Original Research Paper

ENGINEERING

POWER GEN-UTILIZING WASTE POWER

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ABSTRACT The thermoelectric generator (TEG) is a device for directly converting thermal energy into electrical energy based on the Seebeck effect and it has presented urgent potential in the case of waste heat recovery. The TEGs have many advantages such as no moving mechanical parts, long-lived, quiet, environmentally friendly and requiring little maintenance. As a significant cause for the fuel crisis and environmental pollution, the internal combustion engine (ICE) drives vehicles with only 30% of the total heat generated by the gasoline used. During this process, the other 40% of the heat is lost through waste gas exhaust and 30% by the coolant. The TEG using automobile waste exhaust as heat source is believed a new way to reduce ICE loads as well as the alternator and then decrease fuel consumption and environmental pollution.

KEYWORDS : TEG, Thermal Energy, Environment, Fuel Crisis

1. INTRODUCTION

1.1 Thermoelectric Generator (TEG)

Many automobile manufacturers, such as GM in the USA, BMW in the Germany, successfully developed TEGs to recover the exhaust waste heat. Considering the challenges of complex automotive environment and being made commercially, the Be_2Ti_3-based bulk thermoelectric material was selected by most of the automobile manufacturers for application. However, limited by the thermoelectric materials, the efficiency of TEG system was limited and totally less than 5%. It was noticed that the temperature of exhaust gas is not constant and reducing along the flow direction in the TEG system in Lu's work. The thermal variability and poorly controlled thermal conductivity accounts for the individual module's poor working performance under temperature mismatch conditions. Hsu et al. suggested applying an appropriate pressure on the thermoelectric modules to improve performance. Andrea et al. xperimentally quantified the power loss due to temperature mismatch in TEG arrays and discussed advantages as well as drawbacks of TEG arrays in series and parallel. It is convinced that the thermoelectric modules in series connection perform better than in parallel connection.

In this study, an individual thermoelectric module (TEM) test system has been adopted for the measuring, testing and analyzing of the data acquired from the TEM used. The effect of clamp force pressed on the module is discussed and a database about the max power output is obtained under various temperature differences. Based on the experiment of individual module, the performance of TEG system (TEMs connected electrically in series) is tested and analyzed with a test bench. In addition, the power lost due to mismatched conditions is quantified and discussed. The performance of the TEG is improved by the adjustment of thermal insulation, as explained in the following sections.

2. EXPERIMENTAL SETUP

A TEM is composed of many thermoelements in series electrical link to increase operating voltage and in parallel thermal connection to increase the thermal conductivity. TEMs convert thermal energy to elecrical energy based on Seebeck effect when temperature difference occurs. As is shown in Fig. 1b, the electrical equivalent circuit of the TEM includes an ideal voltage Voc and an internal resistance RL, which is similar to a battery. The configuration of the TEG is presented in Fig. 1c. TEMs are placed on the top and the bottom surface and mounted uniformly over the available surface of the heat exchanger (60% of total surface area) as is shown. The inlet and outlet ports of the box are connected to the exhaust pipe of the automobile. The cold-side temperature of the modules is maintained by the engine coolant systemTwo bench tests are adopted for the measurement of TEM and TEG system.

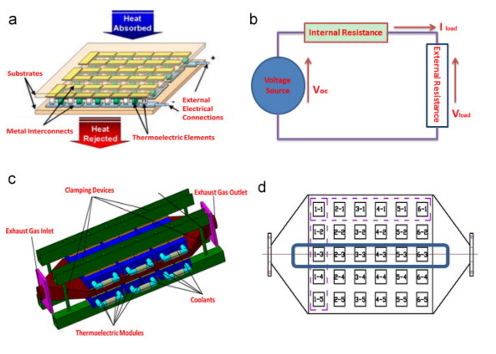

Fig. 1. Schematics of a TEM and TEG: (a) a TEM in generator mode, (b) electrical model of the TEM, (c) the structure of TEG, (d) the locations of TEMs in TEG system.

As is shown in Fig. 2, an individual TEM test system is used to measure the performance of a single TEM under different temperatures. An individual TEM (50*50 mm) provided by Institute of New Material in Wuhan University of Technology is sandwiched between a cold block on the upper side and a hot block on the bottom side. The former contains an oil tank cooled by a thermostatic oil bath (−10 °C to 120 °C), while the latter is a high-temperature heater (20 –700 °C) powered by a DC power supply. An adjustable load cell is used to apply the pressure over the TEM and the output power, as well as voltage, can be measured by an electronic load.

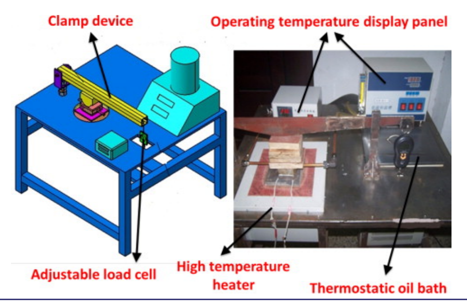

Fig. 2. The setup of the individual module test system.

3. THERMAL INSULATION

In the TEG system, the temperatures attached to the hot side of the TEMs decrease along the exhaust flow direction, which leads to different individual electrical performance of the six modules. When linked in series, the six modules operate at the same current and some power lost due to this temperature mismatch conditions, as is discussed in Section 3.2. Limitation of the selected TEM that restricts the allowable operating temperature is another factor resulting in temperature mismatch condition. The electrical characteristics change and shift when the temperature difference varies by regulating the thermal conductivity.

Three different thickness of silica fiber cloth, ranging from 0.1 mm to 0.3 mm, are selected to adjust the heat transferred to the hot side and investigate the effect to the electrical performance. The experiment is carried out with the individual module test system and the silica fiber cloth is mounted between the hot block and the hot side of the TEM as is showed in Fig. 3. The clamp load pressed on the module is set as 180 kg. As shown in Fig. 4, the electrical characteristic of the same module varies greatly with different thermal insulations, which works at the temperature of hot side 250 °C and cold side 90 °C. The maximum electrical power reduces from 2.2 W to 1.33 W with 0.1 mm silica fiber cloth thermal insulation, while the current of the operating point changes from 1.2 A to 1 A. In the cases of 0.2 mm and 0.3 mm, the optimum operating current shifts from 0.8 A to 0.6 A, while the maximum power changes from 0.92 W to 0.6 W. Table 1 lists the electrical characteristics of the module with 0.1 mm, 0.2 mm and 0.3 mm thermal insulation cases when the working temperature exceeds 350 °C. The thermal insulated module works safely with the temperature above 350 °C, which is not allowable for the no-insulation one. The optimum operating point is also changed and the maximum electrical power decreases.

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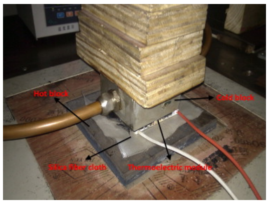

Fig. 3. The schematic of thermal insulation test.

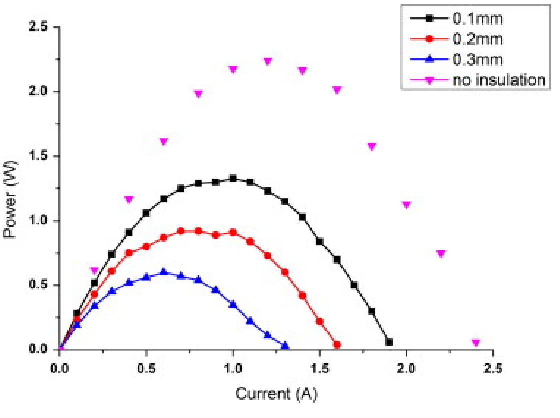

Fig. 4. Results of individual TEM thermal insulation test.

4. CONCLUSION

This work describes the electrical performance of the TEM and TEG system under mismatch conditions, such as the limited working temperature and the inconsistent temperature distributions among the modules in series connection. An individual module test system and a test bench have been designed and adopted to test and analyze the impact of thermal imbalance on the output electrical power at module and system level.

The experimental data are presented to illuminate the effect on the electrical performance when the modules are operated under mismatch conditions, such as mechanical load and temperature. It is concluded that a proper mechanical pressure applied on the module improves the electrical performance. The experimental results show that the power loss of the modules in series connection is significant, 11% less than the theoretical maximum power, due to the temperature mismatch condition. This situation is improved with thermal insulation on the modules and the power loss due to the inconsistent temperature distributions reduces to 2.3% at the same working condition. The maximum output power rises to 17.3 W, 22.5% more than the power generated by the TEG without thermal insulation, when the engine operates at 3400 rpm. It is suggested that thermal insulation method trades a new effective way to regulate the inconsistent electrical characteristics of the modules under mismatch conditions and improve the performance of the TEG system under higher engine speeds.

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