The Effects of an Exhaust Thermoelectric Generator of a GM Sierra Pickup Truck

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Hi-Z Technology Inc.

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Delphi Corporation
Automobile Exhaust Thermoelectric Generator (AETEG)  
Project Overview

• Team – Clarkson University (Prime), Delphi Harrison Thermal System, GM Powertrain Division, Hi-Z Technology, Inc.

• Funding
  – New York State Energy Research & Development Authority (NYSERDA), PM Mr. Joseph R. Wagner
  – Department of Energy (DOE), PM Mr. John W. Fairbanks

• Deliverables
  – Phase I – AETEG Design
  – Phase II – AETEG Integrated into Pick-up Truck, AETEG Performance Test at Test Cell (Delphi), Test Results Analysis

• Vehicle – 1999 Sierra Pick-up Truck
• Engine – V8, 270 H.P., Gasoline
Project Objectives

• Design, Develop, Fabricate and Test 330 W Thermoelectric Exhaust Heat Recovery System for 1999 GMC Sierra Pick-up Truck
• Integrate the AETEG into the Truck Exhaust, Coolant and Electrical Systems
• Design, Develop, Fabricate and Test the AETEG Power Conditioning Unit (PCU)
• Demonstrate Capability of Supplying Electric Power at 12 and 42 V
• Perform Road Test of the AETEG and Estimate the Generator Performance Depending on Driving Conditions
• Develop Computer Model for Truck/AETEG System
• Investigate Opportunities for the AETEG Performance Improvement
• Develop Commercialization Plan for the AETEG System
AETEG Design Parameters

• Electric Power Output
  – 300 to 330 W at hot/cold side $\Delta T = 200^\circ$C and Tcold = 50°C
  – 150-165 W is expected at Tcoolant about 90 °C
• Type of TE Modules – HZ-20
• Number of Modules – 16 each (2 arrays; 8 modules per array)
• Output voltage
  – Suitable to charge 12 V battery
  – Adaptable to 42 V vehicle system
• Power Conditioning Unit (PCU)
  – Automatic match load device
  – DC/DC converter
• Dimensions – 13 inch x 10.75 inch x 8.5 inch
Assembled Thermoelectric Generator (TEG)
AETEG Hot Air Blower Test

AETEG Hot Air Blower Test (Bench PCU Version)

AETEG Hot Air Blower Test (Final PCU Version)
AETEG Power Conditioning Unit (PCU)

- Suitable for
  - 12 V (step down DC/DC converter)
  - 42 V (step down DC/DC converter) vehicle electrical system
- Configuration – combination of automatic match load device and DC/DC converter
- Dimensions – 5 in. x 9 in. x 2 in.
- Weight – 1.17 kg (2.6 lb)

<table>
<thead>
<tr>
<th>PCU Parameters</th>
<th>Capacity</th>
<th>Voltage</th>
<th>Current</th>
<th>Efficiency</th>
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<tbody>
<tr>
<td>Input</td>
<td>330 W</td>
<td>14 – 30 V</td>
<td>(at 30 V) 10 A</td>
<td>88% Average</td>
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<td>Output</td>
<td>290 W</td>
<td>11.5 – 15 V</td>
<td>(at 12 V) 24 A</td>
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# AETEG Hot Air Blower Test Results

<table>
<thead>
<tr>
<th>Regime #</th>
<th>Tc ave, °C</th>
<th>Th ave, °C</th>
<th>AT*, °C</th>
<th>W_{AETEG}, W</th>
<th>W_{PCU}, W</th>
<th>EFF_{PCU}, %</th>
<th>VOC/VLOAD</th>
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<td><strong>March 24, 2004. Test #4</strong> (Before shipping to Clarkson University)</td>
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<tr>
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<td>25</td>
<td>82.5</td>
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<tr>
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<td>47.37</td>
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<td>26.1</td>
<td>120</td>
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<td>78.45</td>
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<td>NA</td>
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<td>65.3</td>
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<td>21.31</td>
<td>90.3</td>
<td>1.36</td>
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</tbody>
</table>
AETEG Hot Air Blower Test Results

![AETEG Power Output vs DeltaT Diagram]

- **AETEG Designed Power Output**
- **AETEG Measured Power Output**

Limitations of Laboratory Heat Source
Test Vehicle – 1999 GMC Sierra Pick-up Truck
AETEG System Schematic

Systems: Red: Exhaust  Blue: Coolant  Green: Electrical

- Battery
- 12 VDC bus
- Rectifier
- Alternator
- Thermo-statically controlled
- Power conditioning unit - buck converter
- PCU
- AETEG
- Exhaust
- Catalytic converter
- Drive shaft
- Engine
- Pump
- Radiator
- Bypass inside engine
- Firewall
- Heater core
- Taps in engine compartment
- Coolant
- PCHX
Left Side View of AETEG Installed in Test Truck
Test Matrix

- Test configuration
  - A: Baseline, No TEG
  - B: with TEG
  - C: with TEG & Exhaust insulation
  - D: with TEG, Exhaust insulation & PCHX

- Speeds
  - Idle
  - 30 mph
  - 50 mph
  - 70 mph

- Tunnel air inlet temperature
  - 40° F
  - 70° F
  - 100° F

- Electrical load
  - Base
  - Base+25 amps
  - Base+50 amps
Power Generated by TEG as a Function of Vehicle Speed Meets Expected Power Production of 150 W.
TEG Power as a Function of Coolant Inlet Temperature

- without PCHX
- with PCHX

Vehicle speed:
- 30 mph
- 50 mph
- 70 mph

Power generated by TEG - (watts)

TEG coolant inlet temperature - (°F)
TEG Power as a Function of Exhaust Gas Inlet Temperature

Vehicle speed:
- Red line: 30 mph
- Blue line: 50 mph
- Green line: 70 mph

- Uninsulated exhaust
- Insulated exhaust pipe

Average catalytic outlet temperature

Power generated by TEG - (watts)

Exhaust gas inlet temperature - (°F)
AETEG Cost-Effectiveness Considerations

(Approach for 1 kW Diesel Truck Cost Benefits Estimation)

Specific Fuel Consumption (SFC) presented in lb/H.P. - hr
Project Achievements

- Waste Heat Recovery System for the 1999 GMC Sierra Truck has been Designed, Developed, Fabricated and Tested
- Power Conditioning Unit Capable of Supplying Electric Power for a 12 V Truck System has been Designed, Developed, Fabricated and Tested (Clarkson and Hi-Z are in process of applying for a patent)
- PCU for a 42 V Vehicle Electrical System has been Designed
- AETEG/PCU System has been Integrated into the Sierra Truck
- AETEG/PCU System was Tested at Hi-Z with Hot Air Blower
- AETEG/PCU Performance was Evaluated Depending on Driving Conditions at Delphi Corporations’ Thermal System Division at Lockport, NY
Project Achievements (Continued)

• Capability of Producing Designed Electric Power Output by the AETEG has been Demonstrated
  – Power Output Over 140 W has been Measured When Tcoolant was about 80°C (expected power production was about 150 W)
  – Power Output About 255 W has been Measured When Tcoolant was about 25°C (expected power production was about 300 W)
  – 300 W Power Production can be achieved with Upgraded PCU

• PCU Capability of Supplying 14-15 V to the Truck Electrical System has been Demonstrated

• PCU Average Efficiency of 88% has been Demonstrated. Lower efficiency measured during the test cell is associated with the defective PCU chip that was later replaced.

• AETEG Computer Model has been Developed and Evaluated Based on the Test Results Analysis
Next Steps

• Phase II B is Currently in Progress
• Evaluate the AETEG Performance (Computer Modeling) Based on Assumption of Using QW Thermoelectric Modules and Data Obtained During the AETEG Tests
• Develop Plan for Further AETEG Performance Improvement, Considering Following Steps:
  – QW Thermoelectric Materials Use
  – Heat Transfer Improvement via Design Optimization
  – Cooling System Enhancement (Separate AETEG cooling loop vs PCHX Upgrading Options)
  – AETEG Weight Reduction Through Innovative Materials Employment
• Manufacturability Enhancement via Design Simplification and Heat Exchanger Casting Instead of Machining Option
• Commercialization Plan Details Development
Acknowledgments

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NYSERDA

Project members

Clarkson University

Hi-Z Technology, Inc.

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