Waste Heat Recovery Using the Inverted Brayton Cycle and Additive Manufacture

HiETA Technologies Ltd
Additive Manufacturing Services
13/09/18
Company Profile

Specialists in thermal management and lightweighting solutions enabled by Additive Manufacturing (AM)

Established 7 years with approximately 50 staff

Technology Centre at Bristol and Bath Science Park

Running 11 Powder Bed AM Machines
Waste Heat Recovery
Current Technologies

- **Turbocompounding**
  - Relatively well known and established for heavy duty vehicles
  - Not pure heat recovery – imposes back pressure on engine (causes issues)

- **Thermoelectric generation**
  - Low efficiencies and very high cost, use of rare earth materials

- **Organic Rankine Cycle**
  - High efficiency
  - System of this size is very heavy (~40kg for typical automotive) and expensive
  - Uses hazardous working fluid
Our Solution
Inverted Brayton Cycle

- Three Innovate UK projects undertaken to develop and prove a novel waste heat recovery option based on the Inverted Brayton Cycle.
- Operating conditions set by collaboration with automotive OEM to date however applications such as stationary power, rail and marine are also promising.
Inverted Brayton Cycle
Standard Arrangement

1 – gas enters system (post aftertreatment) at ambient pressure, high temperature
2 – gas expanded to sub-ambient pressure through turbine
3 – heat is rejected through heat exchanger
4 – gas re-compressed to ambient and exhausted through compressor
5 – net work difference between turbine and compressor is taken off via electric machine

- Imposes no backpressure (or back pressure varied through shaft speed)
- Efficient
- Compact and lightweight
- Use of engine coolant – rapid engine warm up
- Proven low cost technology (heat exchanger, turbocharger, e-machine)
- Can be based around electric turbocharger currently on offer from Tier 1 suppliers

System level patent filed
Inverted Brayton Cycle
Enhanced Energy Recovery

1 – Condensing heat exchanger and water separator reduce compressor heat and mass flow = increased energy recovery

2 – Boiling heat exchanger reduces compressor heat = increased energy recovery and generates superheated steam

3 – Steam generated from condensate by low grade sources (enabled by low pressure)

4 – Patented turbine recovers energy from the exhaust and low and high grade steam streams

5 – Opportunity to use condensate to improve engine performance eg direct cylinder cooling.

6 – Integrated electric machine and compressor = improved packaging

Patents filed for hybrid steam turbine and low grate heat recovery
Additive Manufacture
Heat Transfer Surfaces

Compact heat exchangers with low pressure loss are key to system performance.

Our proprietary AM heat transfer surfaces show volume goodness factors >5x conventional surfaces, meaning units can be >5x smaller.

Brown line shows ‘conventional’ surface

Customer Case Studies *(detail excluded for confidentiality reasons)*

4L vs 15L
8L vs 54L
4L vs 51L
70kg vs 1.5T!
Additive Manufacture Integration

- Additive manufacture design freedoms allow
  - Integration of turbine housing, 30 bar steam injectors and header
  - Integration of heat exchangers into diffusers
  - Fine variable grade lattice structures used to create compact water separators
  - Compressor cooling

- HiETA’s aspiration to manufacture the system as a single part
### System Level Test Data

<table>
<thead>
<tr>
<th></th>
<th>Standard Arrangement</th>
<th>Enhanced arrangement – steam generation and energy recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power generated experimentally</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1 kW</td>
<td>2 kW</td>
</tr>
<tr>
<td>Exhaust temp</td>
<td>650 °C</td>
<td>620 °C</td>
</tr>
<tr>
<td>Shaft speed</td>
<td>80 krpm</td>
<td>85 krpm</td>
</tr>
<tr>
<td>Overall engine efficiency improvement (gasoline)</td>
<td>Drive cycle</td>
<td>2-3%</td>
</tr>
<tr>
<td>Motorway cruise</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5%</td>
<td>10%</td>
</tr>
<tr>
<td>Minimum temperature for power recovery</td>
<td>500 °C</td>
<td>350 °C</td>
</tr>
</tbody>
</table>
Summary

- Compact, lightweight and low cost.
- Can be based around electric turbocharger currently on offer from Tier 1 suppliers.
- Highly efficient
- Models validated through physical testing
- Additional opportunities
  - Low grade heat recovery
  - Rapid engine warm up
  - Direct cylinder cooling
  - Control of exhaust back pressure (+ or -)

- Looking for collaboration opportunities with OEM and Tier1 partners to progress and tailor to an application.
Thank you

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