
</tr>
<tr>
<td>Electric active length [mm]</td>
<td>50–80</td>
<td>55–106</td>
</tr>
<tr>
<td>Fuel reduction</td>
<td>up to 15%</td>
<td>up to 30%</td>
</tr>
<tr>
<td>Functions</td>
<td>Generator Start-stop Recuperation</td>
<td>Generator Start-stop Boost Recuperation Electric drive operation</td>
</tr>
<tr>
<td>Electrical range [km]</td>
<td>1...5</td>
<td>15...45</td>
</tr>
</tbody>
</table>
REFERENCES