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A research on thermoelectric generator's electrical performance under temperature mismatch conditions for automotive waste heat recovery system

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ABSTRACT

The thermoelectric generators recover useful energy by the function of thermoelectric modules which can convert waste heat energy into electricity from automotive exhaust. In the actual operation, the electrical connected thermoelectric modules are operated under temperature mismatch conditions and then the problem of decreased power output causes due to the inhomogeneous temperature gradient distribution on heat exchanger surface. In this case study, an individual module test system and a test bench have been carried out to test and analyze the impact of thermal imbalance on the output electrical power at module and system level. Variability of the temperature difference and clamping pressure are also tested in the individual module measurement. The system level experimental results clearly describe the phenomenon of thermoelectric generator's decreased power output under mismatched temperature condition and limited working temperature. This situation is improved with thermal insulation on the modules and proved to be effective.

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1. Introduction

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 [1]. 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 [2]. 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.

Many automobile manufacturers, such as GM in the USA, BMW in the Germany, successfully developed TEGs to recover the exhaust waste heat [3,4]. 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

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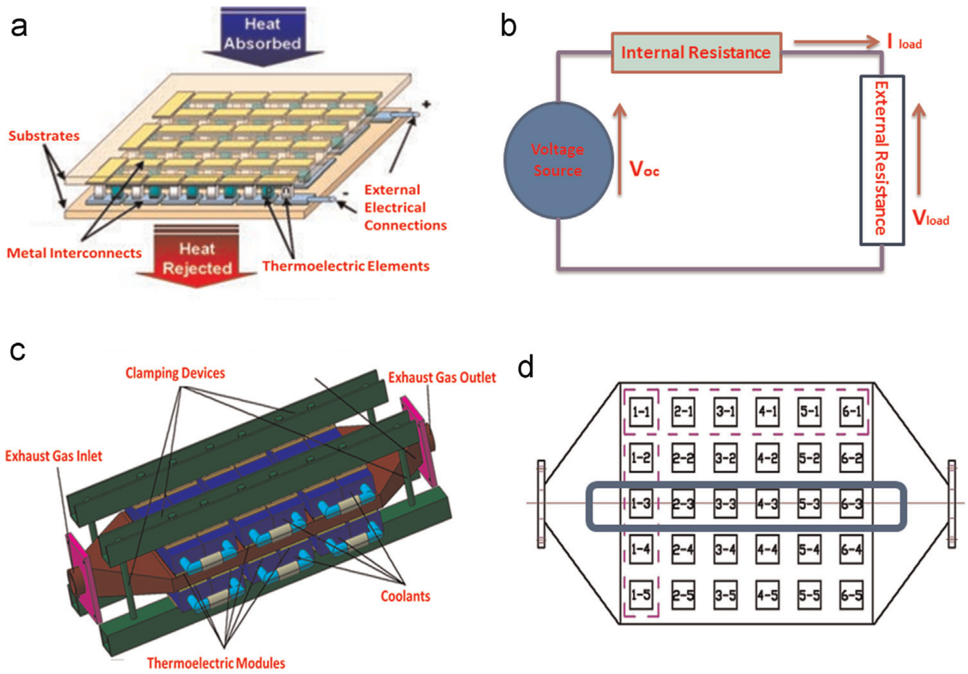

Fig. 1. Schematics of a TEM and TEG: (a) a TEM in generator mode, (b) electrical model of the TEM, (c) the structure of TEG, (d) the locations of TEMs in TEG system.

noticed that the temperature of exhaust gas is not constant and reducing along the flow direction in the TEG system in Lu's work [5]. The thermal variability and poorly controlled thermal conductivity accounts for the individual module's poor working performance under temperature mismatch conditions. Hsu et al. [6] suggested applying an appropriate pressure on the thermoelectric modules to improve performance. Andrea et al. [7] experimentally 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 V_{oc} and an internal resistance R_L, 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 system.

Two bench tests are adopted for the measurement of TEM and 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.

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