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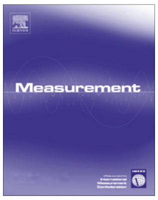

Self-powered wireless thermoelectric sensors

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A R T I C L E I N F O

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Sensors capable of measuring various performance parameters of an operational power generation unit could help improve system performance and overall efficiencies. For example, measurement of temperatures, temperature differences, or exhaust gas concentrations could provide both a quick quantitative and qualitative assessment of system health and allow for operation of power units with smaller safety margins and therefore higher efficiencies. For this study a technique is presented that can transmit data about an operational system wirelessly in real-time to an external location. For these experiments thermoelectric element leads were connected to a solenoid coil. When the thermoelectric was exposed to a temperature difference a current was generated in the thermoelectric and solenoid coil resulting in a magnetic field. A receiver was then used to measure the changes in magnetic field of the system. Two primary configurations were developed to test this wireless sensor configuration: dynamic and static. For dynamic measurements a pendulum and pneumatic air cylinder were used to simulate a moving component that may pass the external Hall sensor such as a fan or turbine blade. For dynamic measurements it was determined that for accurate results it is very important to maintain the distance constant between the Hall sensor and solenoid coil. For stationary measurements the temperature difference across the thermoelectric was related to output measurements from the Hall sensor. Overall, results show that data can be wirelessly transmitted to an external location using this method.

1. Introduction

In many power generation units that are currently in use, information about internal operating conditions is limited. For example, in a gas turbine it is not possible to measure the temperatures of the turbine blades while in use. It is also difficult to measure flow rates and species concentrations of the exhaust gases at the exit of the turbine since few sensors and their components can withstand either the high temperatures or highly corrosive environments. Additionally, most sensors currently used require extensively long cabling and chords which may be undesirable for the end-user. If the temperatures, species concentrations, or flow rates could somehow be measured in real-time and data transmitted wirelessly to another location this would provide both quick real-time assessments of unit health and allow systems, such as gas turbines, to operate with a smaller temperature safety margins improving overall efficiencies and power outputs. This paper presents a proof of concept study of self-powered wireless sensors that can be used primarily to measure temperatures or temperature differences in a power generation unit. Applications of this technology can be realized in many different areas. However, this paper shows some results and presents advantages, disadvantages, and recommendations to advance this technology in the future.

The sensor technology presented in this study focuses on the use of thermoelectrics in order to provide the current necessary to produce a measureable signal. One reason for selecting thermoelectrics as the sensor for use in

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Nomenclature

A	area (m^2)
B	magnetic field (G)
B_z	magnetic field in z-axis (G)
I	current (A)
w	length (m)
N	number of turns (–)
r	radius of solenoid (m)
S	Seebeck coefficient (V/K)
T	temperature (K)
V	voltage (V)
V_H	hall voltage (V)
z	distance from Hall sensor and solenoid coil (m)
ΔT	temperature gradient (K)
ΔV	voltage gradient (V)
μ_0	permeability of free space (T m/A)
φ	magnetic flux (T/m^2)

this project is that these devices can produce a constant power output for a given temperature difference between their hot and cold sides, can operate at high temperatures using the correct material combination, and have proven to be reliable in various applications including harsh space environments [1].

Traditional use of thermoelectric elements is typically for waste heat recovery applications. Love et al. used several thermoelectric devices on a simulated automotive exhaust heat recovery system [2]. Baker and Shi also performed a similar study investigating the characteristics of a conceptual heat exchanger from a diesel exhaust for waste heat recovery purposes [3]. Since thermoelectrics typically have low power output efficiencies, usually less than 10%, use of this technology for waste heat recovery seems limited to the overall conversion efficiencies and ZT values.

Other studies have shown thermoelectrics to have been used to supply power to a variety of sensors in industrial applications. Schilz monitored the absorption of an infrared light beam utilizing the perceived changes in the electrical conductivity using a thermoelectric infrared sensor [4]. Sordiashie developed an electromagnetic harvesting method using thermoelectric devices in order to power energy management sensors in the built environment. The designed system consisted of a small prototype harvesting device wired to an energy management sensor [5]. Another study by Cartens et al. conducted experiments using thermoelectric generators to power radio frequency modules in order to monitor the fuel being spent during dry-cask storage [6]. From the results gathered, the power produced by the generator was determined as a function of the service life of the dry-cask storage system. Other studies are referenced here that highlight the ongoing efforts in this topical area [7–15].

This paper presents a novel study that investigates the potential of using thermoelectric element loops for measurement of temperature differences in a system. This self-powered sensor will transmit the signal wirelessly to a nearby location where data about the system can be collected. The following sections describe in detail the process by which the signal is transmitted and data is processed. Although thermoelectric elements are used in this study, the sensor can be easily replaced with others that produce a similar voltage in response to other changes in the system such as temperature or species concentrations which may be the focus of future investigations.

2. Experimental methodology and setup

2.1. Methodology

Thermoelectrics utilize the principle of the Seebeck effect in order to convert a temperature difference to an electric voltage. For heat recovery applications this voltage is usually used to power some other electrical device. For an automobile thermoelectrics could be applied to the exhaust system and recovered power used to run interior lighting, radio, or headlights which may improve overall system efficiencies. The present study is novel in that it uses the current generated by the thermoelectric to essentially power itself as a sensor and transmit information about the system. This was done by shorting the two ends of the *n* and *p* type semiconductors attached to the thermoelectric in a loop. The current generated by this loop increased proportional to the temperature difference between the two connection points. Since these leads are arranged in a loop from which current passes through, a magnetic flux is generated which can be measured and calibrated to estimate temperature difference in a system.

In order to measure the changes in magnetic flux emitted from the sensor a Hall Effect sensor was used. The Hall Effect sensor generates a voltage proportional to the strength of the magnetic field it is exposed to. Thus the developed system uses magnetic flux density changes induced in the thermoelectric loop (solenoid) as the input parameter and the signal transmitter in the system. Here the magnetic flux density describes the intensity of the magnetic field at a particular point in space and can be computed analytically using the following equation:

$$\varphi = \frac{\mu_0 NIA}{w} \tag{1}$$

where the cross sectional area (A), length (w), number of loops (N), and current (I) are some of the factors that affect the magnetic flux density produced. For the present study all these parameters remained constant. Since these parameters remain constant between tests the system is validated by the Biot–Savart law which states that the magnetic flux density around the conductor (solenoid) is directly proportional to the current flowing through it and inversely proportional to the distance of that specific point from the conductor [16]. The magnetic field at a