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Development and Demonstration of Steelworks Application Technology for Wireless Temperature Sensor Using Energy Harvesting

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Abstract:

In steelworks, furnace temperatures are sometimes measured by workers, but this is a high-load operation with many measurement points even the frequency of measurement per site is low, around several times per day. The wireless temperature sensor using energy harvesting is expected to improve furnace temperature control without power and control wiring and with high frequency temperature measurement, thereby saving energy and reducing CO_2. Stable data transmission/reception for wireless temperature sensors and efforts to develop and demonstrate temperature environment control technology are reported.

1. Introduction

Recently, attention has been focused on wireless sensor networks in which environmental information (temperature, etc.) is acquired and utilized by arranging multiple sensors capable of wireless transmission in the environment. While this has the merit that the use of radio transmission eliminates the cost of cable-laying, the cost of battery replacement is a problem because most of the wireless sensors used are driven by primary (non-rechargeable) batteries. Therefore, a battery replacement-free, power-free system using an energy harvesting device for power supply is desired.

Energy harvesting is a technology that harvests the minute energy which exists in various forms such as heat, vibration, light and radio waves in the surrounding environment and converts it into electric power[1)]. The growing interest in the Internet of Things (IoT), Cyber Physical System (CPS) and Digital Transformation (DX) has also led to expectations for energy harvesting as a key technology for realizing them. Thermoelectric power generation has the possibility to recover minute energy with a temperature of less than 100˚C, which is currently discarded as waste heat, and convert that energy into electric power, and has attracted attention as a self-supporting power source for various devices in the IoT and DX fields.

In the coke ovens of steel mills, there are cases where the oven temperature is measured by personnel because it is necessary to confirm the combustion chamber temperature, but this work has a heavy load due to the large number of measurement points, the high temperature on coke ovens in summer and the dusty, high-temperature environment with a temperature of 40˚C or more. Although the frequency of measurements per site is low, at several times/day, the number of measurements per day is 1 000 times or more, which is a heavy work load, so labor saving and safety are desired. **Figure 1** shows a conceptual diagram of a coke oven. The furnace body of a coke oven consists mostly of a brickwork structure. The main body of the furnace has a coke oven chamber for dry distillation of coal and a combustion chamber which supplies heat on both sides of the chamber. The inside of the combustion chamber is divided into two compartments, and combustion gas and air are supplied to each compartment from the bottom and burn, and the combustion exhaust gas enters another compartment from the top of the combustion compartment and then exits from the bottom.

If the temperature can be measured with a short measurement cycle by a wireless temperature sensor, without a power source or control wiring, by using energy harvesting technology to supply power by utiliz-

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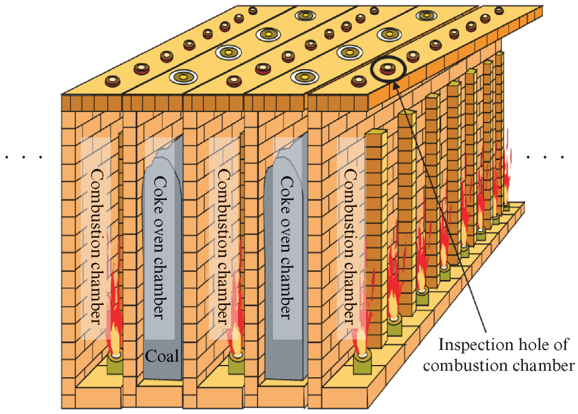

Fig. 1 Schematic illustration of coke oven

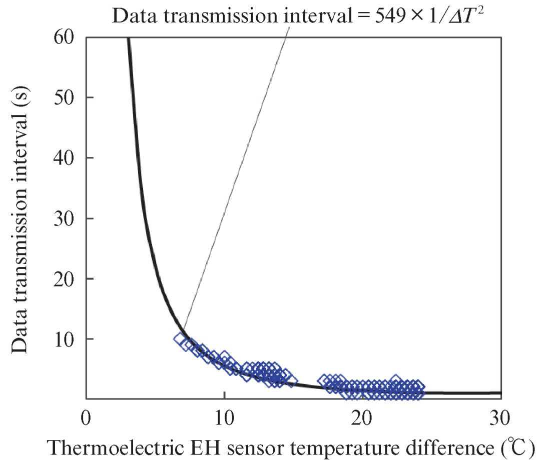

Fig. 2 Relationship between temperature difference of thermoelectric EH device and data transmission interval

ing waste heat of the steel works, furnace temperature management can be upgraded, and energy saving and CO_2 reduction effects can be expected as a result of the reduction of the gas consumption. However, the characteristics of thermoelectric energy harvesting (thermoelectric EH) devices are often unclear. Although the communication distance is about 10 m to 75 m according to 2.4 GHz IEEE802.15.4, the basis for distances of about 10 m or 20 m is unclear in the specification, and the relationship between the distance between the transmitter and receiver and data reception dispersion has not been clarified. Therefore, this paper reports the results of stable data transmission/reception by a newly-developed wireless temperature sensor, the development of a temperature environment control technology and a demonstration in a coke oven in an actual steel works.

2. Experiment

Using thermoelectric EH equipment, the relationship between the temperature difference and transmission interval was investigated in order to clarify the variation of the frequency of transmissions depending on the temperature difference. Next, to clarify the relationship between the distance between the transmitter and the receiver and reception dispersion, the relationship between the distance and the reception interval was investigated, and the usable range was clarified. In order to use a thermoelectric EH sensor with an upper operating temperature limit of about 80°C in a hot and dusty environment on an outdoor coke oven, heat radiation and heat shielding/shading countermeasures were applied to the device. Although an external signal input terminal was provided in the commercial thermoelectric EH device, the possibility of failure at the connection part was a concern in the dusty environment of the steel works. Therefore, a thermoelectric EH device which suppresses defects in the connection was prepared by placing the connection at a distance from the thermoelectric EH device and protecting the connection separately.

3. Results and Discussion

Figure 2 shows the relationship between the temperature difference of the thermoelectric EH device and the data transmission interval[2)]. The data transmission interval is inversely proportional to the square of the thermoelectric EH temperature difference, and it was found that the data transmission interval is about 5 seconds when the temperature difference of the EH sensor is 10°C. Thermoelectric power generation uses a phenomenon in which a voltage proportional to the temperature difference is generated when a temperature difference is applied to both ends of a material. This phenomenon is called the Seebeck effect. Since it is also known that the power is proportional to the square of the temperature difference, the experimental result is considered to be reasonable. The distance between the EH sensor and the receiver was 1 m, the temperature on the heat source side was set to 50°C to 70°C using a heater, the cooling side was air cooled, and the outside air temperature was 32°C.

Figure 3 shows the relationship between the distance between the thermoelectric EH device (transmitter) and the receiver and the data reception interval[2)]. Here, the thermoelectric EH temperature difference was set to about 12°C. If the transmission interval is set to 4 seconds, the data can be received at the same 4 second interval, but when the distance exceeds 40 m, the data reception interval starts to vary. This is thought to be caused by the fact that radio wave intensity decreases with distance. This experiment was conducted under the condition that there were no obstacles between the

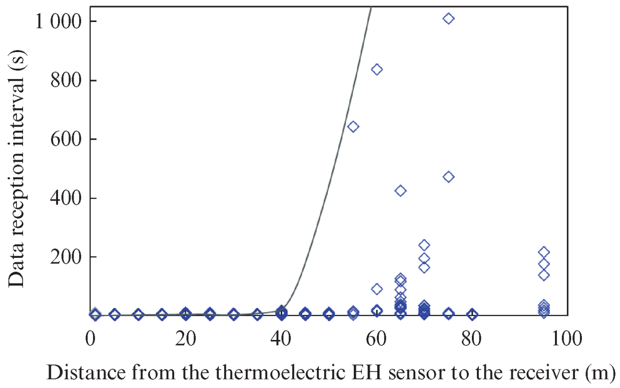

Fig. 3 Relationship between distance between thermoelectric EH sensor and receiver and data reception interval

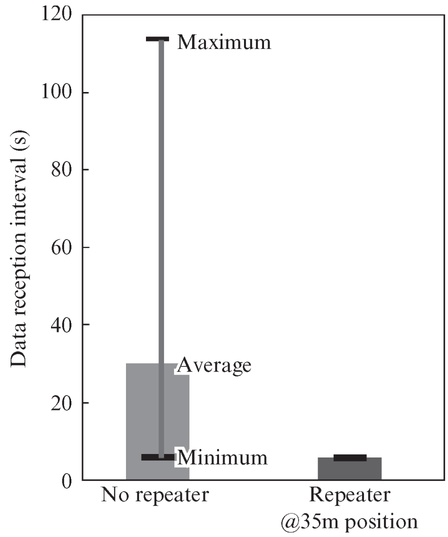

Fig. 4 Effect of repeater on reception interval

thermoelectric EH device (transmitter) and the receiver. The results suggested that the device can be used as it is up to a distance of 40 m, although this will vary depending on the actual use conditions. However, for stable data reception at distances longer than 40 m, transmission through a repeater appears to be necessary.

A practical demonstration test was carried out on a coke oven with the transmitter and receiver separated by 70 m. As shown in **Figure 4**, when there was no repeater, the reception interval varied from 6 to 114 seconds. However, when a repeater was installed at the midpoint (35 m) between the transmitter and receiver, the variation was reduced, and it was found that data could be stably received at approximately 6 second intervals[3].

Figure 5 shows a conceptual diagram of the utilization of a wireless temperature sensor using thermoelectric EH in the steel works based on these results[2]. A thermoelectric EH device is operated by the temperature difference on a coke oven with waste heat, and the thermocouple temperature information measured by the sensor is transmitted wirelessly to a master unit which aggregates communications through a plurality of repeaters. It was confirmed that the radio wave intensity, which indicates the quality of the radio communication equipment, between the thermoelectric EH device and the repeater, and between the repeater and the master unit, changed at a level that would not cause any problems in practical use. In addition, during charging of coking coal, which is an obstacle to radio transmission, the communication destination of the thermoelectric EH device located directly under the coking coal is switched to communication with a repeater installed at another location at the timing when the communication strength with the repeater which is normally used in communication decreases, and it was found that data transmission and reception

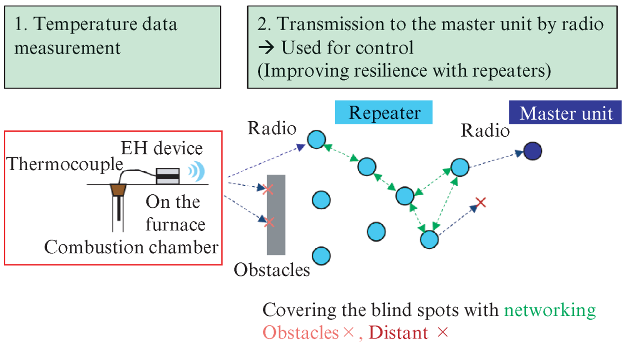

Fig. 5 Schematic illustration of utilization of wireless temperature sensor using EH device in steelworks

can be carried out without any problems. As a result, this experiment confirmed that the developed thermoelectric EH wireless temperature sensor can be utilized for coke oven temperature control.

4. Conclusion

In a steel works, where huge facilities are installed over a wide site and many such facilities are in operation, high expectations are placed on temperature measurement with a short measurement cycle, without power or control wiring, by wireless temperature sensors using thermoelectric EH technology. The authors developed a stable data transmission/reception and temperature environment control technology for a wireless temperature sensor based on laboratory and actual equipment experiments, and confirmed its practicability.

In the future, we will continue to improve this technology with the aim of achieving even higher efficiency and stabilization of the operation.

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