Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Ultrasonic Temperature Estimation for Dry Cask Storage Systems

Eunju Yoo [a], Minsu Park [b], Junhyeok Kang [b], Youngwoo Park [b*], Myounggyu Noh [b]
[a]*Graduate School, Department of Mechatronics Engineering, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134*
[b]*Department of Mechatronics Engineering, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 34134*
[*]*Corresponding author: ywpark@cnu.ac.kr*

1. Introduction

Dry Cask Storage Systems (DCSS) keeps the long cooled Spent Nuclear Fuel (SNF) dry and stores it in an inert atmosphere instead of wet storage utilities at individual reactor sites. The DCSS is important and necessary to keep monitoring for its safe and steady operation. The temperature is one of the most important guiding significance because SNF failure and cask leakage are always accompanied with abrupt temperature increase [1-3]. Therefore, temperature monitoring is the simplest and most representative method of checking the state of the DCSS internal canister. Thermocouple is currently used method which has simple manufacture and low thermal inertia. However, it has drift error during the long term operation and shunting error by hot junction site [4].

Ultrasonic temperature measurement is one of the acoustical transmissions types which is to measure the temperature using the acoustics. So, it has wide measurement ranges with no drift characteristic. Thus, the present paper presents the ultrasonic temperature measurement method based on acoustical transmission principles that is capable to estimate the temperature of the steel plate.

2. Ultrasonic temperature measurement method

Fig. 1. shows the principle of the ultrasonic temperature measurement. When the excitation pulse is applied at one end of waveguide, a small deformation occurs in the waveguide. It propagates along the waveguide and then reflects back at the reflection point. Ultrasonic wave is generated at the fixed reflection position due to interaction between the excitation pulse and the reflection point. The sensing coil output, fixed to the other side of the waveguide, is the induced voltage, which is estimated by using Faraday's law.

The waveform of the sensing coil output is shown at the bottom of Fig. 1. Time-of-flight is obtained by the difference between the time T_0 when the excitation pulse passes the sensing coil and the time T_1 when the ultrasonic wave returning from the fixed reflection point pass the sensing coil. Therefore, the fixed reflection point must be free from position variation with temperature. That is, the reflection point becomes the temperature measurement point.

Also, since the ultrasonic wave travels the distance between the sensing coil and the reflection point reciprocally at a propagation speed corresponding to the temperature, TOF (Time-of-flight) can be expressed as Equation (1);

$$TOF = 2L/V = T_1 - T_0 \tag{1}$$

where, L is distance between the sensing coil and the reflection point. V is the ultrasonic wave propagation speed at the temperature. The time-of-flight difference, ΔTOF, was calculated for the various temperatures using below relationship;

$$\Delta TOF = TOF_i - TOF_r \tag{2}$$

where, TOF_i and TOF_r are time-of-flight at the current temperature and room temperatures, respectively.

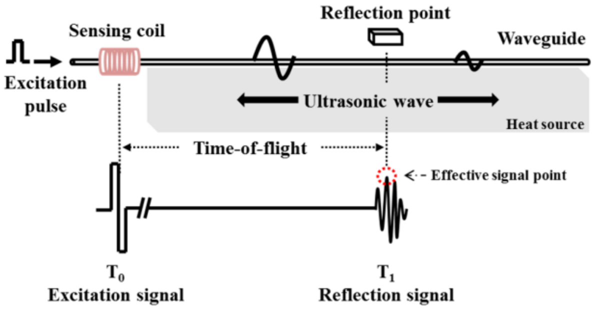

Fig. 1. Principle of ultrasonic temperature measurement.

3. Experimental results

The experimental apparatus setup is shown in Fig. 2. The waveguide is made of ferromagnetic material such as iron-nickel alloy with a diameter of 1 mm and a length of 60 mm. The fixed reflection point is a NdFeB permanent magnet. The signal generator generates an excitation pulse current with an amplitude of 1.4 A, and with a width of 100 μs. Also, the heat source was provided by hot plate which has the temperature limit at 550 ^{o}C.

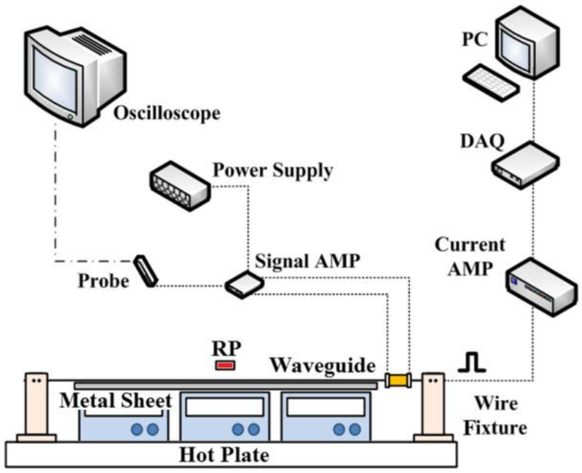

Fig. 2. Experimental apparatus setup.

In order to construct similar the high temperature environment of the surface of the canister containing SNF assembly, a metal sheet with the waveguide on a hot plate was installed. In experiments, the temperature of waveguide was up or down cycles about 25 ^{o}C or 50 ^{o}C intervals.

Fig. 3. shows the effective signal curves of sensing coil output during temperature cycle with DC offset voltage. It is a circle marked with a dotted line of the reflection signal (T_1) in Fig. 1. ΔTOF under various temperatures were collected with instrumentation device, i.e., TDS2014C (Tektronix) and calculated by using Eq. (2). It can be seen that the peak value of the effective signal during the temperature-up cycle moves to the forward and moves in the opposite direction during the temperature-down cycle. Although the temperature measurement point is fixed, the TOF changes because the propagation speed of the ultrasonic wave varies depending on the temperature. Maximum ΔTOF is about 4 μs while the temperature is changing from room temperature to 325 ^{o}C.

4. Conclusions

In this paper, the ultrasonic temperature estimation method using acoustical transmission principle is proposed for the temperature monitoring of DCSS.

The conclusions are as follows:

1. ΔTOF changes as temperature varies.
2. The proposed method is valid from room temperature to 325 ^{o}C.

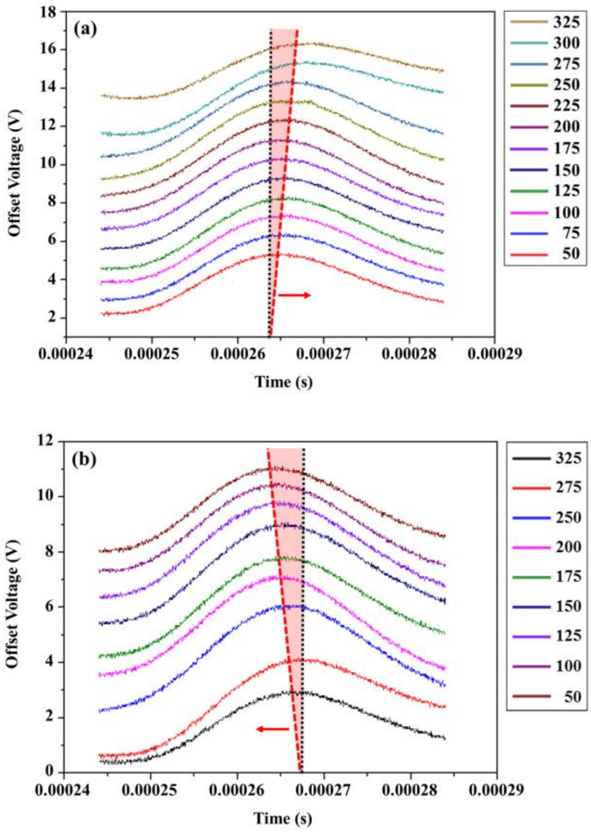

Fig. 3. Effective signal curves during temperature cycle with DC offset voltage. (a) Temperature-up cycle (b) Temperature-down cycle

ACKNOLEDGMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) and the Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20161520101300).

REFERENCES

[1] S. Bakhtiari, T. W. Elmer, E. Koehl, K. Wang, A. C. Raptis, D. C. Kunerth, and S. M. Birk, Dry Cask Storage Inspection and Monitoring, Interim Report, Idaho National Laboratory (INL), pp. 1-38, 2012.

[2] J. Daw, J. Rempe, S. Taylor, J. Crepeau, and S. C. Wilkins, Ultrasonic Thermometry for In-Pile Temperature Detection, American Nuclear Society International Topical Meeting on Nuclear Plant Instrumentation Control and Human-Machine Interface Technologies, 2010.

[3] S. Bakhtiari, K. Wang, T. W. Elmer, E. Koehl, and A. C. Raptis, Development of a Novel Ultrasonic Temperature Probe for Long-term Monitoring of Dry Cask Storage Systems, Proceedings of Annual Review of Progress in Quantitative Nondestructive Evaluation, 1511, pp. 1526-1533, 2013.

[4] S. Periyannan, and K. Balasubramaniam, Multi-level Temperature Measurements using Ultrasonic Waveguides, Measurement, Vol. 61, pp. 185-191, 2015.