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Autonomous wireless sensor with a low cost TEG for application in automobile vehicles

A. Costa[a], D. Costa[a], J. Morgado[a], H. Santos[a], C. Ferreira[a,b,*]

[a]*ESTG, Instituto Politécnico de Leiria, Apartado 4163, 2411-901Leiria, Portugal*
[b]*INESC Coimbra, Rua Antero de Quental 199, 3000-33 Coimbra, Portugal*

Abstract

The present work consists in the development of an autonomous, low cost, reliable, energy scavenger sensor for automotive applications. Thermoelectric generators typically exhibit low efficiency but high reliability, making them suitable for autonomous, low average energy consumption, applications. A prototype sensor was developed for mounting in the engine exhaust pipe using a step-up voltage converter, a microcontroller, temperature and pressure sensing elements, conditioning electronics and a wireless transceiver, all powered by a low cost TEG (Peltier module TEC1-12706), through the scavenging of exhaust gases thermal energy. During the tests the prototype was able to sustain a regular signal transmission throughout the engine operation. The sensor was installed directly at the measuring point eliminating wired cables to hot and vibrating parts, thus, simplifying the installation of components and improving the reliability of the vehicle systems.

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Keywords: wireless sensor; thermoelectric generator; energy scavenger, vehicle exhaust

1. Introduction

Over the past 30 years, exhaust gas emissions from vehicles with internal combustion engines were reduced by a factor of about one hundred. Results came from advances in internal combustion engines (ICEs) and exhaust gas aftertreatment. As shown in Figure 1(a), the exhaust system of modern vehicles has shown an increasing complexity, with multiple components and measuring points.

* Corresponding author. Tel.: +351 244 820 300; fax: +351 244 820 310.
E-mail address: ferreira@ipleiria.pt

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Moreover, nowadays the recovery of the energy wasted as heat through the exhaust pipes has been one of the major quests in the automotive industry. Turbochargers only recover a small part and waste heat recovery techniques, such as the turbo-compounding, thermoelectric generators and the Rankine cycle are being currently developed and employed [1].

Peltier cells (Figure 1(b)) have been around for some time, they use a large number of semiconductor PN junctions, connected in series, to generate a temperature differential between its ceramic plates when a DC voltage is applied at its terminals. Peltier cells are primary used as thermoelectric coolers (e.g. processors coolers and portable freezers), however, using the Seebeck effect, they can also output an electric voltage proportional to the temperature differential between its plates [2,3]. When used as generators Peltier cells are often called to as TEG (Thermoelectric Generator). TEGs typically exhibit very low efficiency but high reliability, making them suitable for autonomous and low average power consumption applications [4].

a b

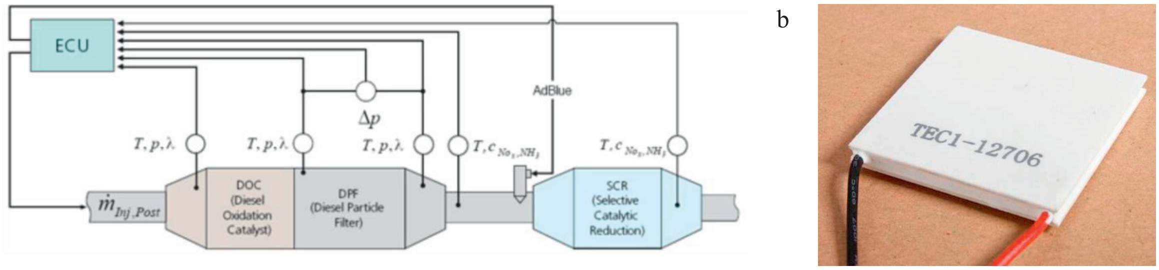

Fig. 1. (a) Schematic of the monitoring and control system needed for a typical Diesel engine exhaust gas aftertreatment system [5]; (b) Thermoelectric generator TEC1-12706, which is made of 127 Peltier individual cells.

A system to characterize Peltier modules as generators was developed. The characterization setup, as shown in Figure 2(a), uses a central heating element and two TEGs with aluminum coolers and cooling fans on the opposite sides. This configuration, use of two TEGs, reduces the heat loss on the surfaces of the heating element, thus improving the accuracy of the system. Additionally to what is shown in Figure 2(a), the heating element and the TEGs were laterally isolated through the use of mineral wool combined with coated aluminum sheet. The efficiency of the TEGs is determined by the ratio between the electric power applied to the characterization system and the one generated by the two TEGs. A load with a resistance equal to the TEGs internal one was used to drive the TEGs. Summing up the results, the tested TEGs (TEC1-12706) presented an efficiency ranging from 0.17 % to 1.39 %, depending on the temperature differential (with an efficiency of 1.0 % being obtained for a 70 ºC temperature differential). Nevertheless, despite the low results, studied TEGs were able to generate as much as 1 W from a temperature gradient of 70 ºC, as shown in Figure 2(b).

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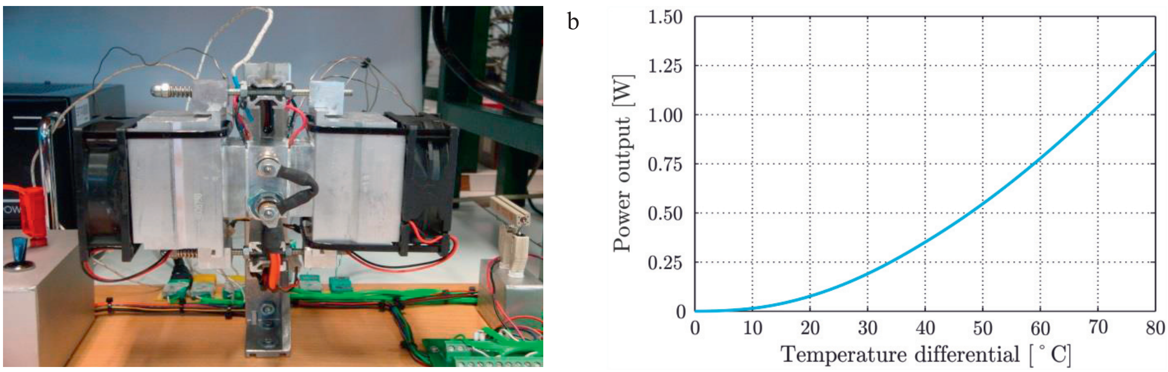

Fig. 2. (a) Workbench developed for the testing and characterization of thermoelectric generators; (b) Maximum power outputted, as function of the temperature differential on its sides, for a low cost TEC1-12706 TEG when working as a generator.

2. Concept of the autonomous wireless sensor

To address the increasing electrification of vehicles systems, we propose an autonomous wireless sensor to be used in automobile vehicles, with a block diagram as shown in Figure 3(a). The sensor harvests energy using a low cost TEG and has a step-up voltage converter to transform the TEG low output to a stable voltage of 3.3V. A microcontroller controls the supply of other sensor parts (sensing units, conditioning electronics and wireless transceiver) and sets the working frequency of the sensor. The sensor starts automatically when the TEG generates enough power (meaning the engine is running), although, a higher capacity energy reservoir and a vibration detector could be used for a faster awakening of the sensor (improving the sensor response).

A set of five step-up voltage converters (DC/DC converters) with varying integrated circuits, coils and configurations were tested. The results obtained for the maximum operating (data transmission) frequency of the sensor given a temperature differential (ΔT) on the TEG are presented in Figure 3(b). As expected, characteristics such as the start-up voltage and output current (max. working frequency) are antagonist and a compromise of both is required. For the application in the exhaust system, with a target frequency of 2 Hz, the DC/DC B based on a LTC3108 from Linear Technology paired with a 1:20 step-up transformer proved the best results. Using the DC/DC B the sensor can start for a ΔT as low as 2 ºC (63 mHz) and present a sustainable 2 Hz transmission frequency for a ΔT of 10 ºC on the TEG. If required (or for another application specifications) a combination of two DC/DC converters (e.g. B and E) could be used to widen the frequency range of the autonomous wireless sensor.

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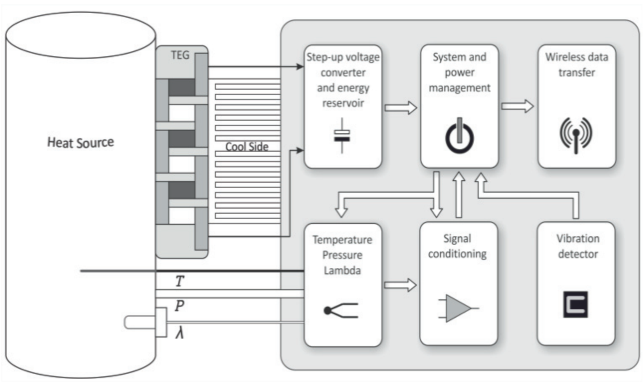

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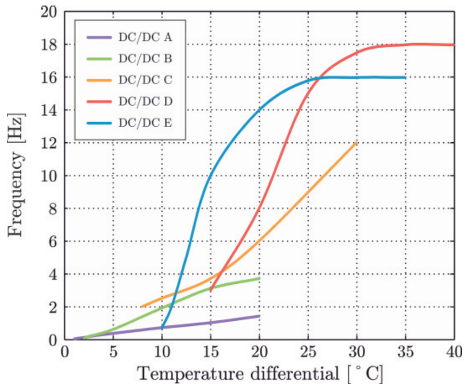

Fig. 3. (a) Block diagram of the proposed wireless sensor concept; (b) Maximum frequency as function of the temperature differential on the TEG obtained for a set of five DC/DC converters, with the autonomous sensor at 3 m of the receptor system.

3. Practical essays and results

Figure 4 shows a prototype of the proposed autonomous wireless sensor applied on an exhaust pipe. As sensing elements, the prototype uses a type K thermocouple (plus an AD8495 precision amplifier from Analog Devices) and a SX15AD2 pressure sensor. A XBee® Series 1 module (protocol IEEE 802.15.4) is used as wireless transceiver.

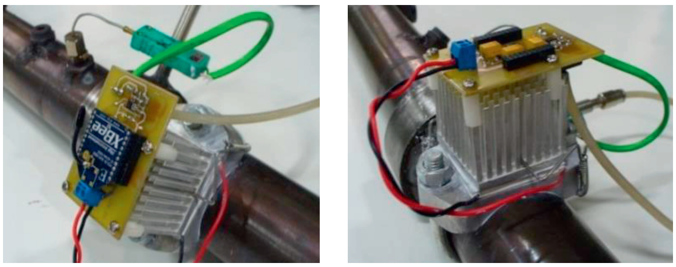

Fig. 4. Images of the built prototype with and without the XBee® S1 wireless transceiver.

The sensor prototype was tested in laboratory placed in the exhaust system of a 1.0 l gasoline internal combustion engine, and was able to sustain a regular signal transmission throughout the engine operation. Figure 5 shows the temperature trend of the exhaust gas at 1.5 m of the combustion chamber acquired with the prototype previously shown. To be note that, when the engine is turned off, the autonomous sensor keeps working until the microcontroller receives information that the TEG is no longer generating energy.

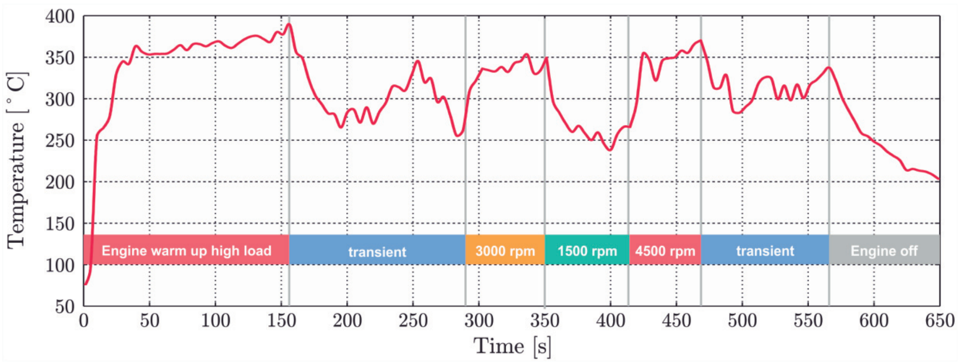

Fig. 5. Temperature of exhaust gas at 1.5 m of the combustion chamber in a 1.0 l gasoline engine, acquired using the developed sensor prototype.

4. Conclusions

This works presents an autonomous wireless system built around a low cost thermoelectric generator type TEC1-12706. To do so a test bench was developed to characterize the efficiency of the TEG used and the characteristics of multiple step-up voltage converters. From the results obtained, we propose an autonomous sensor which uses a step-up voltage converter to transform the TEG low output to a stable voltage of 3.3V, a microcontroller, sensing units, conditioning electronics and a wireless transceiver.

A prototype was built and applied to the exhaust pipe of an internal combustion engine. The prototype was able to sustain a 2 Hz signal transmission to a receptor placed at 3m of the prototype sensor, with a temperature differential of 10ºC recorded in the TEG. The proposed sensor concept proved to be successful in using thermal energy otherwise wasted. The concept can be easily extended to other vehicle parts (i.e. the engine) whenever a minimum temperature differential, necessary for a target working frequency, is available for the TEG.

The proposed sensor can retrieve all necessary data for the today's complex aftertreatment, engine management systems and other vehicle electronic systems. It is installed directly at the measuring points, eliminating the use of wires to hot and vibrating parts, thus, simplifying the installation of components and improving the reliability of the vehicle systems.

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