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# Development of a Pipe-Wall Thinning Inspection Method Based on a Wireless UT Sensor

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**ABSTRACT**

Aiming to reduce inspection time of pipe-wall thickness measurements in nuclear power plants, we have been developing a new inspection method based on a wireless UT sensing technology which was originally proposed by University of Bristol. Utilizing the characteristics of the wireless UT sensor, the new inspection method enables the pipe-wall measurement without removal of pipe insulation which is a time-consuming process in general. One of the issues which needs to be addressed is existence of a metal jacket covering the pipe insulator. Since the wireless UT sensor is based on electromagnetic induction between coils, a magnetic field between the coils is interruped by the metal jacket and the wireless UT sensor is not applicable in this case. In this study, we developed the intermediate coil system (PCT/JP2018/020043) as one of the options to overcome this issue. In this system, two coils and cables are added into the original wireless UT sensor. Firstly, we developed an electrical circuit model to optimize the system design, and confirmed that the developed electrical circuit model has sufficient accuracy by the comparison with the experiment result. Then we performed the feasibility test of the intermediate coil system in the pipe-wall thinning measurement by using the test apparatus which simulates the pipe in the actual nuclear power plant. From these results, we have confirmed the feasibility of the intermediate coil system in the pipe-wall thinning measurement. Further development and evaluation will be conducted to apply this system into the actual plant inspection in the future study.

**KEYWORDS**

*Ultrasonic testing, wireless sensor, pipe-wall thinning, nuclear power plant, inductive coupling*

**ARTICLE INFORMATION**

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## 1. Introduction

Piping systems, such as within an oil and gas system, a chemical plant, a fossil-fuel plant, a nuclear power plant and so on, are subject to corrosion and/or erosion which cause thinning of the pipe wall. Nuclear power plants have experienced some incidents due to the pipe-wall thinning. Representative ones are at the Surry Unit 2 in 1986 [1] and at the Mihima Unit 3 in 2004 [2]. Following these incidents, a number of research programs were conducted [3-8], and then ultrasonic testing (UT) is now commonly used for inspection of the pipe-wall thinning in the nuclear power plants. In Japan, numerous ultrasonic thickness measurements are manually carried out during the outage of nuclear power plants. Most of the pipes in the nuclear power plants are covered with insulators, so the insulator must be removed before the ultrasonic measurement. Since the supplemental works, such as the insulator removal, are known as time-consuming processes, the inspection technology which enables the pipe-wall thickness measurement without the insulator removal is desirable to reduce the inspection time of the pipe-wall thickness measurement.

Zhong et al. from University of Bristol [9] proposed an innovative sensing technology based on electromagnetic induction between coils. Since pulser/receiver and a transducer can be inductively coupled in this technology, no cable is required between them. This means that the sensor has a

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capability to perform the pipe-wall thickness measurement without removing the insulator if the coils can be inductively connected through the pipe insulator. To confirm applicability of this technology (called a wireless UT sensor in this paper) to the actual plant inspection, a feasibility study was performed in the previous research [10]. Measurement accuracy, maximum offset between coils and effect of the insulator on the inductive coupling were investigated. The sensor durability against temperature cycles and irradiation was also confirmed [11]. One of the issues which needs to be addressed is existence of a metal jacket around the pipe insulator. It is known that the electromagnetic induction is strongly affected by the metal materials because magnetic field is converted into an eddy current on the surface of the metal. In this study, we propose a new approach to overcome this issue.

## 2. A Wireless Ultrasonic Sensor

Figure1 illustrates the wireless UT sensor proposed by Zhong et al [9]. It consists of two parts: a sensor and an inspection rod. The sensor, attached on the surface of the inspection target, has a sensor coil and a transducer which are connected with each other. The inspection rod contains a transmitter coil and a receiver coil. As shown in the left of Fig. 1, there is no cable between the inspection rod and the sensor because they are inductively coupled by the coils. The right of Fig. 1 shows an application of the wireless UT sensor to the pipe-wall thinning measurement of the actual nuclear power plant. Firstly, the sensors are bonded to the pipe surface with high temperature adhesive because the temperature of the pipe becomes around 200 deg C. Then the pipe is covered with the insulator as shown in the right of Fig. 1. Once installation of the sensor and the insulator is completed, the ultrasonic measurement without removing the insulator can be available if there is no metal jacket. As described above, the electromagnetic induction is strongly affected by the metal jacket, which is generally installed on the pipe insulator in the nuclear power plant. To resolve this issue, a simplest way is to replace the metal jacket with non-metallic one. On the other hands, it is worth considering other options to address this issue because it might be difficult to replace the metal jacket in some cases.

In this study, we propose the intermediate coil system (PCT/JP2018/020043) which enables the thickness measurement without removing the insulator even if the insulator is covered with the metallic jacket. In this concept, two coils and cables are added into the insulator with the metal jacket as shown in the right of Fig. 1. Since the signal from the inspection rod can be transmitted to the underneath of the metal jacket through the cable, the thickness measurement without removing the insulator and the metal jacket may be achievable by the intermediate coil system. In the following section, feasibility of the intermediate coil system is investigated.

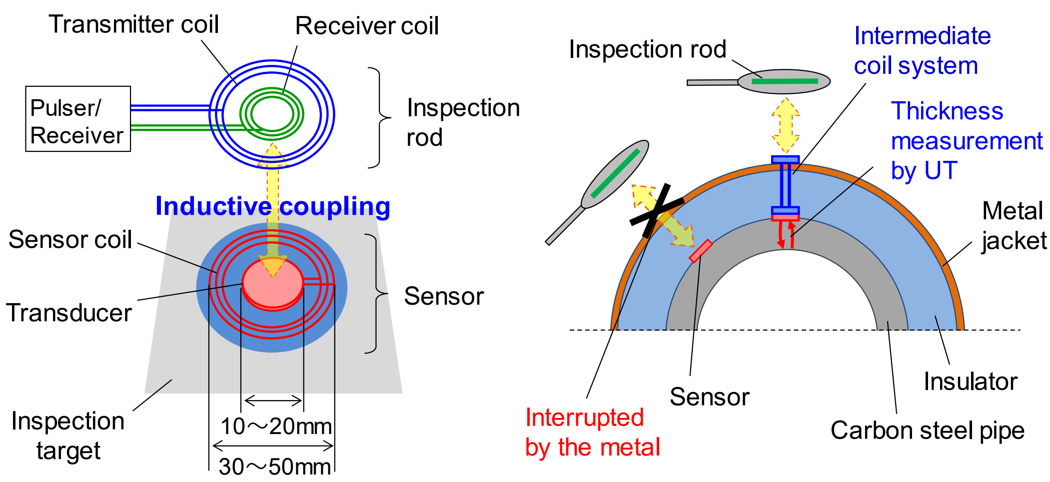



**Fig. 1. Concept of a wireless ultrasonic sensor and its application to the pipe-wall thinning inspection**

## 3. Development of the Intermediate Coil System

To realized the intermediate coil system, we first developed the electrical circuit model. The electrical circuit model of the original wireless UT sensor which consists of three coil circuits was already published by Zhong et al. [9]. By referring to this model, the five coil system was constructed as shown in Fig. 2 to simulate the intermediate coil system. The subscripts of the symbols corresponds to each coil. Each parameter in this electrical circuit model was calculated or measured by the same method as the original wireless UT sensor's one [9]. Because this model includes the impedance of the transducer attached on the inspection target, we can simulate the received signal (i.e. A-scan) with various coil designs. In order to validate the developed electrical circuit model, we manufactured the prototype of the intermediate coil system as shown in the right of Fig. 2. The transducer which can generate 3.5 MHz longitudinal wave was attached on the carbon steel plate with 20 mm thickness.

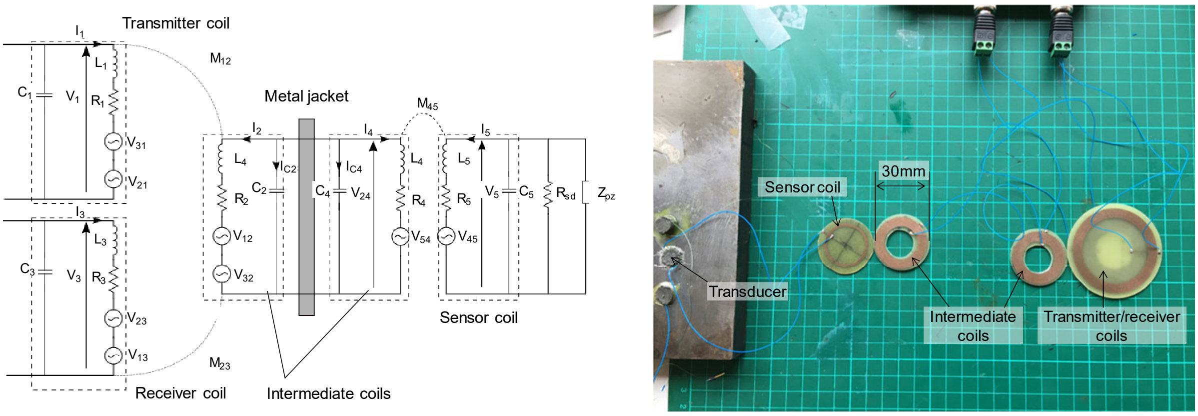
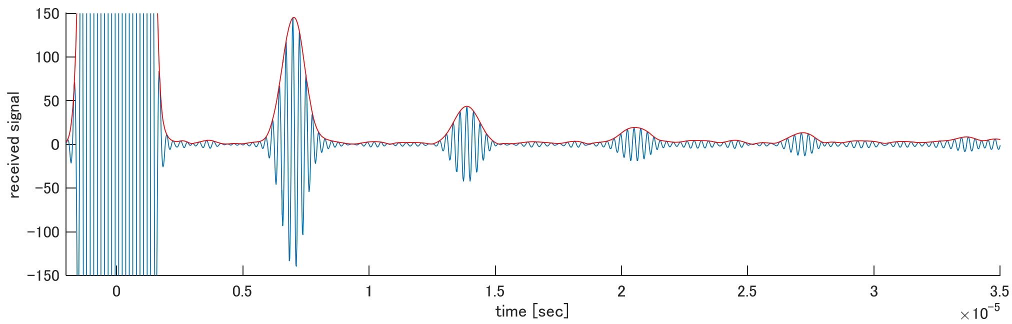
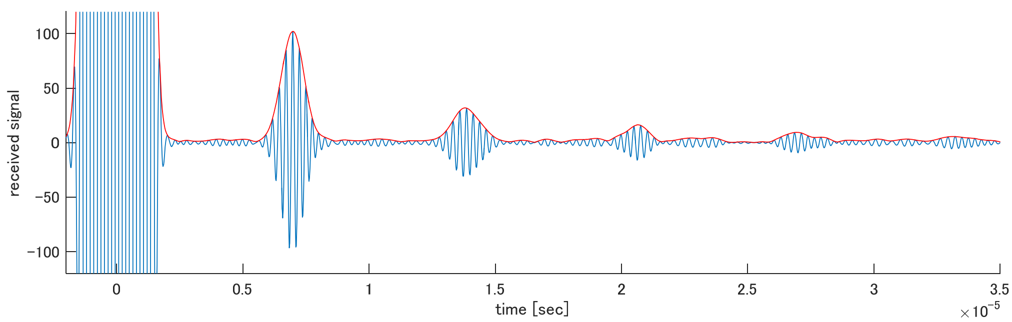



**Fig. 2. An electrical circuit model for the intermediate coil system and the manufactured prototype.**

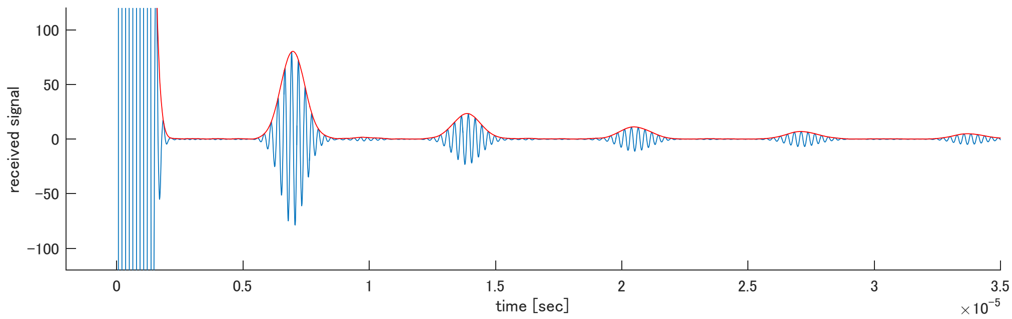



**(a) The received signal from the original wireless UT sensor.**




**(b) The received signal from the prototype of the intermediate coil system.**

**Fig. 3. Validation of the electrical circuit model for the intermediate coil system (continues to next page).**




**(c) The received signal from the simulation of the developed electrical circuit model.**

**Fig. 3. Validation of the electrical circuit model for the intermediate coil system.**

Firstly, we experimentally compared the received signals between the original wireless UT sensor and the prototype of the intermediate coil system. In the experiment, the distance between the coils was kept small to have sufficient signal to noise ratio. As shown in Fig. 3, clear signals were obtained in both cases. The thickness evaluated by the velocity and the time difference between the peaks agreed well with the actual thickness (measured by a micrometer) in both cases. This result has confirmed that the intermediate coil system is realizable. Figure 3(c) shows the received signal by the simulation of the developed electrical circuit model. Although the signal amplitude was slightly different from that of the prototype, the time difference between the peaks agreed well. From these comparison, we have confirmed that the developed electrical circuit model has sufficient accuracy and can be used for the system design.

## 3. Feasibility Confirmation

To confirm feasibility of the intermediate coil system in the pipe-wall thinning measurement, we performed the experiment with the pipe covered with the insulator and the metal jacket. The design of the intermediate coils was optimized by the developed electrical circuit model to increase the signal to noise ratio in this test condition. A test apparatus is shown in Fig. 4. The transducers were attached on the surface of the carbon steel pipe whose outer diameter is 114.3 mm. This is one of the representative sizes in the pipes of the nuclear power plants. The pipe was covered with the silicate calcium insulator with 50 mm thickness. The Metal jacket with 0.4mm was also installed on the insulator in the same way as the pipe in the actual nuclear power plant. The intermediate coil system was installed into the insulator as shown in Fig. 2.

The photo of the manufactured test apparatus and the measurement results are shown in Fig. 5. The red line in the graph shows the received signal from the original wireless UT sensor (i.e. does not

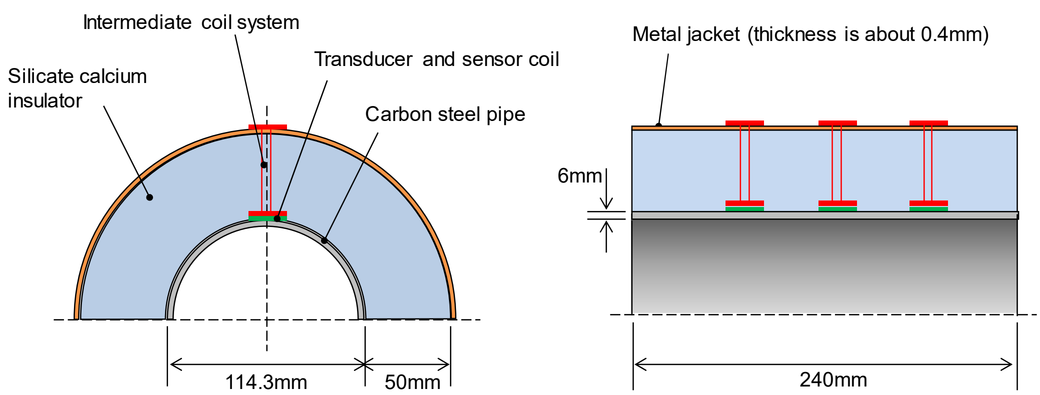



**Fig. 4. A test apparatus for the feasibility test of the intermediate coil system**

include the intermediate coil system). As the insulator is covered with the metal jacket, no signal was obtained in this measurement. This means the electromagnetic induction between the coils was interrupted by the metal jacket. On the other hand, clear signal with sufficient signal to noise ratio was obtained from the intermediate coil system. The evaluated thickness by the velocity and the time difference between the peaks obtained with the intermediate coil system agreed well with the actual pipe thickness. The maximum difference between them was approximately 0.1mm, which is comparable to that of the manual UT measurement. The common wear rate at the downstream of an orifice would be approximately 0.1 to 0.3 mm per year. Thus, the developed sensor has capability to measure the wall thickness variation of the pipes. From these results, we have confirmed the feasibility of the intermediate coil system in the pipe-wall thinning measurement.

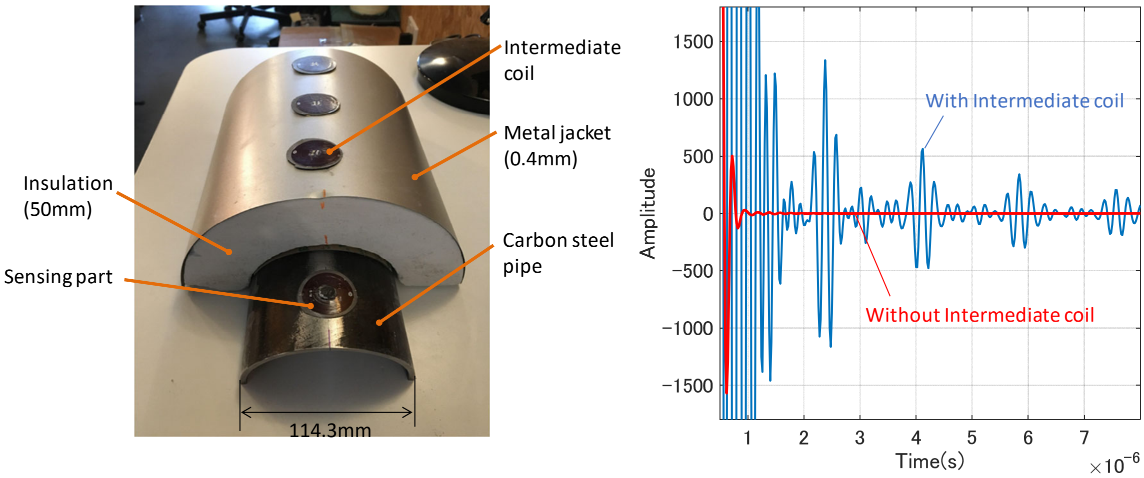



**Fig. 5. A manufactured test apparatus and a representative measurement result**

## 4. Conclusions

Aiming to reduce inspection time of the pipe-wall thinning measurement in nuclear power plants, we have been developing the non-contact ultrasonic sensor which enables the thickness measurement without removing the insulator covering the pipe. Measurement accuracy, maximum offset between coils and effect of the insulator on the measurement performance were investigated in the previous study. The issue which needs to be address is existence of the metal jacket around the insulator because the electromagnetic induction between the coils is interrupted by the metal jacket. In this study, we proposed the intermediate coil system (PCT/JP2018/020043) as one of the options to overcome this issue. Firstly, we developed the electrical circuit model of the intermediate coil system to optimize the design of the coils. Then we validated this model vie comparison of the received signal with the experiment, and found that the developed eclectic circuit model has sufficient accuracy and can be applicable to the system design. Finally, we performed the feasibility test by using the test apparatus which simulates the pipe in the actual nuclear power plant. As a result, we have confirmed the feasibility of the intermediate coil system in the pipe-wall thinning measurement. Further development and evaluation including sensor durability against high-temperature will be conducted to apply this system into the actual plant inspection in the future study.

## References

[1] United States Nuclear Regulatory Commission, "Feedwater Line Break," Information Notice No.86-106, (1986).

[2] United States Nuclear Regulatory Commission, "Secondary Piping Rupture at the Mihama Power Station in Japan," Information Notice No. 2006-08, (2006).

[3] Chexal, B., Horowitz, J., Dooley, B., "Flow-Accelerated Corrosion in Power Plants," EPRI, Paso Alto, CA, EPRI-TR-106611-R1, (1998).

[4] Horowitz, J., "Determining Piping Wear Caused by Flow-Accelerated Corrosion from Single-Outage Inspection Data," EPRI, Palo Alto, CA, 1013012, (2006).

[5] Zander, A., Nopper, H., "The COMSY: Code for the Detecting of Piping Degradation Due to Flow-Accelerated Corrosion," ASME 2008 Pressure Vessels and Piping Conference, Chicago, Illinois, 6, pp.905-910. DOI: 10.1115/PVP2008-61823, (2008).

[6] Sanchez-Caldera, L. E., Griffith, P., Rabinowicz, E., 1988, "The Mechanism of Corrosion–Erosion in Steam Extraction Lines of Power Stations," Journal of Engineering for Gas Turbines and Power, 110(2), pp.180-184 (1988).

[7] Munson, D., Horowitz, J., "Recommendations for an Effective Flow-Accelerated Corrosion Program," EPRI, Palo Alto, CA, 1015425, (2007).

[8] Smith, D., Horowitz, J., "The Role of CHECWORKS in an Effective FAC Program," Proceedings of the 2014 22nd International Conference on Nuclear Engineering, Prague, Czech Republic, ICONE22-30854. DOI:10.1115/ICONE22-30854, (2014).

[9] Zhong, C.H., Croxford, A.,J., Wilcox, P.D., "Investigation of Inductively Coupled Ultrasonic Transducer System for NDE," IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control, 60(6), pp.1115-1125 (2013).

[10] Tamura, A., Zhong, C. H., Croxford, A. J., Wilcox, P. D., “A Feasibility Study of Noncontact Ultrasonic Sensor for Nuclear Power Plant Inspection”, ASME Journal of Nuclear Engineering and Radiation Science, 3, 021012-2 (2017).

[11] Tamura, A, et al., "Investigation into applicability of a non-contact ultrasonic sensor to pipe-wall thinning inspection of power plants," 15th conference of Japan Society of Maintenology, D-2-1-6, Fukuoka, (2018).