A Study on the Applicability of Energy Harvesting Technology for the Sensor Network of Railroad System by Thermal Deviation

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Abstract— **In this study, we verified the applicability of the energy harvesting technology to the railroad system for real-time wireless sensor networks. The origin of the power for this technology is found in the concept of energy harvesting, which resources thermal deviation occurring when a train runs. For this, we measured the temperature generated on the axle box bearing from the train's running environment by using a high-speed train, analyzed the thermal deviation and calculated the estimated energy harvesting power for the sensor network of the railroad system. The thermal deviation occurred in the axle box bearing when a train runs; the deviation was approximately 12.97 ~ 14.68 ℃. We calculated in the assumption of the basic thermo element of the axle box bearing area, which is the area of the temperature sensor attached on the axle box bearing. Theoretically, the energy harvesting power of 63.8mW can be obtained and thus by using the energy harvesting power it will be possible to operate the wireless sensor network for railroad monitoring.**

Keywords-Railroad; Sensor; Energy harvesting; Thermal deviation.

I. INTRODUCTION

With regards to railroads, accelerating the speed of the system always demands absolute development in reliability and safety of passengers and trains, and the increase in system maintenance cost has become another problem. Thus, it is necessary to develop a new technology of maintenance for fulfilling both reliability and safety, and maintenance cost in system speed acceleration. In order to accomplish this, a real-time sensor network system must be established. Usually, a sensor network system is needed for prevention and response before a dangerous situation occurs, by detecting abnormal conditions in the corresponding system during the operation. It is also used for constant monitoring to analyze the information for possible understanding of the situation.

However, present monitoring systems in railroad systems almost exclusively use wired sensor networks, and recently, the demand for monitoring systems with wireless sensor networks has expanded in accordance with their easy installation in places that had previously been considered difficult to access and install in. Specifically, when a wireless sensor network is applied to the railroad monitoring system, it is possible for the real time condition based-maintenance, differentiated from the existing method used for scheduled maintenance, and by this, the reliability and safety of maintenance is increased [1]. Though, in the case of a wireless sensor network with easy installation, it is necessary to solve the problem of power supply for using it in a monitoring system. This is because the regular changing of batteries is necessary for additional maintenance. Therefore, for the wireless sensor network in a railroad system, it is necessary to develop an 'Energy Harvesting' technology in order to be maintenance-free from the changing of batteries. It is also environment-friendly and semi-permanent [2]-[4].

Therefore, in this study, we verified the applicability of the energy harvesting technology to the railroad system for real-time wireless sensor networks. The origin of the power for this technology is found in the concept of energy harvesting, which resources thermal deviation occurring when a train runs. For this, we measured the temperature generated on the axle box bearing from the train's running environment by using a high-speed train, analyzed the thermal deviation and calculated the estimated energy harvesting power for the sensor network of the railroad system.

II. THE TEMPERATURE CHANGE OF AXLE BOX BEARING DURING THE OPERATION

A. The expriments

In this study, surrounding energy generated at the normal train operation environment was measured using high speed rail train in operation and to identify the applicability of the energy harvesting, the energy source was measured with the train running 586.2km (return way from Seoul to East-Daegu) at maximum operating speed 300km/h. And to measure the temperature variation of the heat sources generated during train operation at 300km/h, temperature sensor (Model: TC1047AVNB, 2.64mm x 3.05mm x 1.02mm, temperature-ranges of -40℃ ~125℃) was installed on axle bearing which is one of the part on which the temperature varies significantly with Bluetooth module as shown in Fig 1 and the temperature variation of axle bearing was measured on a real-time basis using wireless sensor.

Figure 1. The temperature measuring on the axle box bearing

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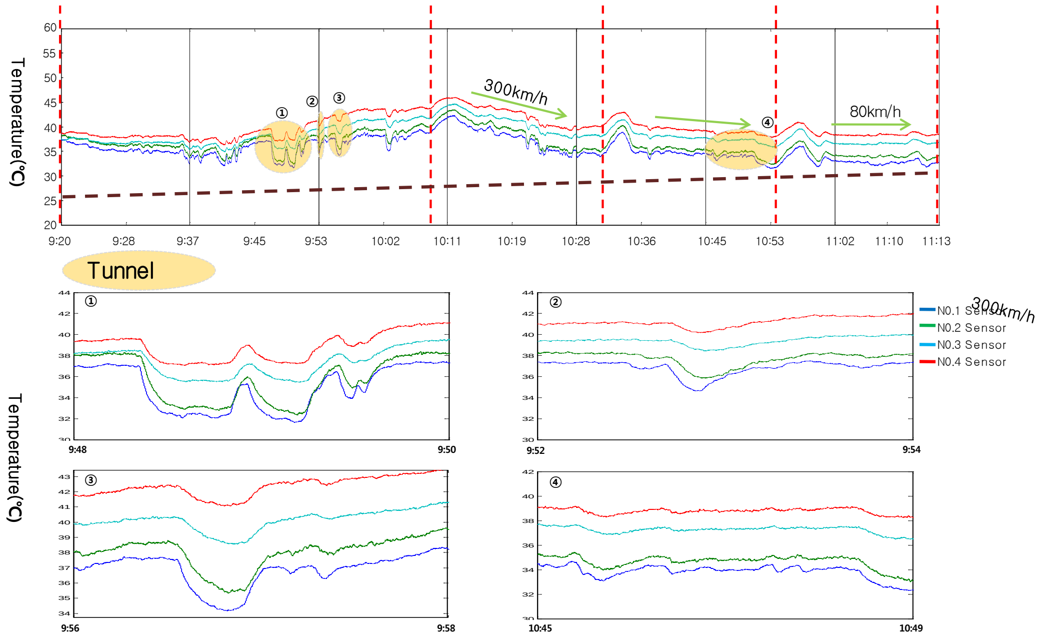

Figure 2. The temperature change of axle box bearing during the operation and zoom-in of tunnel section

B. The result of temperature change of axle box bearing

We analyzed the temperature of the axle box bearing in a 300km/h maximum speed operation train. As a result, as shown in Fig. 3, the temperature of the axle box bearing during the operation repeats up and down in accordance with the surroundings; tunnel, bridge, speed and stations, etc. If we look closely at Fig. 2, the temperature of the axle box bearing starts with a temperature similar with the outside air temperature, but increases as the train runs. The deviation between outer air and axle box bearing is 15～20℃ in the summer. Especially, the temperature tends to decrease when the train passes tunnels and each sensor's temperature change occurs by the location of the sensor on the same axle box bearing, as in Fig. 3, which depends on the direction of operation. The reason is the air-cooling effect taking place during the train operation, so the temperature of No. 1 and No. 2 sensors is lower than the temperature of No. 3 and No. 4. Also, regarding the temperature between the axle box bearing and outside air, we can use this thermal deviation to make energy harvesting possible if a thermo element is applied as the power.

In addition, the tunnel section of Fig. 2, the temperature changed very rapidly; the train enters the tunnel, the temperature of the axle box bearing descends, and after the train passed the tunnel, it ascends again. This is because of the air-cooling effect from the outside air temperature of going in and out of the tunnel. The outside air temperature in the tunnel is lower than the outside air temperature outside of the tunnel in the summer. Also, the average temperature data from the axle box bearing of high-speed trains is stated in Table 1. The outside air temperature was measured approximately 28℃～30℃ and the average thermal deviation (ΔT) was measured approximately 12.97℃～14.68℃.

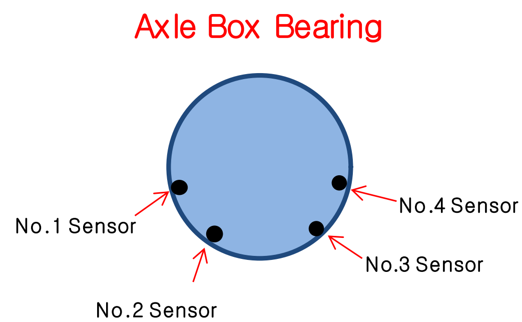

Figure 3. The temperature sensors location on the axle box bearing

TABLE I. THE AVERAGE TEMPERATURE OF AXLE BOX BEARING

Sensor No.	1	2	3	4
Temperature(℃)	43.39	42.97	44.68	44.31

III. APPLICABILITY OF ENERGY HARVESTING TECHNOLOGY FOR THE SENSOR NETWORK OF RAILROAD SYSTEM BY THERMAL DEVIATION

When looking at the results of the average temperature on the axle box bearing, we notice that the highest temperature was 44.68℃. Thus, if we suppose the outside air temperature is fixed at 30 ℃, the biggest thermal deviation obtainable from the axle box bearing is 14.68℃; generally, the thermo element is known to properly gain efficiency when the temperature deviation between high and low temperature parts is over 300℃ [5]. However, if the thermo element form is made as thin as a form of Thin-Film,

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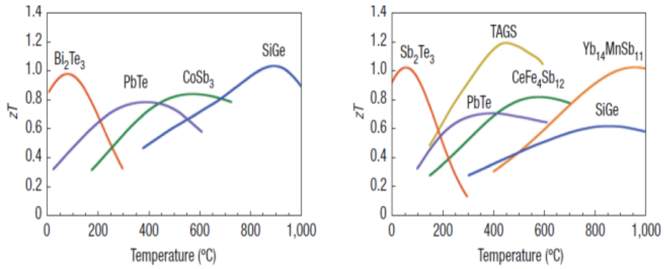

Figure 4. Figure-of-Merit vs. Temperature [6]

TABLE II. THE ESTIMATED ENERGY HARVESTING POWER BY THERMAL DEVIATION (SINGLE SIZE THERMO ELEMENT : A=4 , D= 1 ㎝, LARGE SIZE THERMO ELEMENT : Ø= 25.4 ㎝, W= 2 ㎝, D=1 ㎝)

sensor	Δ T	Power (mW) : Single size element	Power (mW) : large size element
1	12,97 K	1.2	47.9
2	13.93 K	1.4	55.8
3	14.31 K	1.5	59.8
4	14.68 K	1.6	63.8

it is not easy to obtain electricity and efficiency in small temperature deviation [6]-[8]. Of course, in this case, the Thin-Film thermo element has the most optimum quality index in corresponding temperature and should be chosen. As you can see in Fig. 4, when the thermal deviation is 14.68 ℃, n-Type should be selected as Bi_2Te_3 (Bismuth Telluride) and p-Type as Sb_2Te_3 (Antimony Telluride) for Figure-of-merit theoretically [6]. For the normalization of obtainable power by thermal deviation occurring in the axle bearing, we calculated in the assumption of the most basic thermo element, a single rectangular Thin-Film thermo element of 4 ㎠ area, 1 ㎝ thickness. Also, the axle box bearing symmetry and the thermal deviation in the axle box bearing is relatively even in all locations. Therefore, the maximum energy harvesting power obtainable by using average temperature measured in the 4th sensor was 1.6mW as shown in Fig. 5 and the power estimated through ΔT is shown in below Table 2.

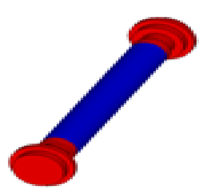

Figure 5. Estimated energy harvesting energy on the axle box bearing

We estimate the energy harvester need to generate more than 20mW for self powered (= energy harvesting) wireless on-board condition monitoring system. As shown in Fig. 6, sensor consumes very small energy, 15uW ~1mW, but wireless data transmit requires 10mW~15mW energy, even Zigbee protocol [9].

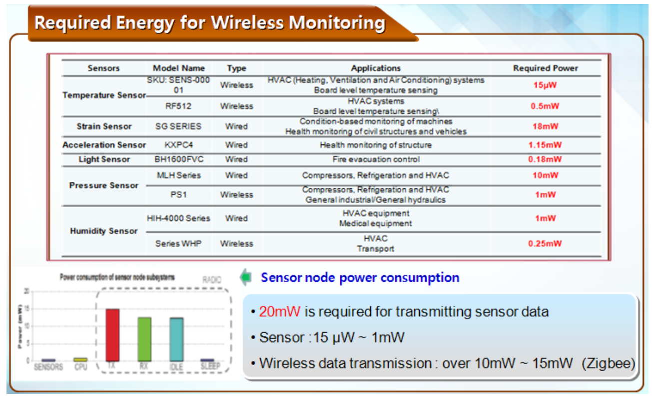

Figure 6. Required energy for wireless monioring

Regarding the larger sized thermo element of the axle box bearing area, the size is Ø= 25.4 ㎝, width= 2 ㎝, thickness=1 ㎝, which is the area of the temperature sensor attached on the axle box bearing. Theoretically, the energy harvesting power of 63.8mW can be obtained; so if more thermo elements are attached on the axle box bearings of high-speed trains though optimum design, hundreds mW of electric power can be obtained, and thus by using the energy harvesting power it will be possible to operate the wireless sensor network for railroad monitoring.

IV. CONCLUSION

This study was to confirm the applicability of energy harvesting technology, with new energy resources from the environment, for wireless sensor networks in railroad systems. We measured the temperature and thermal deviation during high-speed train operation, and estimated the energy harvesting power by thermal deviation on the axle box bearing.

1) The thermal deviation occurred in the axle box bearing when a train runs; the deviation was approximately 12.97～14.68° C

2) As a result of calculating the energy harvesting power by the thermal deviation, about 1.6mW power was obtainable in the rectangular thin film thermo element on the axle box bearing during the operation: 4 ㎠ area, 1 ㎝ height.

3) Concerning the larger sized thermo element of the axle box bearing area, the size is Ø= 25.4 ㎝, width= 2 ㎝, thickness=1 ㎝, which is the area of the temperature sensor attached on the axle box bearing. Theoretically, the energy harvesting power of 63.8mW can be obtained; so if more thermo elements are attached on the axle box bearings of high-speed trains though optimum design, hundreds of mW of electric power can be obtained, and thus by using the energy harvesting power it will be possible to operate the wireless sensor network for railroad monitoring.

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