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Modeling of a Thermoelectric Generator for Thermal Energy Regeneration in Automobiles

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In the field of passenger transportation a reduction of the consumption of fossil fuels has to be achieved by any measures. Advanced designs of internal combustion engine have the potential to reduce CO_2 emissions, but still suffer from low efficiencies in the range from 33% to 44%. Recuperation of waste heat can be achieved with thermoelectric generators (TEGs) that convert heat directly into electric energy, thus offering a less complicated setup as compared with thermodynamic cycle processes. During a specific driving cycle of a car, the heat currents and temperature levels of the exhaust gas are dynamic quantities. To optimize a thermoelectric recuperation system fully, various parameters have to be tested, for example, the electric and thermal conductivities of the TEG and consequently the heat absorbed and rejected from the system, the generated electrical power, and the system efficiency. A Simulink model consisting of a package for dynamic calculation of energy management in a vehicle, coupled with a model of the thermoelectric generator system placed on the exhaust system, determines the drive-cycle-dependent efficiency of the heat recovery system, thus calculating the efficiency gain of the vehicle. The simulation also shows the temperature drop at the heat exchanger along the direction of the exhaust flow and hence the variation of the voltage drop of consecutively arranged TEG modules. The connection between the temperature distribution and the optimal electrical circuitry of the TEG modules constituting the entire thermoelectric recuperation system can then be examined. The simulation results are compared with data obtained from laboratory experiments. We discuss error bars and the accuracy of the simulation results for practical thermoelectric systems embedded in cars.

Key words: Energy regeneration, heat losses, automotive, thermoelectric generator, driving cycles, MATLAB simulation, waste heat

Variables

P_{el}	Electrical power (TEG output) (W)
P_{TEGS}	Electrical power (TEG-S output) (W)
U_{q}	Open-circuit voltage (TEG output) (V)
U_{L}	Loaded circuit voltage (TEG output) (V)
I_{L}	Load current (TEG output) (A)
R_{L}	Electrical load (TEG) (Ω)
R_{i}	Internal resistance (TEG) (Ω)
σ	Electrical conductivity ($\frac{\mathrm{S}}{\mathrm{m}}$)
κ	Thermal conductivity ($\frac{\mathrm{W}}{\mathrm{mK}}$)
η_{TEG}	Efficiency (TEG) (%)
η_{Carnot}	Efficiency (Carnot) (%)
η_{TE}	Efficiency (thermoelectric material) (%)
$\eta_{\mathrm{DC/DC}}$	Efficiency (DC/DC converter) (%)
T_{h}	Hot-side temperature (K)
T_{c}	Cold-side temperature (K)
ΔT	Temperature difference (TEG) (K)
S	Differential Seebeck coefficient ($\frac{\mathrm{V}}{\mathrm{K}}$)
$\dot{Q}_{\mathrm{in}}$	Heat flow (hot side) (W)
$\dot{Q}_{\mathrm{out}}$	Heat flow (cold side) (W)
T	Temperature (K)
ZT	Thermoelectric figure of merit (1)

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