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

Ultrasonic Guide Tube Sensor for Under-Sodium Inspection in Sodium-Cooled Fast Reactors

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Keywords : sodium-cooled fast reactors, SFR, in-service inspections, under-sodium viewing, ultrasonic sensor

1. Introduction

Recognized as a leading example among advanced reactor designs, sodium-cooled fast reactors (SFRs) are a promising generation 4th nuclear reactor technology. [1-2] The liquid sodium coolant acts as a heat sink, absorbing and dissipating the heat generated by the nuclear reactions in the reactor core. However, the opaque nature of the sodium coolant presents a significant challenge for visually inspecting the internal structure of these reactors, impacting safety and reliability.

To perform in-service inspections (ISI) of the reactor internal structure in a sodium-cooled fast reactor, it necessitates under-sodium viewing (USV) technology utilizing ultrasonic waves and the development of ultrasonic sensors resilient to high-temperature and high-radiation conditions. [3] The application of ultrasonic visualization aids in detecting obstacles along fuel transfer routes. This technology facilitates in-service inspections of reactor internal structures and devices, allowing for thorough assessments of their condition and integrity during operation. These sensors are important for enhancing the safety and reliability of advanced nuclear systems.

In this study, we developed the C-Scan system using ultrasonic waves under-water and addressed the considerations required for sensor development under-sodium.

2. Methods and Results

The C-Scan system was designed and optimized with specific considerations for reliable operation in high-temperature under-sodium environments. To validate its effectiveness, we conducted testing in water. Furthermore, we constructed the C-Scan system in a glove box for testing in high-temperature under-sodium environments.

2.1 Real-time imaging

Developing techniques to process and visualize the ultrasonic data in real-time is essential to provide operators with immediate feedback on the condition of the high temperature liquid sodium and detect any anomalies or defects promptly. We designed C-Scan system to obtain images using ultrasonic Guide Tube Sensor at room temperature under-water, conducted etching on the ‘FNC’ letters and ‘one-line’ samples. The C-Scan system enabled real-time image acquisition. It is shown in Figure 1.

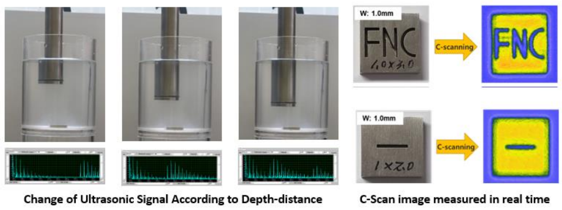

Fig. 1. The C-scan for room temperature under-water

2.2 Coupling Medium & Transducer Design

Identifying suitable coupling mediums that well work and endure in high-temperature sodium conditions is vital. The transducer is a crucial component of the ultrasonic sensor that converts signals into ultrasonic waves and vice versa. It needs to be designed to operate efficiently in high-temperature conditions. Considerations must be made for the type of backing material, and overall structural design. We designed a protection tube for indirect contact with the sodium medium, sensor cooling, and maintenance, and determined the delay line length considering the ultrasonic sound velocity/near-field sound field/attenuation characteristics. The manufactured probe was designed to protect the sensor at high temperatures, it was determined to tube type, the material of the delay block was SUS or Ni. The detailed structure is shown in Figure 2.

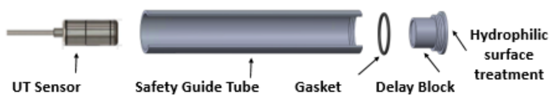

Fig. 2. Concept design Uutrasonic sensor using delay block

2.3 Isolated glove box from outside

Reacting rapidly with moisture in the air, high-temperature sodium generates sodium hydroxide and hydrogen gas, posing fire and explosion risks. The glove box's use of inert Ar gas creates an oxygen-free environment, reducing chemical reaction, corrosiveness and minimizing structural compromises. Above all, ensuring operator safety, it prevents chemical burns and respiratory irritation while controlled high-temperature sodium handling.

Inside the glove box, a motion controller equipped with a C-Scan ultrasonic sensor was installed to facilitate the production of Big-Data. Cables and motors were carefully chosen for external connection, ensuring minimal interference from high temperature and noise. Sodium is in liquid form, it was applied to be transported along the flow path by injecting argon gas. The overall structures are shown in Figure 3.

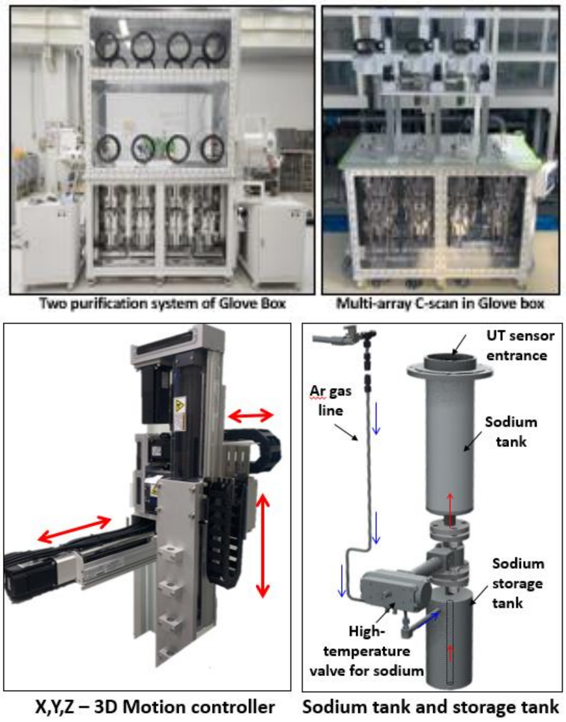

Fig. 3. C-scan system and hot sodium storage tank with Glove box

3. Conclusions

This study involves the active utilization of C-Scan system for real-time measurements in underwater environment, a guide-type sensor was designed and manufactured to protect against high temperatures and determine optimal probe specifications. And with the establishment of a basic test.

The result of test under-water helps to gain meaningful findings into the sensor's behavior, signal transmission, and response to different conditions, providing a solid foundation for further testing in high-temperature sodium environments. However, the challenge lies in subjecting the ultrasonic guide tube sensor to actual high-temperature under sodium conditions. The harsh and demanding nature of such an environment requires the sensor to withstand extreme temperatures, maintain accuracy in signal readings, and remain to potential corrosive effects.

The development of this ultrasonic guide tube sensor technology has the potential to revolutionize in-service inspections and monitoring of critical structures within high-temperature sodium environments.

The acquired images are then being subjected to review using super-resolution, data augmentation, and defect discrimination artificial intelligence models. As a future, we plan to create a C-Scan image data base in high-temperature under-sodium settings using a glove box.

Acknowledgement

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (2022M2D4A1054827)

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