Available online at ScienceDirect

Nuclear Engineering and Technology

journal homepage: www.elsevier.com/locate/net

Original Article

Thin-plate-type Embedded Ultrasonic Transducer Based on Magnetostriction for the Thickness Monitoring of the Secondary Piping System of a Nuclear Power Plant

Taehoon Heo [a,b] *and Seung Hyun Cho* [a,b,*]

[a] *Center for Safety Measurement, Korea Research Institute of Standards and Science, Daejeon, 34113, Republic of Korea*

[b] *Department of Science of Measurement, Korea University of Science and Technology, Daejeon, 34113, Republic of Korea*

ARTICLE INFO

Article history:
Received 12 April 2016
Received in revised form
16 May 2016
Accepted 18 May 2016
Available online xxx

Keywords:
High Temperature
Magnetostrictive Transducer
Nuclear Power Plant
Secondary Piping System
Shear Horizontal Wave
Wall Thinning

ABSTRACT

Pipe wall thinning in the secondary piping system of a nuclear power plant is currently a major problem that typically affects the safety and reliability of the nuclear power plant directly. Regular in-service inspections are carried out to manage the piping system only during the overhaul. Online thickness monitoring is necessary to avoid abrupt breakage due to wall thinning. To this end, a transducer that can withstand a high-temperature environment and should be installed under the insulation layer. We propose a thin plate type of embedded ultrasonic transducer based on magnetostriction. The transducer was designed and fabricated to measure the thickness of a pipe under a high-temperature condition. A number of experimental results confirmed the validity of the present transducer.

1. Introduction

Wall thinning of a secondary piping system is a critical issue related to the safety of nuclear power plants (NPPs). This condition can even lead to fatalities when, for instance, the main feed-water pump has an elbow rupture, as occurred in the Surry Unit 2 in the USA or when the condensate system has a straight pipe rupture, such as in Mihama Unit 3 in Japan [1]. Accordingly, a secondary pipe with a thin wall must be supervised under careful control. This is mainly managed with thickness measurements using ultrasonic waves. However, the secondary pipe has various thicknesses and shapes, and it is typically too long to be inspected. Furthermore, most of the pipe is covered with heat-insulating material that must be removed before ultrasonic testing can be performed. This makes inspections difficult to carry out during the operation of

* Corresponding author.
E-mail address: seungcho@kriss.re.kr (S.H. Cho).

http://dx.doi.org/10.1016/j.net.2016.05.007

Please cite this article in press as: T. Heo, S.H. Cho, Thin-plate-type Embedded Ultrasonic Transducer Based on Magnetostriction for the Thickness Monitoring of the Secondary Piping System of a Nuclear Power Plant, Nuclear Engineering and Technology (2016), http://dx.doi.org/10.1016/j.net.2016.05.007

the NPP. Generally, during the overhaul of an NPP, ultrasonic nondestructive testing is conducted to measure the thickness of pipes. All NPPs have management plans specific to pipe wall thinning [2–4], and the target objects to be managed in the thousands or more. In-service inspection tasks should be done during the overhaul roughly every 18 months. Regular monitoring is necessary when the pipe becomes thinner than a certain standard. Thus, online thickness monitoring techniques are required to determine the progress of wall thinning.

During the operation of the plant, the working temperature of the secondary piping system can reach as high as 300°C. Consequently, conventional ultrasonic transducers cannot be applied due to their low working temperature range. As a result, a new transducer capable of withstanding a high-temperature environment is necessary. In an effort to develop such a device, various studies of high-temperature transducers [5–7] and methods that use a waveguide to avoid direct contact with the heat-affected zone [8–14] have been proposed. Among them, Nisbet [8] reported a water or liquid waveguide for thickness measurements in the roles of both a couplant and a coolant. Cegla et al [9–11] reported a crack and wall thickness monitoring method that uses shear horizontal (SH) waves with dry-coupled waveguide transducers. Hernandez-Valle and Dixon [12,13] reported the design and testing of a high-temperature electromagnetic acoustic transducer with a pulsed electromagnet. Ashish et al [14] reported a rod-type magnetostrictive transducer (MsT) for *in-situ* inspections with a longitudinal wave.

An insulation layer covers numerous pipes to protect them and to retain heat. In this situation, a transducer installable under the layer is necessary for structural health monitoring. Such a transducer must be very thin to be embedded between the surface of a pipe and its insulation layer. Waveguide transducers are not appropriate in such a case because of installation problems.

In this study, we propose a thin-plate-type transducer that satisfies the requirement of install ability under the insulating layer in the secondary piping system of a NPP. The proposed transducer can be applied in a high-temperature condition, and it was fabricated based on magnetostriction fundamentals for a very thin shape. Magnetostriction refers to the coupling phenomenon between a magnetic field and mechanical deformation. Ultrasonic waves then can be generated and measured using this principle. This phenomenon occurs in a ferromagnetic material and its alloys. The magnetostriction disappears beyond the Curie temperature of the material [15]. Iron–cobalt (FeCo) alloy, used in this work, can be sufficiently applied to a temperature of approximately 300°C, the maximum operating temperature of a secondary piping system, as its Curie temperature reaches nearly 940°C [16]. Generally, an MsT is composed of a magnetostrictive material, a coil, and a magnet. The coil and the magnet can be manufactured to endure a high-temperature condition.

Very thin plate-type transducers can be fabricated because the FeCo alloy can be formed with a thickness of 0.15 mm in this work. The coil and the magnet can also have a thin form. Hence, each component of the transducer is designed to be thin to measure the pipe thickness. To design the transducer, an analysis model was initially established for an acoustic field analysis, after which the layout of the coil was devised. Finally, a prototype transducer was fabricated to a thickness of approximately 3 mm. Subsequently, several tests were conducted to verify the transducer, during which the high-temperature characteristics of the transducer were assessed. In the experiment, we observed the effect of the bias magnetic field of the transducer. Eventually, the fabricated prototype transducer was tested in a performance evaluation for high-temperature conditions and to determine the wall thickness. The transducer showed sufficient performance to detect them. In conclusion, for this study we developed a thin-plate-type MsT that can be embedded between the surface of a pipe and its insulation layer. This permanently installable transducer will be a useful tool for monitoring the wall thicknesses of pipes in the high-temperature environments of secondary piping systems of NPPs.

2. Design and fabrication of the thin-plate-type embedded MsT

2.1. *Principle of the MsT*

An MsT can generate and detect ultrasonic waves based on the magnetostrictive effect [17]. The effect denotes a relationship between material deformation and magnetic field induction. Thus, an MsT is only applicable to a ferromagnetic material and its alloys. Typically, the MsT is comprised of magnetostrictive patches, actuating and sensing coils, and permanent magnets (or electromagnets). These components should be deployed to transduce specific ultrasonic waves.

Fig. 1 depicts the patch-type MsT. It can easily transmit and receive SH waves in this arrangement [16]. It also operates via the magnetostriction of the ferromagnetic patch materials. An MsT uses actuating and sensing coils to create a dynamic magnetic field and permanent magnets to produce static magnetic field. The cross combination of these magnetic fields can be converted to the shear deformation of the patch. Hence, SH waves are propagated on the patch and the waves are conducted from the patch to direct-coupled materials.

A patch-type MsT usually has higher sensitivity than a noncontact-type MsT, because a magnetostrictive patch is mechanically coupled to the structure and the material of the patch deforms better than a general ferromagnetic

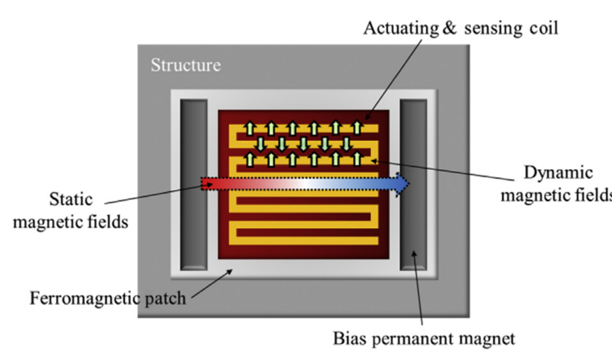

Fig. 1 – Schematic of the magnetostrictive transducer utilizing shear horizontal waves.

Please cite this article in press as: T. Heo, S.H. Cho, Thin-plate-type Embedded Ultrasonic Transducer Based on Magnetostriction for the Thickness Monitoring of the Secondary Piping System of a Nuclear Power Plant, Nuclear Engineering and Technology (2016), http://dx.doi.org/10.1016/j.net.2016.05.007