Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 26-27, 2023

Gamma Ray Irradiation Effects on Distributed Temperature Sensor for Condition Monitoring of NPP Structures

Gukbeen Ryu*, Young-Woong Kim, Jong-Yeol Kim, Young Gwan Hwang
Nuclear System Integrity Sensing & Diagnosis Division, Korea Atomic Energy Research Institute(KAERI), Daejeon, South Korea
**Corresponding author: gbryu@kaeri.re.kr*

***Keywords :** optical fiber based distributed sensor, distributed temperature sensor, condition monitoring

1. Introduction

The fiber-based distributed sensor is a sensor that can measure the spatially-continuous distribution of physical quantities over a wide area where the fiber is installed, with all points on the fiber as sensing points. Information about the external physical quantity(temperature, strain, vibration, etc.) can be extracted by using the principle that the optical properties (intensity, phase, wavelength, etc.) of scattered light along the fiber vary linearly due to changes in the environment around the fiber. The distributed optical fiber sensor is attracting attention as a sensor for special environments because they can withstand extreme environments such as high temperature, high radiation, high pressure, and high humidity due to the material characteristics of optical fibers. In particular, research is being actively conducted to monitor the condition of nuclear power plant(NPP) structures such as pipes, reactors, and waste facilities in a radiation environment.

In this paper, we show the results of analyzing the effect of gamma rays on the fiber-based distributed temperature sensor(DTS). The final goal is to condition-monitor the safety of NPP structures by measuring changes in temperature distribution by applying the DTS to NPP structures, and this study is conducted to verify the applicability. The DTS consists of general optical fiber and radiation-resistant optical fiber, and the effect of gamma-ray irradiation on sensor performance is experimentally analyzed.

2. Methods and Results

The DTS measures the temperature distribution along the optical fiber by using the principle that the intensity of Raman-scattered light passing through the optical fiber changes linearly with the temperature change around the fiber. At this time, the optical fiber acts as a sensing unit that acquires external physical quantity information and a medium that transmits the information at the speed of light. The conceptual diagram of the DTS is shown in the Fig. 1. The optical pulse is input into the optical fiber, and Raman-backscattered light along the fiber is measured in the time domain. Raman scattered light appears as a stokes and an anti-stokes component, and the intensities of the two components varies linearly with temperature changes. Compared to the stokes component, the intensity of anti-stokes varies greatly depending on the temperature around the optical fiber, so the temperature information can be obtained by calculating the rate of change in intensity for the both components. In addition, by measuring the scattered light in the time domain and converting time into distance using the propagation speed of lihgt in the optical fiber, the position of the point at which the temperature change occurred can be specified [1].

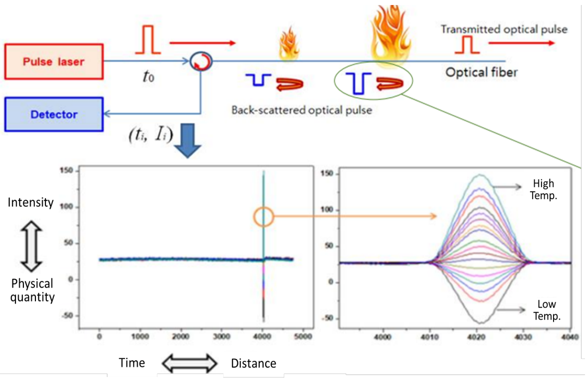

Fig. 1. Conceptual diagram of a optical fiber-based distributed temperature sensor.

Figure 2 illustrates the composition of the gamma-ray irradiation experiment to analyze the effect of gamma-ray on the distributed temperature sensor. Optical fiber samples were placed inside the gamma-ray irradiation facility and connected to the DTS outside the facility using an extension fiber. The Raman-scattered light signal and the temperature distribution data were measured remotely in real time, and changes in the measured result were analyzed while irradiating gamma rays. Optical fiber samples were used in two types of optical fibers : general optical fiber for communication (germanium doped single mode fiber, 500 m, Taihan Fiber Optics) and radiation-resistant optical fiber (pure silica core single mode fiber, 300 m, OFS optics). When optical fibers are exposed to gamma rays, the transmission loss of the light increases, and the radiation-resistant optical fiber is an optical fiber that minimizes the effect of radiation induced attenuation (RIA) [2]. The experiment was conducted using the gamma-ray irradiation facility of the Advanced

Radiation Research Technology Institute (irradiation source : Cobalt-60). Fiber samples were irradiated for 2 hours at a dose rate of 1 kGy/h, and recovery characteristics were measured for about 30 minutes.

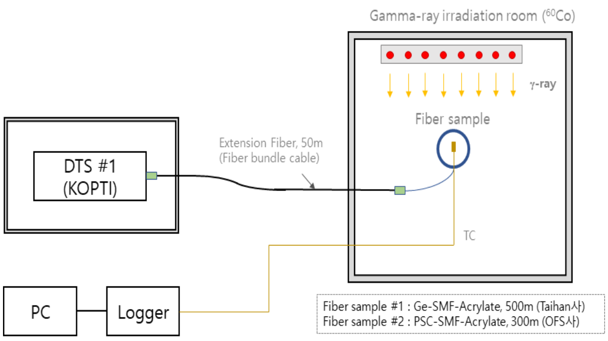

Fig. 2. Schematic diagram of the gamma ray irradiation experiment.

The results of measuring Raman-scattered light signal while irradiating gamma rays to general optical fiber for is shown in the Fig. 3. The intensity of the Raman scattered light signal before gamma-ray irradiation remains constant with fiber distance, while the intensity is gradually reduced by RIA as gamma-rays are exposed (decreased by 17 dB for 2 kGy irradiation). The noise component increased as the intensity of the Raman scattered light decreased, which means that the temperature measurement accuracy decreased. The temperature distribution data calculated from the Raman scattered light signal is shown in the Fig. 4. It is a graph showing temperature distribution information measured along the entire length of a general optical fiber sample, and the measurement error gradually increased as gamma rays were irradiated. The measurement error before and after(2 kGy) irradiation was 3.1°C and 48.6°C, respectively, which significantly degrades the temperature measurement performance after gamma irradiation (no temperature change during gamma ray irradiation). After 30 minutes of discontinuing irradiation, the measurement error recovered to 26.7°C.

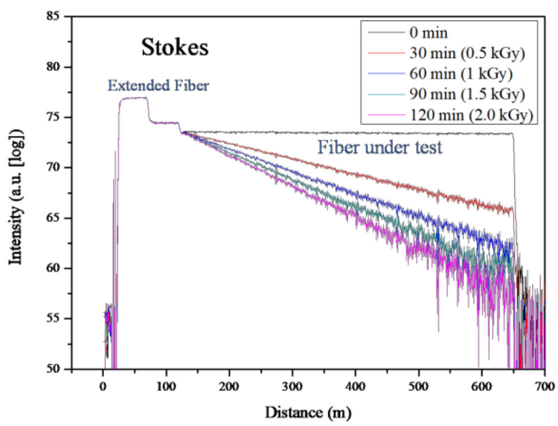

Fig. 3. Raman-scattered light signal measured while irradiating gamma-rays on the general optical fiber.

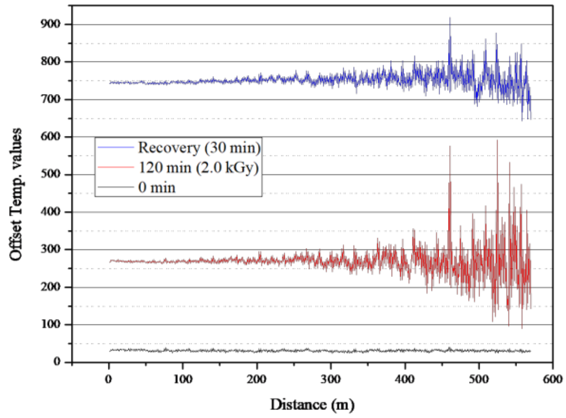

Fig. 4. DTS temperature data measured while irradiating gamma-rays on the general optical fiber.

The result of measuring the Raman-scattered light signal while irradiating gamma rays to the radiation resistant optical fiber is shown in Fig. 5. The intensity of the Raman scattered light signal before gamma-ray irradiation remains constant with fiber distance, while the intensity is gradually reduced by RIA as gamma-rays are exposed. Compared to the general optical fiber (17 dB attenuation), the intensity attenuation of Raman-scattered light along the radiation resistant optical fiber was significantly lower at 2.5 dB. The temperature distribution data calculated from the Raman scattered light signal is shown in the Fig. 6. It is a graph showing the temperature distribution information measured along the entire length of the radiation resistant optical fiber, and it can be seen that the measurement error did not change significantly even when exposed to gamma rays. The measurement error before and after(2 kGy) irradiation was 2.6°C and 4.0°C, respectively (no change in temperature during gamma ray irradiation). The slope of the measured temperature distribution gradually changes as the fiber is irradiated, which is caused by the difference in RIA coefficients in the stokes and anti-stokes wavelength bands, and this effect need to be compensated.

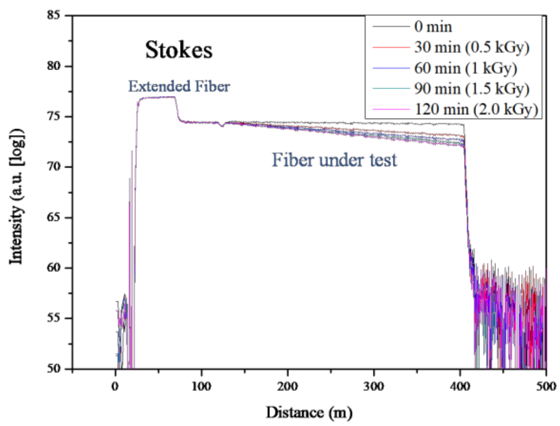

Fig. 5. Raman-scattered light signal measured while irradiating gamma-rays on the radiation-resistant optical fiber.

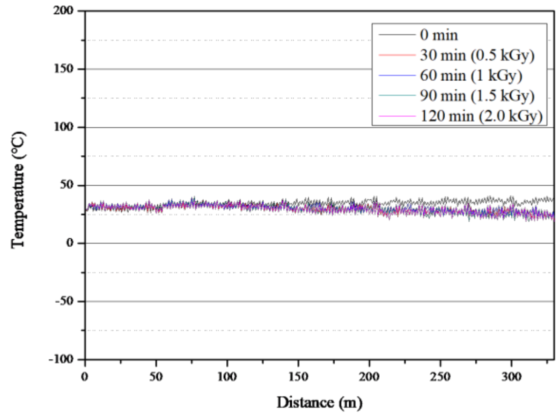

Fig. 6. DTS temperature data measured while irradiating gamma-rays on the radiation resistant optical fiber.

3. Conclusion

A fundamental study was conducted to condition-monitor the state of NPP structures using an optical fiber-based distributed temperature sensor. Gamma rays were experimentally irradiated to the optical fiber of the DTS and the effect of sensor performance was analyzed. In conclusion, when the distributed temperature sensor was constructed using the radiation-resistant optical fiber, it was confirmed that the sensor's measurement performance was hardly degraded even when 2 kGy gamma rays were irradiated. By installing distributed sensors on NPP structures and measuring temperature distribution data over a wide area along the fiber in real time, it is expected to be able to condition-monitor the safety state of the structures in the radiation environment.

REFERENCES

[1] J. P. Dakin, D. J. Pratt, G. W. Bibby, J. N. Ross, Distributed optical fiber Raman temperature sensor using a semiconductor light source and detector, Electron. Lett., Vol. 21, pp. 569-570, 1985.

[2] S. Girard, A. Morana, A. Ladaci, T. Robin, L. Mescia, J. Bonnelois, M. Boutillier, J. Mekki, A. Paveau, B. Cadier, E. Marin, Y. Ouerdane, Recent advances in radiation-hardened fiber-based technologies for space applications, J. Optics, Vol. 20, No. 9, 2018.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea Government (Ministry of Science and ICT) (No. RS-2022-00144110).