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Analysis of Annular Thermoelectric Couples with Nonuniform Temperature Distribution by Means of 3-D Multiphysics Simulation

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Thermoelectric (TE) modules with annular geometry are very attractive for waste heat recovery within the automotive world, especially when integrated as stacks into tubular heat exchangers. The required temperature difference is built up between the coolant, which flows inside an inner tube, and the exhaust gas, which flows around an outer tube. The flow pattern of the exhaust gas can be axial or circumferential, which can lead to higher heat transfer coefficients on the outer surface of the tube. However, this multidimensional construction in combination with a complex flow pattern can lead to a nonuniform heat flux. Additionally, the system experiences a nonuniform temperature distribution which consequently leads to complex conditions regarding the electrical potential. The relevant effects are investigated using a three-dimensional (3-D) numerical model implemented in the computational fluid dynamics (CFD) simulation environment Star-CCM+. The model supports temperature-dependent characteristics of the materials, contact resistances, and parasitic effects in the TE module. Furthermore, it involves techniques to quickly find the exact maximum power point of the TE module with the given boundary conditions. Using the validated model the influence of the nonuniform temperature distribution is investigated with emphasis on the electrical output and TE efficiency.

Key words: Thermoelectric, nonuniform temperature distribution system modeling, 3-D simulation, CFD, Star-CCM+

INTRODUCTION

In the next few years the worldwide demand for individual mobility solutions will increase and new governmental laws will require passenger cars to be highly efficient. In order to achieve these goals waste heat recovery is very attractive within the automotive world. A thermoelectric generator (TEG) can help increase the efficiency by converting waste heat from the exhaust gases directly into electrical energy. This energy can be fed into the vehicle's power system, thus reducing the load on the conventional generator. Consequently, fuel consumption and CO_2 emissions can be reduced.

In recent years, much work has been done and several prototype TEGs have been built and tested in passenger cars. For these concepts mainly thermoelectric (TE) modules with planar structure or with shunt configurations have been used.[1–3]

Another very interesting design for automotive use are ring-structured TE modules, which have been known for several years.[4] So-called TE tubes (Fig. 1) are based upon this principle and comprise flat annular "washers," made up of p-type and n-type material. In this configuration the annular washers are electrically connected in series via metal conductors and thermally in parallel. They are surrounded by an inner and an outer tube where each has three functions: to act as the electrical

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