A Study on the Wireless Onboard Monitoring System for Railroad Vehicle Axle Bearings Using the SAW Sensor

Jaehoon Kim[1], K.-S. Lee[1], and J.-G. Oh[2]

[1] Korea Railroad Research Institute, 360-1, Woram-dong , Uiwang- city,
Gyeonggi-do, 437-757, Korea
`{lapin95,kslee}@krri.re.kr`
[2] Corechips, Shin-dong, Youngtong-gu, Suwon-city, Gyeonggi-do, 443-734, Korea
`jgoh@corechips.co.kr`

Abstract. This study aimed to replace the current discontinuous rail monitoring system by applying "Plug and Play" technology to rail system monitoring to enable real-time monitoring, and by confirming on-condition maintenance efficiency and reliability. It examined a wireless sensor monitoring system which uses SAW (Surface Acoustic Wave) technology to monitor temperature changes in the axle box bearing of railroad vehicles during operation. The results of the experiment were compared with HDB measurements to confirm the reliability of the real-time monitoring results measured on vehicles during operation.

Keywords: Monitoring, Wireless, Surface Acoustic Wave, Railroad.

1 Introduction

In the railroad system measurement field, real-time measurements are an essential feature for the various sensors used for vehicle maintenance. These sensors are currently powered by batteries or through electric wires. However, such power supply methods can only be installed in certain locations and many improvements can be made in terms of long-term maintenance cost efficiency. This means that vehicle maintenance system developments require smaller sensors and technical improvements which enable "Plug and Play" so that sensors can be installed in any location.

Axle box bearing heating and adhesion during vehicle operation damage the axle, causing derailments and other accidents. However, the current limitations in monitoring system installation locations and technology do not allow direct axle bearing temperature monitoring during vehicle operation. Instead, the temperature is monitored using wayside Hot Box Detectors (HBD) installed at fixed distances along the track. This is discontinuous monitoring, and there have been reported incidents in which vehicles that passed the HBD with no problems suddenly derailed due to axle box bearing damages [1, 2].

This study aimed to replace the current discontinuous rail monitoring system by applying "Plug and Play" technology to rail system monitoring to enable real-time

G. Parr and P. Morrow (Eds.): S-Cube 2010, LNICST 57, pp. 52–58, 2011.

monitoring, and by confirming on-condition maintenance efficiency and reliability. It examined a wireless sensor monitoring system which uses SAW (Surface Acoustic Wave) technology to monitor temperature changes in the axle box bearing of railroad vehicles during operation. The results of the experiment were compared with the existing HDB measurements to confirm the reliability of the real-time monitoring results measured on actual vehicles during operation [3-5].

2 SAW Sensor for Real-time Wireless Axle Box Bearing Temperature Monitoring

For axle bearing boxes of vehicles that travel at high speeds, it is difficult to employ temperature sensors that use standard power supplies due to the influence of the surrounding environment, interference from high voltages and electronic parts and the unique location of the axle box bearing. Moreover, if the temperature sensor is employed in vehicles currently in commercial operation, the sensor and bearing structure need to be changed and this would incur significant replacement costs. Sensors such as the real-time wireless SAW temperature sensor, which do not require a power supply and can wirelessly monitor temperature immediately after semi-permanent installation, fully overcome the limitations described above and do not require changes in the parts structure of commercial vehicles. They can be employed in both existing and newly-produced vehicles, giving them high research value.

2.1 SAW Sensor Design

In general, SAW (Surface Acoustic Wave) sensors do not require any power supplies and can take measurements wirelessly. They are being studied intensively as a power-free wireless sensor, and are expected to be of great use in areas such as axle box bearings where it is not easy to install and operate sensors that require a standard power supply. Researchers in Europe published a research paper on measuring braking disc temperature in high-speed railroad vehicles using SAW sensors [6].

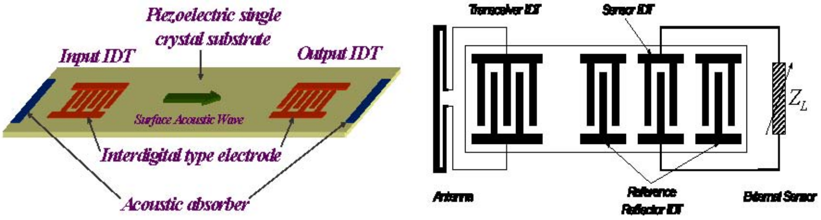

Fig. 1. SAW Sensor Concept (ZL : Variable impedance temperature sensor)

This study looked at the SAW temperature sensor which allows temperature monitoring on the axle box bearing. As shown in Figure 1, the SAW temperature sensor in this study has a substrate surface that can transfer acoustic waves, which is where the input and output Interdigital Transducers are located. At the input IDT, electric signals applied to the comb finger electrodes are transformed into acoustic waves by the inverse piezoelectric effect. The waves are transferred along the substrate to arrive at the output IDT, and a voltage is created at the electrode by the piezoelectric effect. The signal produced at the output IDT reacts with the IDT finger and substrate material. Substrate characteristics are applied to the acoustic wave transfer process, and the waves are converted to electric signals after reacting with the substrate material at the output IDT.

The characteristics that can be expected from the SAW temperature sensor in this study are firstly, a filter characteristic and secondly, a delay characteristic. In actual application, there are many products such as the VCO and Band Pass Filter in which communication systems composed of devices with filter characteristics play a key role. However, though devices with delay characteristics are being used as communication devices such as Delay Lines, the delay characteristic of SAW devices is a key feature of the power-free/wireless sensor to be developed through this study. In an actual device, the medium used on the substrate which transfers acoustic waves has a certain amount of thickness. Acoustic waves that are generated on the IDT on the substrate surface are not all transferred along the surface, but partially transferred as bulk waves.

The amount of bulk waves depends on the substrate material and electrode design. If bulk waves transferred into the substrate reflects off the bottom surface of the substrate, they disrupt the surface acoustic waves and decrease the filter and delay characteristics of the SAW device. This means that it is extremely important in the development of power-free/wireless SAW sensors and transponders to select appropriate IDT finger shape and substrate material. In this study, YZ-LiNb03, a popular SAW filter substrate material, was used to produce power-free/wireless SAW transponders and the IDT finger was designed to operate at a center frequency of 433MHz.

A numerical analysis was carried out in order to confirm the transponder design for the SAW transponder design in Figure 2. The results showed a matching performance of near 50 ohms at a center frequency of 433MHz with Reflector Finger IDT (Inter Digital Transducers) of 24 pairs and a Finger IDT Overlap Length of $500\mu m$. A SAW Mask Pattern as shown in Figure 2 was designed and produced based on these results. The estimated performance based on the results was a one-way traveling wave insertion loss of around -9dB. When used as a SAW power-free/wireless transponder, the two-way loss, 2-step piezoelectric conversion and inverse piezoelectric conversion result in a -6dB loss. Therefore, the basic design policy was set to have a structure with a loss of around -24dB (-9dB-9dB-6dB).

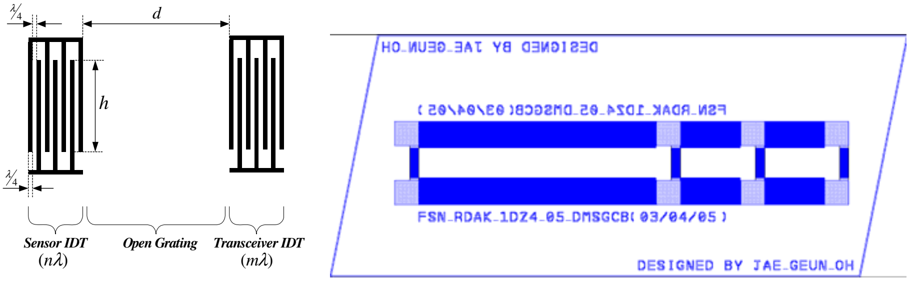

Fig. 2. SAW Model and Actual Production Sample Mask Pattern

The loss varies according to the SAW IDT number and the distance between the Sensor IDT and Transceiver IDT, and this was also analyzed. The analysis conditions and results are shown in Table 1. Note that the conditions and results apply when aluminum was (Al) is used as the metal layer, with the external impedance of the Sensor and Transceiver IDT matching at 50oe, a finger overlap (h) of 3mm), and an open grating distance (d) of 7mm. As Table 1 shows, insertion loss is low when the IDT number is 25 or fewer.

Table 1. Insertion Loss by Sensor IDT and Transceiver IDT Number

N_{Sensor} IDT	$N_{Transceiver}$ IDT	Insertion loss (dB)	3dB BW (MHz)
1	5	-25	60
5	5	-13	40
10	5	-11	30
15	25	-11	20
20	25	-11	14
25	25	-11	14
30	40	-15	14
35	40	-15	12
40	40	-18	12
50	50	-22	10

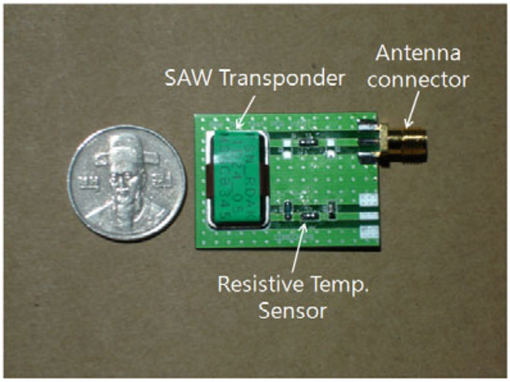

Fig. 3. Power-free SAW Temperature Sensor Prototype Combined with a Thermistor (Resistive Temp. Sensor)

A validation test and vehicle application test were carried out in order to monitor axle box bearing temperature in real-time by producing an SAW Transponder with an excellent measuring distance and noise coherence at 1°C precision, and an SAW temperature sensor with a variable impedance structure, as shown in Figure 3. The variable impedance temperature sensor was developed into a form which combines the Thermistor (Resistive Temp. Sensor) , which is commonly used in measurements that require precision, with the SAW transponder as shown in Figure 3, and the characteristics of the Thermistor is as shown in the graph in Figure 4. For the validation test, the current study also measured changes in sensor value with temperature changes in the precision hot-plate. Changes in sensor temperature were measured on the hot-plate instead of the standard incubation chamber because for axle box bearings, the monitoring target of this study, the existing HBD monitoring device measures the axle box bearing surface temperature during operation. Surface temperature was measured using hot-plates instead of incubation chambers in order to create similar conditions.

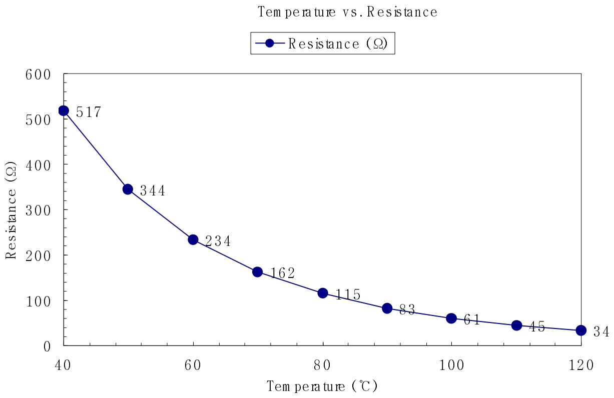

Fig. 4. Changes in Thermistor Resistance by Temperature

2.2 System Application Test Using High-speed Railroad Vehicles

An application test was carried out for axle box bearing temperature monitoring during vehicle operation using the SAW temperature sensor from the validation test described above. The aim of the application test was to replace the existing HBD (Hot Box Detector), which detects axle box bearing damages through a discontinuous temperature monitoring method, with a SAW temperature sensor to enable continuous temperature monitoring. It also compared SAW temperature sensor measurements with HBD temperature measurements to confirm the data, reliability, and validity of real-time monitoring.

Fig. 5. SAW Temperature Sensor and Antenna Installation for Axle Box Bearing Temperature Measurement

As shown in Figure 5, a SAW temperature sensor was installed on the axle box bearing of a vehicle that travels at 300km/h to wirelessly monitor temperature changes in real-time. To minimize errors due to installation location, the sensor was placed at a location closest to where the wayside HBD makes contactless temperature measurements on the axle box bearing surface.

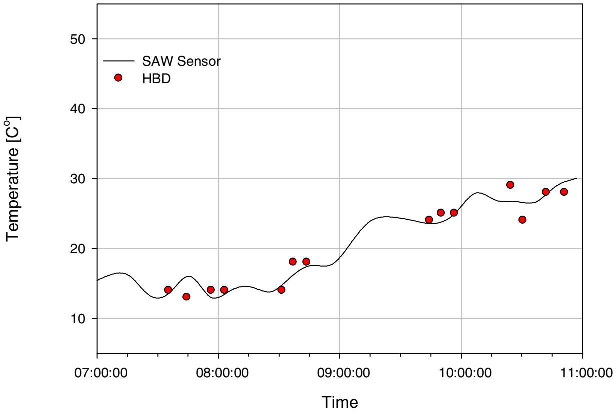

Fig. 6. SAW Sensor Temperature Results vs HBD Temperature Results (HBD installed in 7 locations along the route)

Figure 6 shows that during the two-way operation of the vehicle at the maximum speed of 300km/h, the SAW temperature sensor measurements were similar to the HBD measurements. For the entire period, both the SAW temperature sensor measurements and HBD measurements show fluctuations in axle box bearing temperature according to operation conditions such as stopping at stations or passing through tunnels, and both show an overall increase in temperature with operation time. Furthermore, the SAW temperature sensor and HBD temperature measurements differed only by 0.02℃~4.02℃ for each section. This confirmed the reliability of the SAW temperature sensor developed for r real-time wireless monitoring of axle box bearings on railroad vehicles.

The real-time monitoring validity was compared with the HBD. The HBD is only installed in 7 locations on each of the upward and downward routes. This does not allow continuous monitoring as the axle box bearing temperature is measured only when the vehicle passes these locations, and errors may occur in data analysis. In particular, it is difficult to determine whether sudden temperature changes in vehicles operating at 300km/h indicate problems in the axle box bearing with only HBD measurements. For example, in Figure 6, there is a sudden change in HBD data between 10:15 and 10:30. In order to determine whether this indicates a problem in the axle box bearing, another HBD measurement must be taken after 15 minutes. 15 minutes is a long period of time for a high-speed vehicle and if the axle box bearing has in fact been damaged, there may be an accident before the problem can even be checked. However, for real-time SAW sensor measurements, increases and decreases in axle box bearing temperature can be analyzed continuously, allowing quick and accurate damage detection. The SAW temperature sensor measurements in Figure 6, unlike the HBD measurements, show continuous changes in axle box bearing temperature between 10:15t and 10:30 to allow accurate monitoring of the axle box bearing.

This study confirmed the reliability of the real-time wireless SAW temperature sensor, and demonstrated that the temperature sensor can be made useful in vehicle integrity assessment and maintenance by using it to monitor axle box bearings and take continuous temperature measurements.

References

1. Rail Safety Investigation Report- Derailment of Pacific National Freight Services CB76 and 1WB3. Office of Transport Safety Investigations, Sydney, Australia (2007)
2. Rail Safety Investigation into the Derailment of Train 6WP2. Australian Transport Safety Bureau (2003)
3. Sodano, H.A., Inman, D.J., Park, G.: Comparison of piezoelectric energy harvesting devices for recharging batteries. Journal of Intelligent Material Systems and Structures 16, 799–807 (2005)
4. Horowitz, S., Kasyap, K.A., Liu, F., Johnson, D., Nishida, T., Ngo, K., Sheplak, M., Cattafesta, L.: Technology Development for Self-Powered Sensors. In: Proc. of 1st Flow Control Conference, AIAA-2022-2702 (2002)
5. Roundy, S.: On the Effectiveness of Vibration-based Energy Harvesting. Journal of Intelligent Material Systems and Structures 16, 809–824 (2005)
6. Pohl, A., Seifert, F.: Wirelessly interrogable surface acoustic wave sensors for vehicular applications. IEEE Transactions on Instrumentation and Measurement 46, 1031–1038 (1997)