Implementation of low-power sensing technology for wireless leakage monitoring

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1. Introduction

Monitoring technology is introduced from the design stage of primary system in operating nuclear power plants (NPPs), however monitoring of balance of plant (BOP) is lacking. In effect, it is very difficult to build additional monitoring system for lots of devices in the BOP, because one typical commercial NPP contains, for example, 462 pumps, 1,200 devices, 16,350 valves, and 247 km of pipes. The need to apply wireless technology for sensing and monitoring has been continuously raised because it is impossible to install and operate cables when using conventional wired sensors for above devices [1]. To meet the needs, however, the battery replacement issue for the wireless devices must be addressed. Here, we report a development of a low-power leakage monitoring instrument for pressure devices, such as pipes and tanks of NPPs.

2. International Standards

An acoustic ultrasonic detection technology for leakage monitoring was developed to satisfy the ASTM E 1002-05 Class II device qualification standard of the American Society for Testing and Materials. The standard requires the acoustic ultrasonic signal emitted, under the condition of 0.024 gpm gas leaks from a nozzle with a diameter of around 0.2 mm under a gauge pressure of around 0.7 atm, must be detected at a distance of 5 m or more.

When a leak occurs in a pressure device, ultrasonic waves are generated due to the eddy phenomenon. We accept the signal range between 20 kHz and 100 kHz due to its favorable S/N (signal to noise) ratios, and removed the audible sound region below 20 kHz. The reactor coolant pressure (RCP) boundary leak detection system requires detection of 1 gpm leak less than an hour. Our calculation of leak amount with respect to the temperature and pressure reveals that the detection was successful [2].

Table 1. ASTM E 1002-05 for Wireless Leak Detection

International Standard	Class	Requirements	
ASTM E 1005-05 (USA)	Class I	Orifice Diameter	0.2 mm
		Distance	10 m
		Pressure	0.7 atm
		Frequency	20 ~ 100 kHz
		leak	0.024 gpm
	Class II	- Distance : 5 m - Same as Class I (except distance)	

3. Development of Low-power wireless sensing for leakage monitoring

Acoustic ultrasound signals are severely attenuated with distance, and include very big noise in the audible frequency region. Typical leak signal collected using an acoustic ultrasonic sensor is shown in Figure 1.

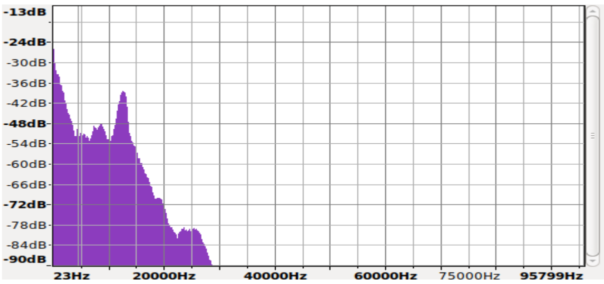

Figure 1. Acoustic-ultrasonic Signal.

Very big noise is included below 20 kHz, and it is difficult to detect meaningful signals above 100 kHz. Between 36 kHz and 40 kHz, the leakage signal appears most clearly. Thus, we use signals in the range between 20 kHz and 100 kHz. Since the signal strength in this range is very weak, signal amplification by tens of thousands to hundreds of thousands times is required. Then, we face a power consumption problem. We resolve this problem through designing optimal configuration of the amplification element of the amplification circuit (Fig. 2).

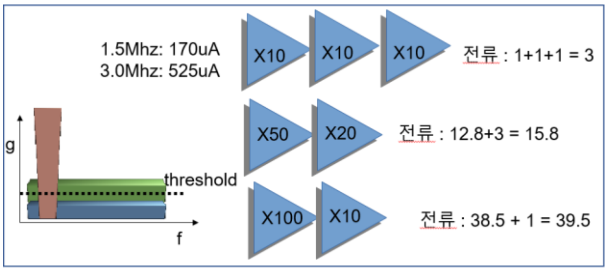

Figure 2. Arrangement of Amplication Elements.

The wireless sensing module developed for leak detection can monitor more than 36 months at a cycle of about 130 seconds with a battery of 9,000 mAh capacity. The correlation among average current consumption, operating period of wireless device and monitoring period is follows (Fig. 3).

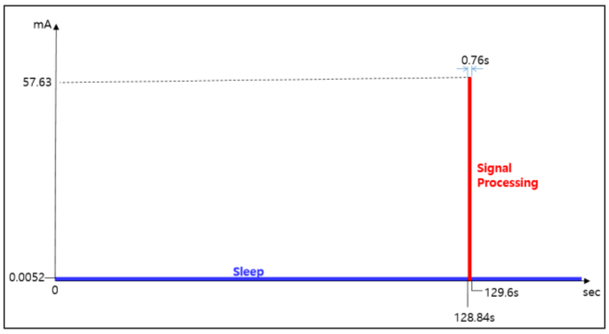

Figure 3. Arrangement of Amplication Elements.

In simple math, 36 month equals 26,280 hour (3 × 365 day × 24 hour) and 9,000 mAh / 26,280 hour equals 0.343 mA (343μA). Thus, the device can last for 3 years if the average current consumption is less than 343 μA. In Figure 3, sleep and leak detection are performed in a period of *t*. The leak detection execution time is 0.76 s and the average current consumption at this time is 57.63 mA. The idle mode execution time is (*t* – 0.76 s), and the average current consumption at this time is 5.2 μA. Therefore, the total current consumption during leak detection is 0.76 × 57,630 μA, which equals 43,798.8 μA. Since (43,798.8 μA + (5.2 μA × (*t* – 0.76 s))) / *t* equals 343 μAs and *t* = 129.6 s. For signal processing, it is converted into a digital signal through an analog-to-digital conversion circuit (A/D Converter) at a sampling frequency of 256 kHz. Here, 30 FFTs are performed for 0.76 s during signal processing, and the average value is calculated. If data sampled at 256 kHz is converted to hexadecimal and transmitted, the amount of data to be transmitted is 256,000 × 4 bytes per second or 256,000 × 4 kbytes. However, the developed sensing module calculates 320 average spectrum values at 0.25 kHz intervals in the 20 kHz to 100 kHz frequency band, and expressing them as real values in the form of 4 byte Float results in a total monitoring data size of 1280 bytes.

Given that wireless communication is an important factor in current consumption, it is necessary to reduce the size of transmission data. However, 320 average spectral values must be able to sufficiently express meaningful signal changes using artificial intelligence.

4. Conclusion

We report the development of a wireless sensing module that is capable of sensing the leakage of a pressure vessel with low-power. Low-power technology is absolutely necessary for practical use of wireless devices for BOP monitoring in NPPs. The implementation of low-power electronic circuit and data size reduction technology is presented. We note that reducing current consumption in idle mode needs further research.

REFERENCES

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[2] ASTM International, ASTM E1002-11 (2018), Standard Practice for Leaks Using Ultra-sonics, 2018.

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