Numerical Design of a Test Plant for Dynamic Analysis of High Temperature Thermoelectric Generators

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Abstract

Thermoelectric generators (TEG) use Seebeck's effect to directly convert heat into electricity. They are therefore a promising option for energy harvesting of waste heat and can contribute to an increase in energy efficiency and reduction of CO2 emissions. Because of the multilayer construction of modern TEG and the different thermal expansion behavior of each layer's material, thermal stresses occur and possibly destroy the TEG, especially in applications with cyclic temperature changes like car exhaust systems. To investigate the dynamic behavior of high temperature TEG made of Mg- and Mn-silicides, a test facility was numerically designed and finally constructed.

The intended use of the TEG with recurrent temperature changes leads to a specific set of requirements for the test facility. The main demand was to realize a periodical temperature change of both the hot and the cold side temperature of the TEG of at least 13 K/min for the entire temperature range between 100 °C and 600 °C. The heating is done electrically, whereas the cooling is realized by an internal air flow. A specific heat exchanger had to be designed to combine both heating and cooling capabilities. COMSOL Multiphysics® was used to calculate the needed heater power with respect to heat losses and market available heater cartridges. Different flow channel configurations were developed and evaluated by calculating the resulting heat transfer and pressure drop for a given air flow.

With the aid of COMSOL a transition body between heat exchanger and TEG was designed to ensure a homogeneous temperature distribution on the TEG interface area. Finally, COMSOL was used to estimate peripheral component temperatures and the system behavior.

A test facility for dynamic analysis of TEG with recurrent temperature changes was designed and numerically evaluated. A heat exchanger was developed containing three heater cartridges to raise the TEG's hot side temperature by up to 50 K/min (Figure 1). The final sixty integrated small cylindrical flow channels allow a system cooling of about -30 K/min. These results allow a cycle time of between 8 and 14 minutes, depending on the needed temperature range and absolute system's temperature. Validation measurements taken on the constructed test facility are in good agreement with the simulation.

COMSOL simulations lead to an optimized T-shaped transition body between the heat exchanger and the TEG. The resulting temperature distribution with a mean deviation of about 0.5 K met the goal. During the system`s behavior analysis a pressure drop of 200 Pa was calculated and the heat losses sum up to 150 W at the maximum temperature of 600 °C. These values were used to select suitable heater cartridges, system's insulation and air

supply.
A test facility to investigate the dynamic behavior of thermoelectric generators was numerically designed and finally constructed. COMSOL was used to simulate the heating and cooling behavior of the system and the results were used to optimize the heat exchanger geometry (Figure 2). Measurements taken on the constructed test facility are in good agreement with the simulated data. Also the simulated cycle times were experimentally validated.

Figures used in the abstract

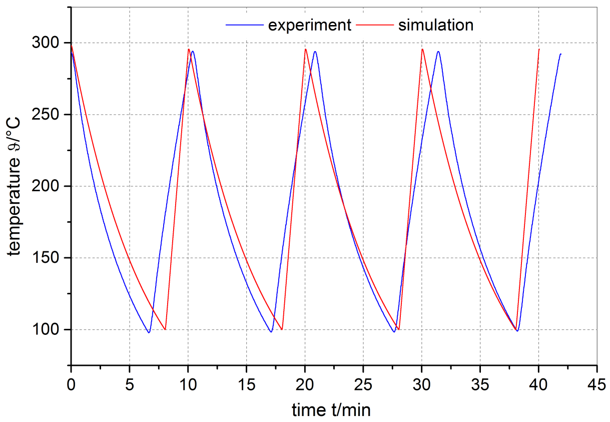

Figure 1: Comparison between measured and simulated temperature at the hot side of the TEG.

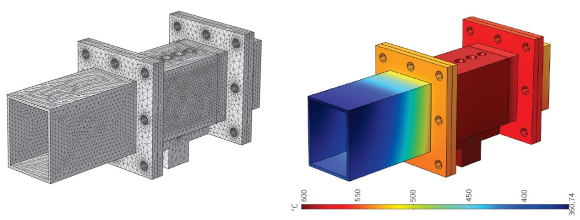

Figure 2: Mesh and temperature distribution of the hot side flow channel.