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Development of portable measuring system for testing of electrical vehicle's heat energy recovery system

K Sarvajcz[1], A Váradiné Szarka[2]

[1,2]University of Debrecen, Department of Electrical and Electronic Engineering, Debrecen, Hungary

[1]sarvajcz@science.unideb.hu, [2]angela.varadi@science.unideb.hu

Abstract. Nowadays the consumer society applies a huge amount of energy in many fields including transportation sector. Internal combustion vehicles contribute substantially to the air pollution. An alternative solution for reducing energy consumption is replacing the internal combustion vehicles by electrical or hybrid vehicles. Today one of the biggest disadvantages of the electrical vehicles is the finite capacity of batteries. The research topic presented in this paper is the „Energy Harvesting", and development of energy recovery system for electrical vehicles which largely contributes in increasing the driving range. At the current phase of the research efficiency analysis of the heat energy recovery devices are investigated in real driving circumstances. Computer based mobile and wireless measurement system for the analysis was developed, tested and installed in a real vehicle. Driving tests were performed and analysed in different circumstances.

1. Introduction

In this research we examine methods of Energy Harvesting, which contributes to reduction of energy consumption's losses with special attention to the investigation and development of energy recovery systems in electric vehicles. In this paper authors introduce detailed operation of thermoelectric devices and provide detailed information on development of a new calibration and test system for TEGs. This newly developed testing system is able to analyse thermoelectric processes applying different semiconductor elements and changing temperature difference between the cold and hot points in range of 0 and 400 °C. The paper introduces workpoint measurement of different TEG types defining its maximum extractable electrical output power and also it includes detailed examination of measurement system developed for energy recovery, which can be applied in hybrid and electrical vehicles. The measuring system is able to detect two temperatures, current and voltage of TEG, GPS data and dynamic data of vehicle in the same time. Measured data are sent via wireless communication to cloud based storage.

2. Thermoelectric generator

The largest part of electrical losses is dissipated in form of heat while electrical and electronic producers spend huge resources to develop ideal cooling systems for electrical equipment. As thermoelectric generators use temperature difference, besides of the energy harvesting the cooling effect is an additional advantage of the application.

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TEGs have three main parts: N-type semiconductor, P-type semiconductor, and also a copper conductor providing contact surface between semiconductors. The most commonly used semiconductor is Bismuth Telluride (Bi2Te3). The element is installed between two insulating surfaces made of ceramic material (Al2O3) in most of cases. [1] Theory of operation of TEGs is based on thermoelectric phenomena and processes described by Seebeck, Peltier and Thomson effects. [2], [3], [4]

3. Calibration system for thermoelectric generators

Validation of TEG modules of different types and sizes require a calibration system of high reliability and repeatability therefore the research group decided to develop a new system for our special needs.
Temperature of the heated side is generated by a 450 W Infrared Top Ceramic Heater. It can generate 750 °C temperature, therefore housing with special heat insulation should be used. The house is made of Bakelite plate with width of 15mm. The Bakelite is one of the best heat insulating material with 0.23 [W/mK°] heat conductivity coefficient. Inside of the Bakelite housing a secondary insulation is applied which made of a special non-combustible asbestos alloy. This material is used for inner insulation of combustion chamber in household furnaces. Between the heater piece and TEG an aluminium inner spreader is included in order to provide homogeneous temperature on the surface of the TEG. As there are many different TEG sizes are available from different producers, modular aluminium spacers are designed for general applicability of TEGs. These spacers are used for flexible assembling and insertion of K type thermocouples measuring temperature of hot point. The spacer also ensures the homogeneous temperature on the full surface of TEG's.
For cooling of the cold point a flow water cooler is used which is connected to household water tube. Also an aluminium spacer measuring temperature of cold point is inserted between the cooler and TEG module. Aluminium spacers are designed for all standard sized TEGs in order to ensure homogeneous temperature distribution on the full surface.

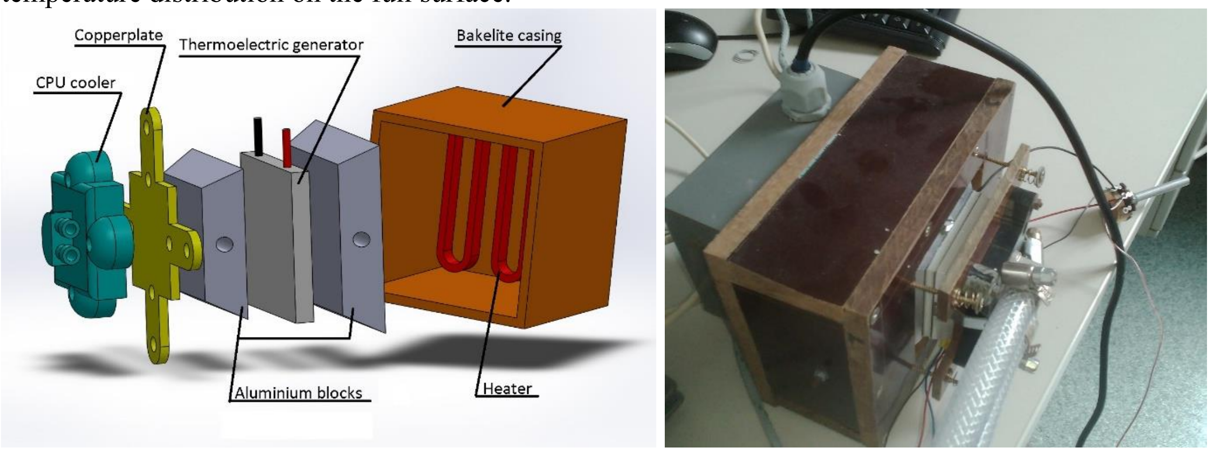

Figure 1. Measuring and calibrating equipment

Control of tests are developed using National Instruments hardware and software. The system was also presented at IMEKO's World Congress [5]. Different TEG modules tests were performed including workingpoint tests of two different types of TEG module provided by the same manufacturer. In these measurements eight different temperature differences were applied and the load resistance values were set by 0.1 Ω steps in the 0-5 Ω range. The aim of our examination was determination of maximum power of TEG modules at different temperature differences. These tests have proved that the maximum extractable electric power is 2.8 W in case of the 200 °C temperature difference and 0.002809 m^2 surface which is shown on Figure 2 and Figure 3.

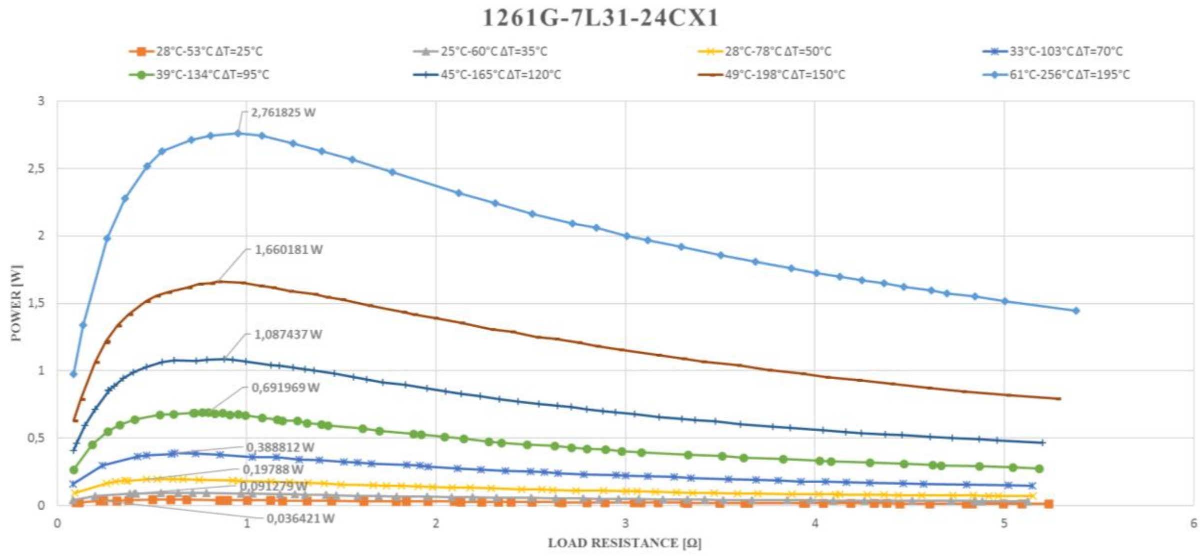

Figure 2. 1261G-7L31-24CX1 TEG module operating point measurements

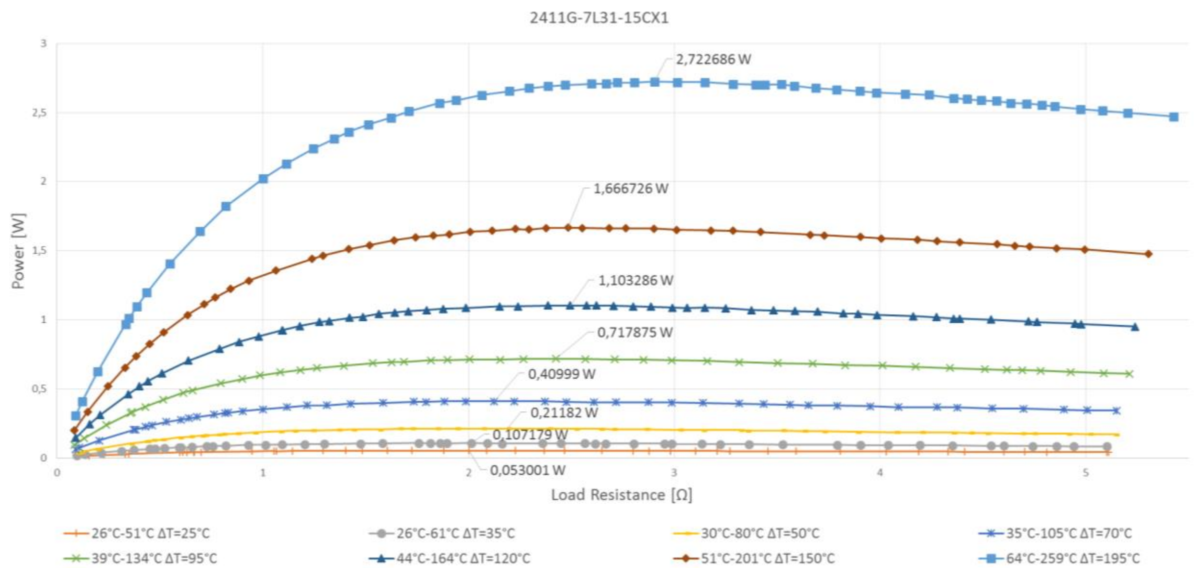

Figure 3. 2411G-7L31-15CX1 TEG module operating point measurements

4. Measurement system for heat energy recovery system tests

The main points of the system development included reliability and accuracy of the measurement, transfer, storing and processing of data but also the mobility and wireless communication possibility were in the centre of our concept. Another important condition was using the vehicle's DC power network for powering the instrumentation. The measuring system is based on compact RIO system from National Instruments. The cRIO module can be operated by 9-30 VDC power-supply voltage, which is also provided by the cigarette lighter charger of the vehicle. Four different modules are applied. The first is a voltage-measuring module, which has ±10Vfs input range and 24 bits resolution. The module measures the TEG's output voltage. The second is a current-measuring module, which has 5 Afs input and also 24 bit resolution. This module measures the TEG's output current value. The third module is a thermocouple module, which receives 2 K type thermocouples' signals. One thermocouple measures the engine-produced hot side temperature, the other thermocouple measures the cold side temperature, which is originated from the wind. The last module is a CAN bus module, which is applied to process dynamics parameters of the engine via OBD diagnostic interface. GPS module is also linked to the measuring system via USB interface for storing the GPS coordinates. The measured data are uploaded to a cloud-based storage using mobile internet. The first three modules measure the TEG's instantaneous power, and some other instantaneous operational parameters of the vehicle received also from the CAN module via OBD diagnostic interface. These are the instantaneous power, revolution, temperature of the engine and the vehicle's speed. GPS coordinates are added to the instantaneous data in order to get road characteristics and conditions in later processing. Two different driving tests are compared in each diagnostic phases. Data are stored in database and processed using a special self-developed data analysing software.

5. Testing of the measurement system

After building up the measurement system real tests were performed. Unfortunately until now the research team hasn't got possibility for testing in an electrical vehicle. The subject of the test was a combustion engine vehicle instead of an electrical vehicle. The most difficult task was simulating and producing as closest as possible temperature circumstances in the combustion engine vehicle's engine compartment to the electrical vehicle's drive train system. Different types of electrical motors were tested in order to define characteristic curves of variable load and temperature on the basis of which surface of the combustion engine was defined. This surface has almost the same temperature behavior as the electrical engine. The temperature of this surface does not exceed 100 °C and the surface is not cooled sharply by the wind. The surface size is 60x60 mm and it has appropriate thermal conductivity and sufficient strength material. The combustion engine's heat shield of exhaust manifold satisfies these parameters. According to our measurements, the temperature of the heat shield should not exceed 100 °C with no cooling, furthermore it has an adequate surface for inserting the TEG on.

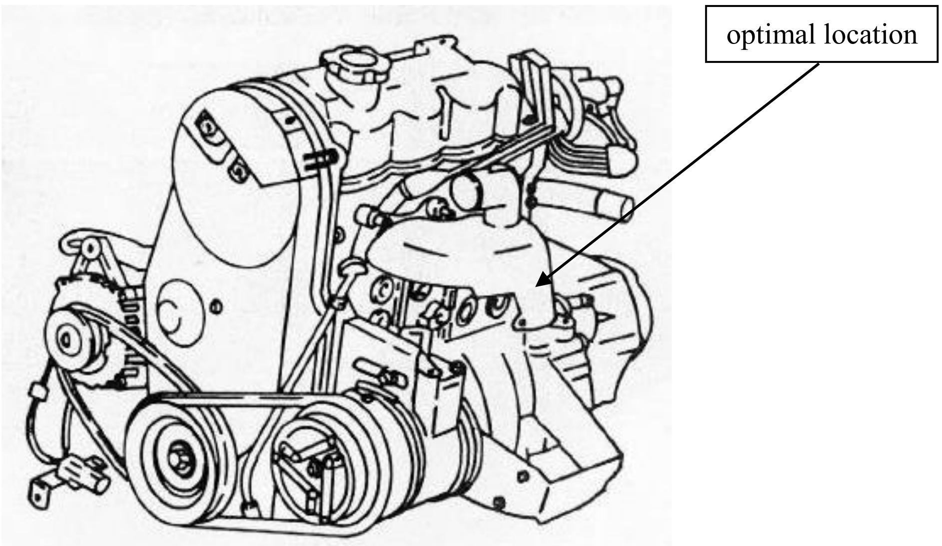

Figure 4. Select surface

After allocating appropriate surface testing periods and routes were defined. Tests were performed in the winter period, in order to ensure cool enough ambient temperature on the cold side of the TEG. The first part of the testing route included urban conditions while the second part did the highway conditions. Each measurements were performed on the same path. Saving GPS coordinates helped to fit the routes on the map shown on figure 5.

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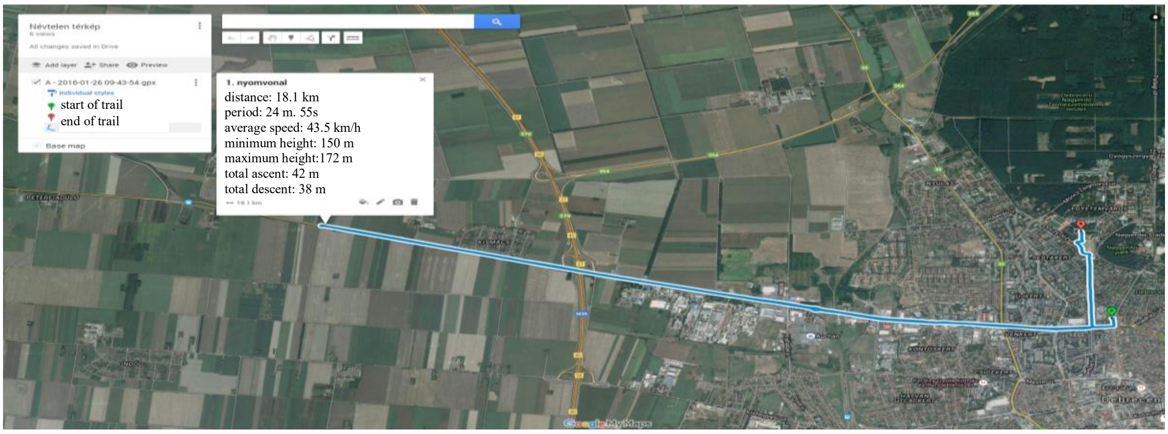

Figure 5. Test routes

One of the most critical tasks was definition of the correct fixture method of TEG. Several solutions were elaborated to ensure proper holding of the hot and cold sides. There were three possibilities for fixing the hot side. The first one is when the TEG module was fixed on the heat shield in direct way; the second is when an aluminum piece was put between the TEG module and the heat shield, and the third case is when a brass piece was put between the TEG and the heat shield.

For the cold side also several alternatives were elaborated. Similarly to the hot side in the first version no additional piece is attached to the cold side of the TEG, so the wind cools directly the surface of the cool side. After that, different types of heatsinks were applied. The heatsinks are different in their shapes and sizes. Finally, a thin aluminum and brass cuboid was set on the cool side of the TEG, which was blown by the wind. According to our measurements at high velocities the strong overcooling was experienced, therefore an air deflector box was prepared preventing direct cooling of the heat shield. The thermometers to both sides were attached. Figure 6. shows installation of the instrumentation.

Figure 6. Test installation

6. Results

Result of the tests (Figure 7.) shows the generated power in function of temperature differences. Results of four measurements performed by different concepts are presented on the diagram. In the first concept aluminium piece on the hot and on the cold side was applied without wind deflector. In the second concept brass piece on the hot and on the cold side together with the wind deflector is applied. The third is the hot and the cold side without any metal pieces and without wind deflector. In the forth one aluminium on the hot side and brass on the cold side without wind deflector is used. The third concept has much more dynamic changes, because the cold and the hot side did not contain thermally conductive pieces. In the case of fourth measurement heat conductive paste was not applied, the contact of the surfaces was not appropriate. The measured electrical power values belong to a determined temperature difference. The deviation of electrical power can be explained that the temperature differences can be produced by difference of several temperatures. Figure 7. shows an example for this. On Figure 7. in case of Concept 4 the cold side's temperature can range between 20 °C and 45 °C, and the hot side's temperature can range between 27 °C and 70 °C. According to the operating characteristic of TEG in an other temperature range other electrical power will be measured. According to the measurement's results the generated power can not reach the results of laboratory testing. Applying only one TEG without any energy investment from a 52x52 mm^2 surface 15-16 mW energy was produced. In the further research phase, we would like to reach a better surface contact, and examine the results of several TEG modules connected in series and parallel.

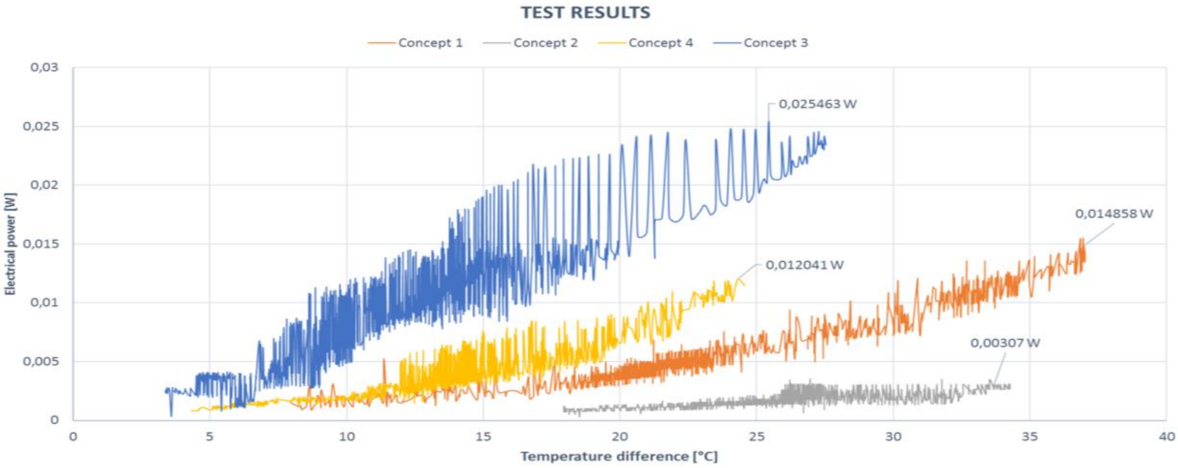

Figure 7. Test result

7. Summary

Results of the research project show positive effect of using TEGs as tool of energy harvesting in electrical vehicles. Simulation and calibration system is an essential instrument of the research providing reference characteristics and basics for comparison and evaluation of real tests in vehicles. In the phase of the project presented in this paper a mobile and wireless measurement system was developed and tested. The system includes sensors and transducers for TEG's measurement and uses CAN module for receiving the car's performance parameters. Efficiency comparisons underline differences between ideal and practical application, therefore in the next phase of the research increasing efficiency of practical application will be considered.

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