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Design of a Thermoelectric Energy Harvesting Module for a Wireless Pressure Measurement in Vehicles

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Abstract

A thermoelectric energy harvesting module for the pressure measurement of air induction system of heavy duty vehicles is designed. A positive contribution for cable complexity, fuel consumption and vehicle performance is intended by creating a sensor node after the air filter. A sensor node basically measures the pressure drop before the compressor inlet through air filter of a vehicle and transmits the pressure wirelessly to the engine control unit (ECU). System is capable of generating electrical energy by means of a thermoelectric generator to the sensor node for its life time with a 1 Hz sampling frequency.

Keywords: Thermoelectric energy harvesting, fuel consumption, pressure drop

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1. Introduction

Sensor usage in automotive industry increased dramatically in the last twenty years because of the significant government regulations and increasing trend on customer expectations regarding to the power consumption and engine performance [1]. Therefore, automotive manufacturers have to phase in new sensors to control the electronic systems. This situation causes cable complexity and maintenance issues for the life time of the vehicle. Moreover, original Equipment Manufacturers (OEM) have to handle fuel consumption and performance characteristics of the vehicle, which is the supreme problem in automotive industry. The increasing number of sensors also leads to the wiring

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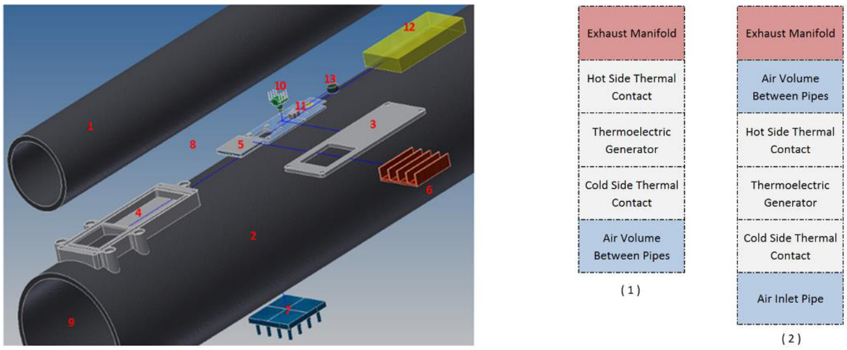
complexity and maintenance in the vehicle's physical on-board power systems and adds additional weight to the vehicle. Also, fuel consumption and acceleration performance of the vehicle is affected directly by air filter and its clogging percentage [2].

This study, which proposes a self-powered wireless pressure monitoring system (WPMS) for air induction pressure measurement in heavy duty vehicles, presents a positive contribution for vehicle performance and cable complexity. The system basically measure the pressure drop before the compressor inlet through the air filter of a vehicle and transmit the pressure value wirelessly to the engine control unit (ECU). Thus, the ECU have the chance to regulate the mass air flow to the compressor when the inlet pressure is continuously monitored. The air induction system consists of an air snorkel, an air filter, a mass air flow sensor, a pressure sensor and the compressor inlet pipe. During the operation of the internal combustion engine (ICE), the power of the system is supplied from a thermoelectric based energy harvesting system where the waste heat from the ICE exhaust manifold is utilized.

2. System Overview and Simulations

The computer aided design of the WPMS is given in Fig. 1.a where it basically consists of a pressure measurement sensor node, an energy harvesting module and a wireless communication module. In addition to them, a microcontroller that is based on an ultra-low power management (MSP 430) architecture is embedded to the system for the power management and sensor node control. The energy harvesting module is based on thermoelectric generator (TEG) and the waste energy is recovered from the exhaust pipe.

The thermoelectric devices generate an electrical energy when there is a temperature difference between the two faces. When the TEG is used for a thermoelectric power generation, the usual and efficient setting is to put the hot side of the TEG to the heat source where the cold side is exposed to mostly a chiller. Moreover, the amplitude of the substantial temperature difference may change during the operation and is needed to be maintained sufficiently at all the time for both side of the thermoelectric generator (TEG) for adequate power output. The first option is to place the TEG to the exhaust pipe which behaves as a constant heat source whereas the volume between the inlet and exhaust pipe acts as a heat sink as seen in Fig.1.b.1. Although this type of configuration seems to be an efficient design in terms of the temperature difference available between the two sides, there are some constructional and operational difficulties. Firstly, the exhaust pipe temperatures reach up to 700 °C depending on the drive conditions which limit the use of commercially available TEG's and results in stability problems over time. Secondly, since there is an enormous temperature difference between the air space volume and exhaust pipe, the temperature of the two sides of the thermoelectric generator eventually becomes equal in the steady state regime that produces zero power output. Therefore, the cold side of generator is consistently needed to be cooled by utilizing an external chiller which is not feasible for our case. The second option is to use the hot surrounding between the inlet and exhaust pipe inside the ICE as a heat source where the air flow inside the inlet pipe would behave as an effective chiller. Therefore, it is possible to create efficient heat sink and sources of the TEG that is available inherently during the operation of the ICE.



(a) **(b)**

Fig. 1. (a) Computer aided design (CAD) of the system: 1-Exhaust manifold, 2- Air inlet pipe, 3- Top cover, 4- Bottom Cover, 5- Thermoelectric generator, 6-Hot side fin, 7- Cold side fin, 8- Air volume between pipes, 9- Inlet of air inlet pipe, 10- Pressure sensor, 11-Electronic circuit board, 12- Protection gel, 13- Battery. (b) 1- Inefficient design, 2- Efficient design.

An approximate heat transfer analysis of the thermoelectric generator is performed to serve a foundation for the heat transfer rate of the system between the exhaust and inlet pipe. In this model, the time dependent of the system is not considered. Therefore, the system is analyzed in the steady-state regime only. An equivalent thermal circuit of the thermoelectric generator is build-up as given in Fig.2. As an initial design, heat transfer problems can be handled without considering any numerical equations with the following of equivalent thermal resistance concept in an analogous to the electrical circuit problems. In this case, the thermal resistance corresponds to electrical resistance, temperature difference corresponds to voltage and the heat transfer rate corresponds to electric current. Here, a one dimensional steady-state heat transfer with no heat generation through the layers of the thermoelectric generator is assumed. Also, it is presumed that the conductivity of the each layer in the system model is a constant and any radiation coming from the exhaust pipe to the system may be neglected.

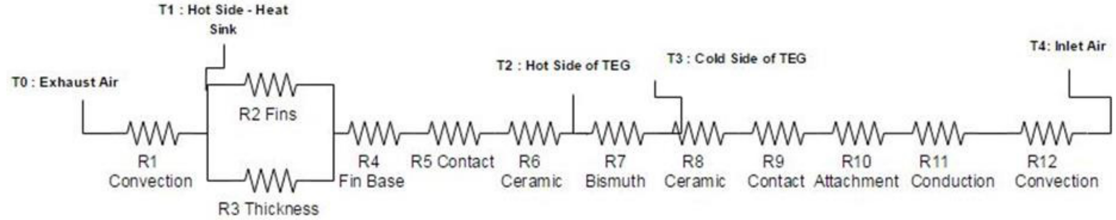


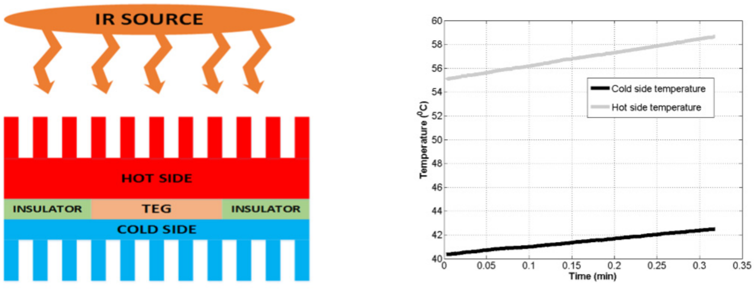
Fig. 2. Equivalent thermal resistance model of the system.

The temperature boundary condition for the exhaust air of thermal network model is established considering thermocouple instrumentation results of air induction system. For this location, the maximum temperature of the space in a commercially available truck is measured as 400 K for a sample vehicle level test. Again, the air inlet temperature velocity is taken as the room temperature of 293 K. Using the specified boundary conditions, the heat diffusion equation is solved considering the convection on the boundaries whereas the conduction is conceived in the solid structures. An approximately 20 ℃ temperature difference is calculated between the hot and cold side of thermoelectric generators using the specified boundary conditions which are calculated as 52.1℃ and 32.4℃, respectively. Although, the temperature difference between the two sides seems enough for the sufficient power supply to the WPMS, the difference value is the maximum attainable temperature air induction location at the free space. Moreover, it is certain that the boundary conditions of the model in terms of the temperature and velocity changes with the engine speed, it is proposed to place another heat fin to the cold side. Thus, the air flow inside the inlet pipe may behave as an efficient chiller when the heat fin is immersed inside the inlet pipe.

3. Experimental Results and Discussion

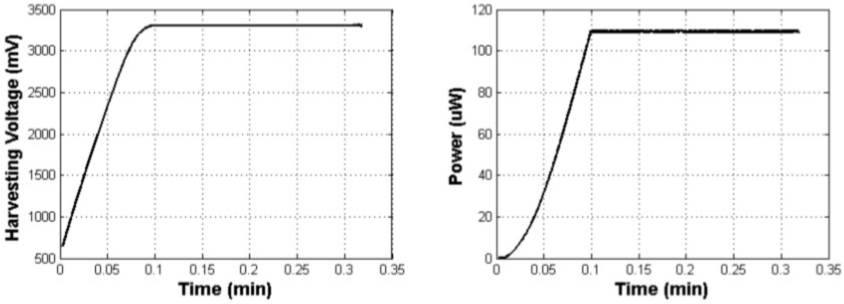
Laboratory tests are performed to characterize the energy harvesting module that is tested using a custom build experimental setup which is shown Fig. 3.a. The thermoelectric generator is sandwiched between heat fins on each side. The hot side heat fin exposed to an infrared (IR) heat source which behaves as an effective heat source. The IR heat source allows rapid warm up and cool down throughout the tests. Two thermocouples are placed inside the unit to determine the temperature difference between the hot and cold side of TEG.

A sample data is obtained from vehicle level testing before the laboratory test is conducted. Different hot side temperatures are obtained using the experimental setup that simulates the behavior of the sample data. Although, it is not possible to reach the temperatures of the exhaust pipe within the given experimental setup, it is just possible to capture the trend of sample exhaust temperatures. In order to accomplish the simulated temperature change reference to dynamometer test, the IR source is opened and closed several times during a 0.3 minutes test. The temperature difference as well as the voltage output of the TEG is measured as given in Fig. 3. (b). Voltage and power output of the TEG on the 100 kΩ load is measured as shown in Fig. 4. (a, b). The initial laboratory tests on the prototype of the WMPS shows a maximum 20 °C temperature difference between the sides of the TEG which results a nearly 110 µW power output. Thus, it is proven that the power level is vastly sufficient for a limitless operation of the pressure sensor node through the vehicle operation life for a 1 Hz data transfer to the ECU.



(a) (b)

Fig. 3. (a) Energy harvesting unit test setup illustration; (b) The temperature of hot and cold side of the TEG.



(a) (b)

Fig. 4. (a) Voltage output of the TEG; (b) Power output of the TEG.

4. Conclusion

In this study, a wireless pressure measurement system is proposed in order to measure pressure drop across air induction systems which is capable to generate its own energy using the waste engine heat energy. By means of WPMS, obstruction in the air filter is monitored continuously and real time pressure information can be transmitted to the engine control unit (ECU) of the vehicle.

Acknowledgements

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References

[1] W. J. Fleming, New automotive sensor; a review, Sensors Journal IEEE. 11 (2008) 1900–1921.
[2] J. Thomas, B. West and S. Huff, Effect of air filter condition on diesel vehicle fuel economy, SAE Technical Paper. 1717 (2012).