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Fuel Economy Analysis of a Series Hybrid Vehicle Equipped with a Thermoelectric Generator

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Hybrid electric vehicles (HEVs) fueled with synthetic fuels from renewable energy are one of the promising techniques for carbon-neutral mobility. Thus, it is important to improve fuel economy of HEVs with internal combustion engines. Thermoelectric generators, sometimes called Seebeck generators, have been attracting attention as a method to convert the waste heat energy in exhaust gas from internal combustion engines to electric energy for batteries. In this research, the authors evaluate the fuel economy of a series hybrid electric vehicle (s-HEV), which is becoming more and more popular, equipped with a thermoelectric generator (TEG) as a waste heat recovery technology, by using one-dimensional numerical simulation. The purpose of this research is to clarify the potential to improve fuel economy and issues of the technology.

First, models of a spark-ignition engine and a three-way catalyst (TWC) were developed using an engine simulation software GT-POWER. Next, the integrated vehicle model was developed by coupling the engine-TWC model with the s-HEV model built in MATLAB/Simulink. It was confirmed that the integrated vehicle model reproduced the performance characteristics of the engine, motor, generator, and battery, which are measured when the authors tested a production s-HEV on a chassis dynamometer. Then, a model of the thermoelectric module (TEM) with the heat exchanger was developed in GT-POWER and coupled with the engine-TWC model.

Next, the mounting position of the TEG was investigated. The TEG is mounted close to the engine, which increases the amount of electricity generated. However, if the TEG is mounted upstream of the TWC, the temperature of the gas flowing into the TWC will be decreased, resulting in a deterioration of the emission gas purification performance. The increase in pumping loss is small regardless of the position of the TEG. Therefore, the TEG was mounted downstream of the TWC, and the number of TEM modules and that of layers were investigated.

As the number of modules arranged in the TEG aperture increases, the aperture area increases, which suppresses the increase in pumping loss and improves the engine brake power. On the other hand, when the number of modules in the gas flow direction increases, the pipe friction increases and pumping loss increases, resulting in a lower the brake power. As the number of layers increases, the aperture area is enlarged and the Reynolds number decreases, which suppresses the increase in pumping loss and improves the brake power. The TEG array with the best fuel consumption improvement was the aperture array m=7, gas flow direction array n=5, and number of layers=1. When the TEG was mounted downstream of the TWC, the fuel economy under WLTC cycle (Low, Medium, High phase) was improved by 0.7 %. A comparison of fuel economy in each phase of the WLTC showed that the largest improvement was achieved in the High phase, where the average vehicle speed was high. This is due to the longer operating time of the engine, which increases the amount of electricity generated by the TEG.

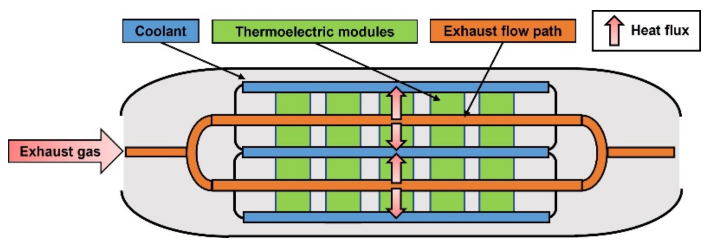

Fig. 1 Installation structure of thermoelectric generator

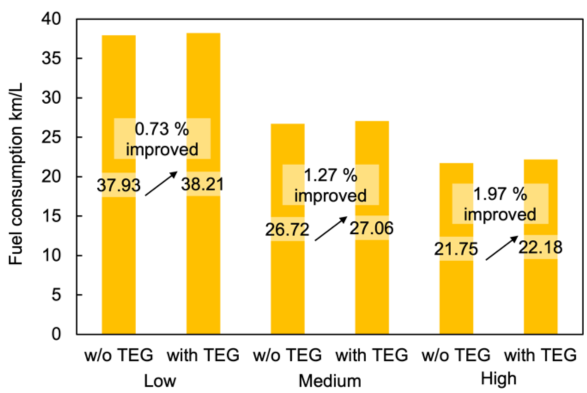

Fig. 2 Effect of TEG on fuel consumption in each phase of WLTC