

Thermoelectric Generator (TEG) for Heavy Diesel Trucks

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Abstract

An improved TEG for the Heavy Duty Class Eight Diesel Trucks is under development at Hi-Z Technology. Previous efforts were focused on TEG prototype development, fabrication and testing. The prototype was able to generate about 1kW of electrical power from the Cummins NTC 350 Diesel engine exhaust but exhibited mechanical degradation during the subsequent road test due to module movement. The current TEG is designed to be equipped with the improved HZ-14 Thermoelectric (TE) modules, which features better mechanical properties; also, the modules are securely held in place.

The TEG is comprised of 72 TE modules (9 in one array, 8 parallel circuits), which are capable of producing 1kW of electrical power at 12 V DC during nominal engine operation. This device utilizes an engine coolant to cool the cold side of the modules. The hot side of the modules is placed on the octagonal shaped surface of the adjacent side of the Diesel exhaust heat exchanger. The center body of the heat exchanger directs incoming exhaust flow that interfaces with the internal heat exchanger fins in order to optimize the heat transfer and deliver the maximum energy to the TE modules.

Currently the upgraded generator has completed testing in a test cell and later will be tested on a Diesel truck under typical road and environmental conditions. It is expected that the TEG will be able to replace or augment the existing shaft driven alternator, resulting in significant fuel saving or to generate additional power that is required by the truck's accessories.

Background

The current project started late 2000 as a four-year effort funded by the U. S. Department of

Energy (DOE). The major goal is to design, fabricate and road test 1 to 3 kW TEG for Class 8 Heavy Diesel Trucks. Previous efforts⁽¹⁾ demonstrated the feasibility of 1kW TEG but experienced some mechanical problems during the road test⁽²⁾. New improved thermoelectric modules (TEM), HZ-14 were utilized for this project.

These modules are manufactured by the newly patented technology that allows for a large-scale automated production with an associated reduction of the production cost. The HZ-14 contains 49 bismuth-telluride couples electrically separated by a special frame called an "eggcrate". The eggcrate is manufactured by an injection molding process that makes the TEM fabrication less expensive. The eggcrate and HZ-14 module are presented in Figure 1.

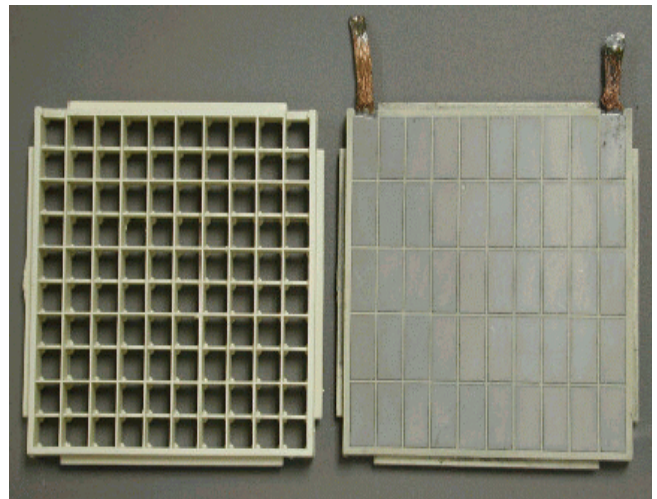


Figure 1— Eggcrate and HZ-14 thermoelectric module

Current - Voltage Curves
HZ-14 with 200° C Temp Difference

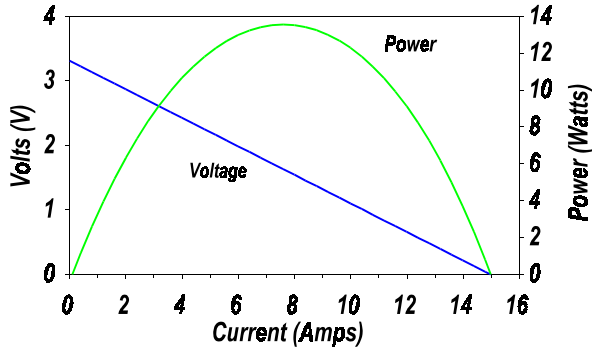


Figure 2—) T vs. Open Circuit Voltage

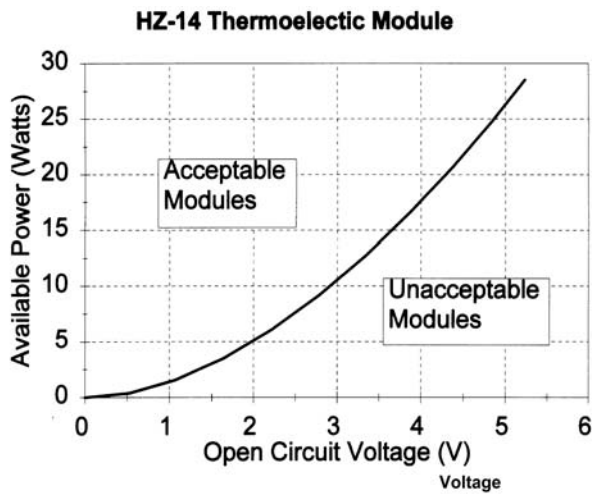


Figure 3—Power vs. Open Circuit Voltage

A set of 72 TEM (8 arrays with 9 module in each array) was selected for this project by performance and thickness. The TEM thickness variation for each array was less than 0.001" to ensure uniform compression of the modules.

In order to prevent TEM lateral movement aluminum strips (0.032" thick) were epoxy bonded to the heat sinks on each side of the module. In addition, RTV was applied to the heat sink at the TEM corner.

A new high temperature thermally conductive grease was formulated and tested at Hi-Z. It demonstrated superior performance at TEM hot

side operating temperature (about 250 - 275/C) and was selected for the TEG assembling.

TEG Design and Assembling

The generator is comprised of the following major components:

- Steel heat exchanger - manufactured of Ni Resist steel. . . , the external surface has octagonal cross section, flat surfaces precisely machined in order to have an adequate flatness for better heat transfer from the heat exchanger to TEMs. The internal surface of the heat exchanger is equipped with fins (as shown in Figure 4) that enhance the heat transfer rate from the Diesel exhaust to the heat exchanger.

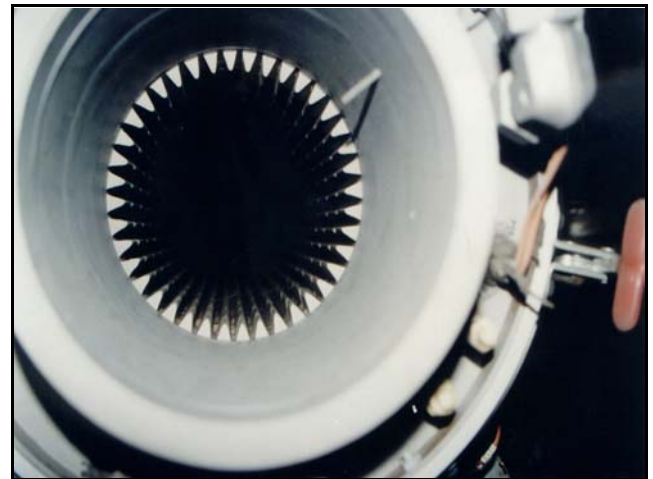


Figure 4—Internal surface of the heat exchanger.

- Displacement central body - hollow structure manufactured from steel, external surface equipped with the vanes that provide for a vortex creates a more uniform temperature profile of the heat exchanger surface and TEMs. Figure 5 illustrates the displacement body during installation into the heat exchanger.

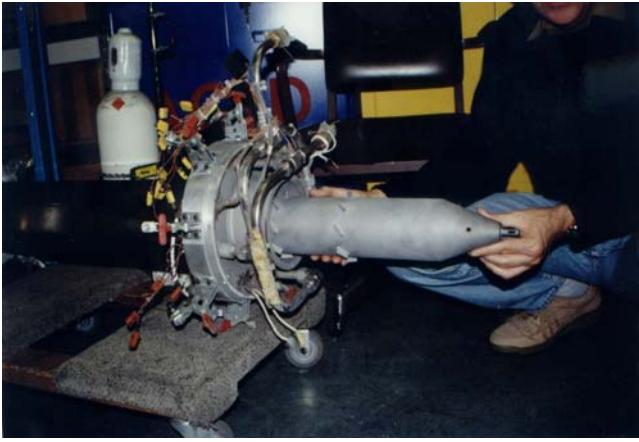


Figure 5—Displacement central body installing in the heat exchanger.

- Heat sink - manufactured from aluminum, the heat sink is actually on an elongated box with the fins inside for better heat transfer. Eight heat sinks are used in the design, each heat sink services nine TEMs. The heat sink is designed for a liquid cooling system in order to keep the cold side of the TEM at the lowest possible temperature. Two manifolds: one for the coolant inlet, another for the outlet, are incorporated into the TEG design. The heat sink with the TEMs and ceramic wafers are displayed in Figure 6.

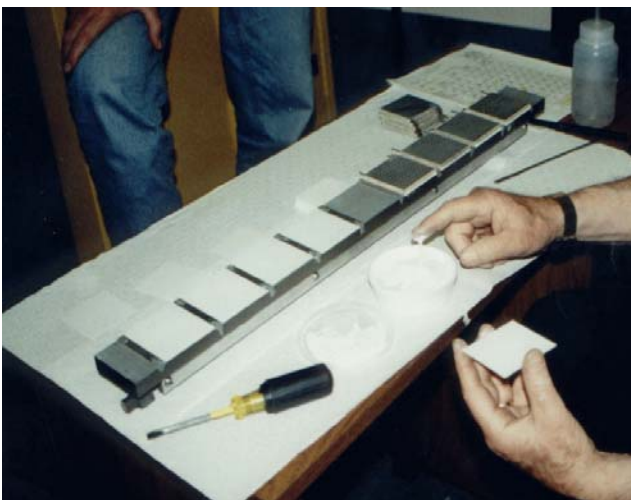


Figure 6—Heat sink with TEMs and ceramic wafers.

- TEMs design and fabrication - discussed above. The TEM is mounted on the heat

sink with the ceramic wafers (0.010" thick) on the cold and hot sides in order to prevent electric contact between the couples. All the surfaces (heat exchanger, both surfaces of the ceramic wafers, both surfaces of the TEM and the heat sink) are covered with a thin layer of thermally conductive grease in order to minimize any ΔT_s at the interfaces.

- Electric system - the TEMs are connected in series within each heat sink (array) and the arrays connected in parallel/series combination that generates an electric power of about 30 V DC at match load.

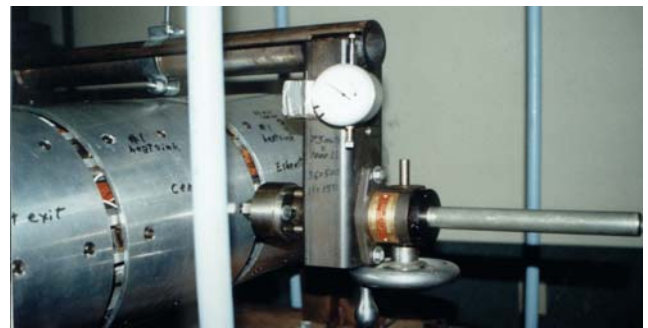


Figure 7—Applying pressure to the TEMs.

- Compression system - consists of three aluminum rings with threaded holes that allow screws and Belleville washers to apply the adequate pressure on the heat sink and TEM. The process of applying pressure to the modules is displayed in Figure 7.

The assembling process was similar to that described by Bass ⁽²⁾. The displacement body was installed into the heat exchanger. The TEMs, ceramic wafers, heat exchanger and heat sinks are covered with thermally conductive grease and fixed on the flat surfaces of the heat exchanger with a special fixture. The cooling system was assembled by connecting the heat sinks and manifolds with special hoses. The TEMs and array bus bars were electrically interconnected and then the compression rings were installed and pressure applied. Complete assembly of the TEG is presented in Figure 8.

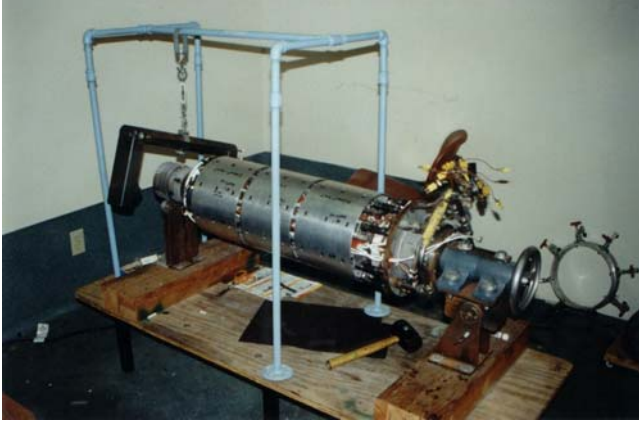


Figure 8— Complete assembly of the 1kW TEG.

TEG Hot Air Test

Prior to in-cell testing, the TEG was tested at Hi-Z with the hot air blower that simulated Diesel engine exhaust. The hot air blower (with integrated heater) is capable of supplying about 165 cfm of air heated up to 500/C. This test was conducted in order to the general functionality of the TEG and major subsystems such as electrical (array interconnection, bus bars, terminals), cooling system and measurement system.

Two loading devices were designed and fabricated. The first - the electronic loading device (ELD) allows for fine-tuning the load and to setting the optimal voltage/current conditions. The ELD is shown in Figure 9. The second loading device is comprised of six car headlights, interconnected in parallel/series way to match the TEG resistance.

The TEG is equipped with the 12 thermocouples that to measure the temperatures at different places the generator, such as hot and cold side of the TEMs, temperatures on the face of the heat exchanger and heat sinks.

One array of the TEMs (heat sink #1) has special wiring that allows measuring open circuit voltage and voltage under loading from individual modules. These measurements indicate the uniformity of the temperature differential profile and the amount of power produced in different sections of the generator.

Figure 10 illustrates the TEG test setup with the hot air blower and car light bulbs loading device.

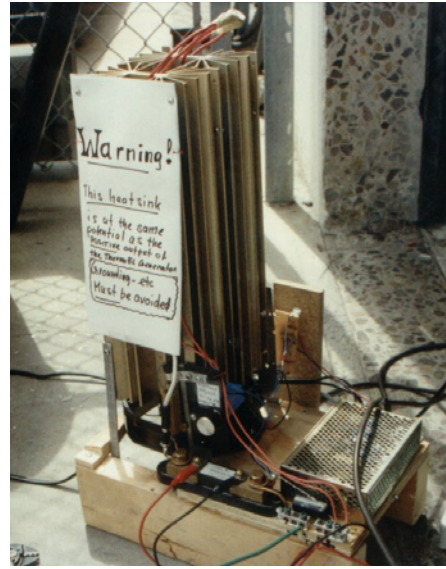


Figure 9— Electronic Loading Device.



Figure 10—Hot air blower TEG test setup with car light bulbs load.

In-Cell TEG Test

The in-cell generator test was conducted with Cummins 335 Diesel engine. The experimental test setup is shown in Figure 11.

During this test the engine loading was changed from 75 to 290 horse power (HP), the engine was ranged from 1300 to 2100 RPM. The exhaust flow rate at 2100 RPM, 335 HP and 627/C exhaust temperature estimated of 2500 CFM.

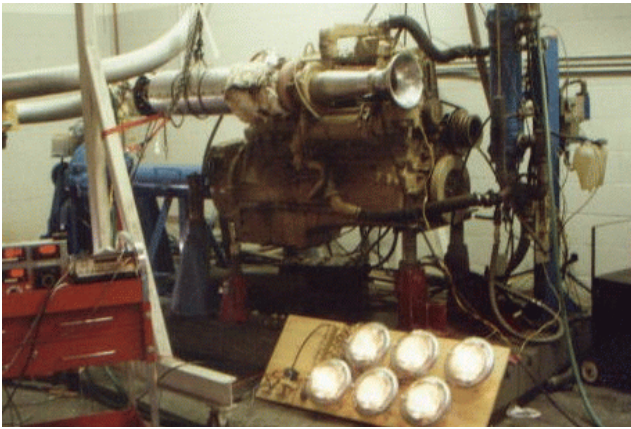


Figure 11—1 kW TEG in-cell test. ELD and light bulb load operate simultaneously.

It was found that TEG power output strongly depended on engine loading and less on the engine speed as illustrated in Figure 12 and in agreement with the data reported by Bass⁽²⁾. The highest electric power output from the TEG (over 900W) was recorded at engine load close to 300W. The test engine did not allow us to reach nominal load that limited power production by TEG.

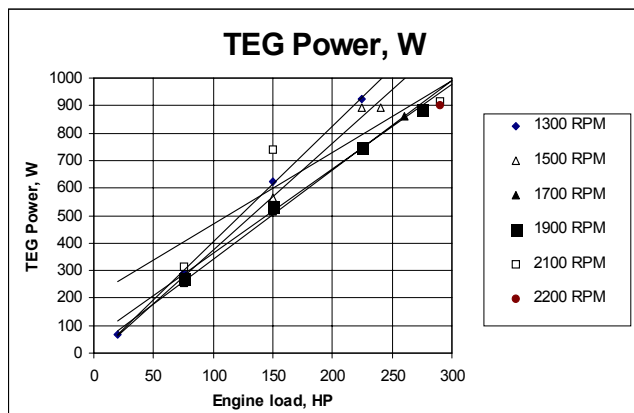


Figure 12—TEG power output as a function of the engine load and speed.

The next test of the generator is scheduled to start in June as a joint effort with our industrial partner, Paccar. The test will be conducted on a real truck equipped with the Cummins 550 HP engine. The TEG performance will be evaluated at different driving conditions. In addition, the resistance to shock and vibration will be investigated.

Taking into account the in-cell and road driving test results the new generation of the TEG will be designed, fabricated and tested in the next year.

Acknowledgments

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References

1. Bass, J. C., Elsner, N. B. and Leavitt, F.A., “Performance of the 1kW Thermoelectric Generator for Diesel Engines...”
2. Bass, J.C., “Design and Test of Prototype 1kW Generator for Diesel Engines” Final Report, June 23, 1997, contract 500-90-025, California Energy Commission, Energy Technologies Advancement Program, Transportation Energy Technologies Advancement Program.
3. Leavitt, F.A., Elsner, N.B., Bass, J.C., “Use, Application and Testing of the HZ-14 Thermoelectric Modules”.