P08441: Auto Exhaust Heat Recovery Test Plan

***Standard Test Conditions*:**

- Mass Flow Rate = .04kg/s
- Gas Inlet Temperature = 550K
- Blower Air Velocity Over Fins = 17m/s
- Room Temperature = 295-305K

The **Standard Test Conditions** define the conditions at which the Thermoelectric system will be tested to verify the engineering specifications. The design of the thermoelectric generator has been optimized for the test conditions which are based on real world data. For the general test procedure, and details for collecting data needed in the specification verification, refer to the Preliminary Test Plan at the end of this document.

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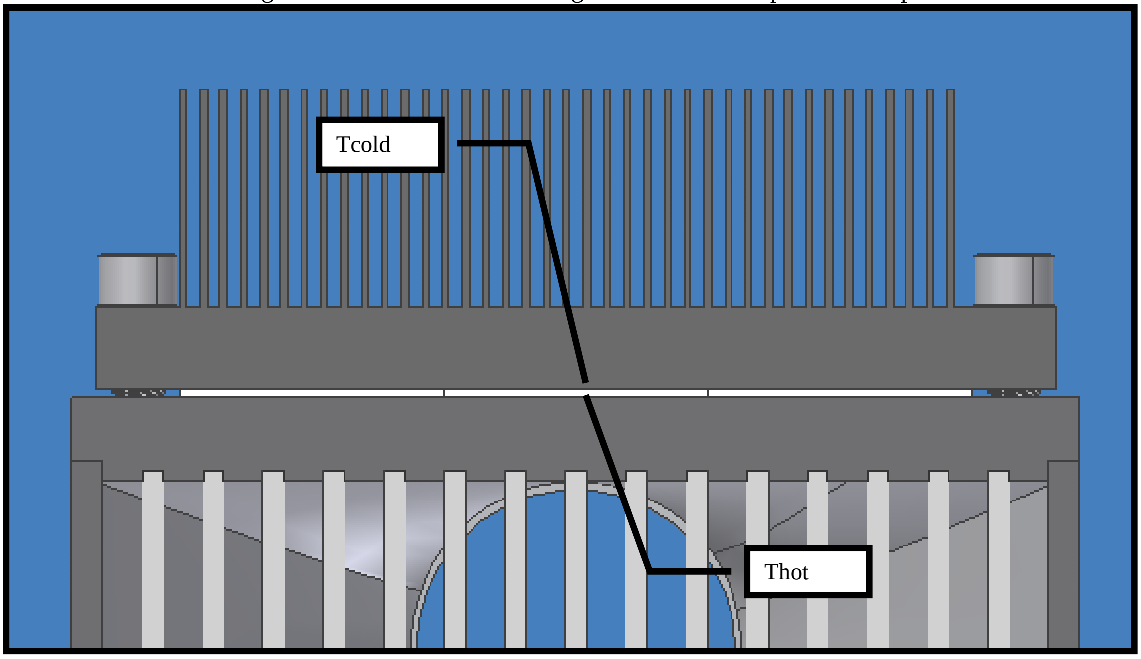
Metric	Need	Test Plan	Units	Marginal Value	Ideal Value
1	Appropriate exhaust temp.	T_{INLET} will ensure that the exhaust gas temperature entering is an appropriate temperature for operation.	Kelvin	500	550
2	Appropriate exhaust flow	The test stand has a flow meter built in. The flow can also be adjusted over a range from .01-.08kg/s on the test stand.	kg/s	0.02	0.04
3	Appropriate exhaust material: melting point	The melting point of the 6061 Aluminum being used is over 1000C while the temperatures that the aluminum will experience will be 400C as a maximum.	Celsius	1000	1500
4	Temperature range for test fixture	The test fixture has the ability to range from 300-600C. Furthermore, the T_{INLET} thermocouple will measure the incoming exhaust gas temperature.	Celsius	300-400	300-600
5	Flow range for test fixture	The specification is within the test stand limitations and will be monitored with the built in flow meter.	kg/s	.02-.06	.01-.08
6	High thermoelectric module efficiency	The thermoelectric efficiency will be determined under the **Standard Test Conditions**. $\eta_{Thermoelectric} = \frac{P_{Output}}{kA(T_{Hot} - T_{Cold})/t}$ The T_{Hot} and T_{Cold} temperatures come from the thermocouple readings. The k is a given spec from manufacturer of the thermoelectrics and both the thickness and area are measurable.	%	1.5	2
7	Suitable thermoelectric max operating temperature	The maximum operating tempertaure of the Melcor thermoelectrics is 225C.	Celsius	200	225
8	TE can withstand vibrations and shocks	Talk with Dr. Stevens about modifying or removing this specification.	1 Foot Drops	3	5
9	Adequate power generation	To obtain the maximum power generation the thermoelectrics will be attached to a load, a rheostat or similar, and the power supplied to the load will be measured as the load is varied under the **Standard Test Conditions**.	W	65	100+
10	Thermoelectric is optimized for flow temperatures that we are able to model	We need to ensure that we are maximizing the potential of our thermoelectric by creating the largest temperature difference possible. To measure this number we will take the reading from the thermocouples on the hot side and subtract the temperature from the thermocouples on the cold side (both from the inlet end).	Celsius	130	230
11	Low cost for thermoelectrics	The thermoelectrics that we are ordering are under $30 each. This easily meets the specification.	$/TE	<200	<100

12	Average upstream hot side of TEG @ Proper Temp.	Thermocouples will be attached under the upper and lower foremost thermoelectrics on the hot side to monitor the hot side temperature. The maximum temperature the Melcor models can operate at is 225C. An average will be taken between the two thermocouples.	Celsius	200	225
13	Average downstream hot side temperatures are adequate	Thermocouples will be attached under the upper and lower downstream thermoelectrics on the hot side to monitor the hot side temperature. The maximum temperature the Melcor models can operate at is 225C. An average will be taken between the two thermocouples.	Celsius	130	160
14	Average cold side of TEG@ proper temp.	Thermocouples will be attached under the foremost and the furthest thermoelectrics on the cold side to monitor the cold side temperature. An average of the four readings will be taken.	Celsius	100	40
15	Appropriate exhaust material: pipe surface does not oxidize or corrode	Pictures of the inner surface will be taken before any testing is done and after each test performed. Any changes noted upon visual inspection will indicate that corrosion has occurred on the surface of the metal.	Flow reduction (Pa)	50	0
16	Negligible Pressure Drop	The pressure sensors on the thermoelectric test stand will be able to measure the pressure of the gas entering and exiting the TEG structure. The difference between P_{IN} and P_{OUT} will give the pressure drop.	Pa	1100	500
17	Low cost for a mass production unit	We will price out each component as if we were buying it in mass quantity and subtract the testing materials from the BOM for a high production unit.	$	1500	500
18	Maintain adequate contact pressure (set by supplier)	To measure the contact pressure on the thermoelectrics we can use the bolt torque. By measuring the bolt torque at steady state operation we can back out the resultant bolt load and thereby get the equivalent pressure on the thermoelectrics. Furthermore, we will first run a test with pieces of steel in the place of the thermoelectrics and then measure the bolt torque to find the resultant pressure.	psi	225±75	225±25
19	Reasonable size, specifically height	The height of the system can be simply measured using a ruler. The measurement will be from the tops of the fins of each of the heatsinks.	m	0.25	0.15
20	Run Vehicle Sub System	The ability to charge a battery can be determined by measuring the voltage across the battery. A slightly discharged battery, with a lower voltage, will be attached to the system and, after charging, an increase in the battery voltage, from approximately 11 V to 12.65 V, shall be verified. Test will be performed under **Standard Test Conditions**.	n/a	battery	head lights
21	Verify system efficiency	The system efficiency will be tested under the **Standard Test Conditions** and verified with the following equation: $\eta_{System} = \frac{P_{Output}}{\dot{m} C_p \left(T_{Exit} - T_{Inlet}\right)}$ The mass flow rate is measurable and will be known in the standard test conditions. The inlet and outlet temperatures of the gas can be measured from thermocouples in the test fixture.	%	0.5	1

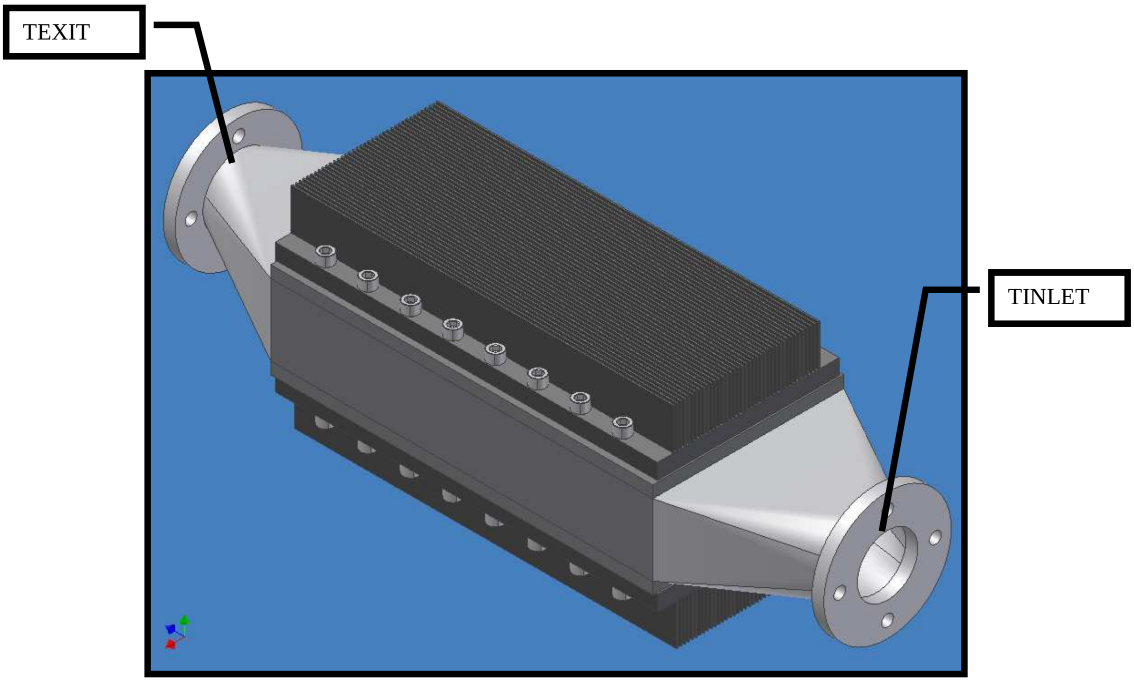
22	System output voltage	The output of the battery charging circuitry will be measured while attached to a load under the **Standard Test Conditions**. This should be sustained while varying the test conditions. After running for 1 hour under **Standard Test Conditions** with a variety of loads, the output of the regulator should again be verified.	Volts	14±3	14±1
23	Durability of System	The design of the system is such that there are no moving or complex parts.	Years	5	10
24	User protected from electrical and thermal components	The thermoelectrics will be inspected before use to ensure that all electrical components are insulated. Furthermore, the wiring scheme will be inspected before testing. Protection diodes and fuses will be implemented to prevent over-current states.	Accidents	<1	0
25	System parameters easily obtained from testing	The placement of the thermocouples will allow easy attachement to the DAQ.	Labview Compatible	Mostly	Yes

Temperature Readings:

It is critical to ensure that the upstream thermoelectrics do not exceed 225C. Above 225C they can be damaged due to the material limitations of the internal construction. Therefore, for both the top and bottom, there will need to be a thermocouple on the hot and cold sides on the lead thermoelectrics and last thermoelectrics. The diagram below shows the labeling scheme for the top thermocouples at the entrance.



The temperatures at the inlet and exit are needed for the system efficiency calculations. These thermocouples are on built into the test stand.



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Preliminary Test Plan:

Equipment:

- 4 Thermocouples
- Labview and DAQ
- Test Stand
- Blower
- TEG Structure
- Multimeter
- Battery and charging circuitry
- Rheostat

Procedure:

1. Attach TEG structure to test stand by bolting the flanges in place and ensure system is secure and ready to operate. The sensors will have been added to the system during the assembly process.
2. Connect the TEG structure sensors to the DAQ. There will be a thermocouple on the center of the hot side surface for both the first and last set of thermoelectrics. Additionally, there will be a thermocouple in the center of the cold side surface for the first and last set of thermoelectrics. Finally, there will be a thermocouple in the exhaust stream inlet and exit which are built into the test fixture. With the flow rates and temperatures one can determine the efficiency of the system.
3. Connect TEG structure to rheostat that is set to be the theoretical internal impedance of the TEGs.
4. Ramp up test stand to 200C at .01kg/s. Also start the blower on high setting to simulate vehicle airflow at cruising speed.
5. Check the torque on the bolts to determine the pressure on the thermoelectrics.
6. Allow the TEG structure to reach steady-state operation. Steady-state will be the point at which the temperatures on the hot and cold side have stopped fluctuating.
7. The rheostat will then be varied in order to verify the internal impedance of the TEGs. Maximum output power will occur when the internal impedance is matched.
8. Note the power output, hot and cold side temperatures, gas temperatures and pressures.

9. Increase flow rate in .01kg/s increments until the flow rate reaches .04kg/s. Record data in step 6 at each increment after the system reaches steady-state.
10. Increase temperature at 25C increments and record data in step 6 at steady state operation for each increase. Stop increasing temperature once the inlet exhaust gas temperature reaches 275C (or 550K). Record the temperatures and power output.
11. Once at steady state, and hot the maximum temperature on the hot side of the TEs is approximately 200C attach TEG structure to battery charging circuitry. Monitor the voltage on the battery using a multimeter to determine whether or not the battery is charging or discharging. Also check the torque on the bolts to determine the pressure on the thermoelectrics.
12. Turn off blower and test stand. Allow the TEG structure to cool and remove is modifications are necessary.