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Numerical parametric study of a waveguide-based ultrasonic sensor for telemetry in a sodium-cooled fast reactor

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ABSTRACT

This paper presents a collaborative work that started out under the framework of the Generation IV International Forum regarding ultrasound telemetry in sodium-cooled fast reactors. The liquid sodium environment imposes harsh constraints on immersed transducers for telemetry. An alternative approach consists in locating a transducer outside of the reactor core and exciting guided waves that are conducted by a waveguide inside the liquid sodium from where they radiate inside the reactor and can be used for telemetry and associated inspections.
This work presents a numerical method coupling the propagation of elastic guided waves in long waveguides with a liquid environment and applies it to conduct a parametric study on several waveguide designs.
The simulated results are compared to data from real waveguides obtained in a water tank, carried out with 9 sensors, in order to cover a large design space and ensure the validity of the modeling approach.
Good agreement is observed with respect to the main measured quantities. The limits of the developed model are discussed with the help of these results. In particular, variations linked to untracked experimental parameters are shown to have an impact on results.

1. Introduction

As the head of a sodium-cooled fast reactor (SFR) (Aoto et al., 2014), which uses liquid sodium as its coolant, shall not be opened during operation to prevent any reaction of the sodium with water or air, refueling is usually proposed based on a rotating head design. In the refueling process, one of the most important issues is the monitoring of existing obstacles that can hinder the rotation of the part of the reactor head. If any obstacle exists during this rotating movement, unexpected accidents can occur, such as the one in the Japanese SFR Joyo in 2007 (Takamatsu et al., 2010). Therefore, one must ensure that no obstacle exists before starting the refueling process. However, conventional optical tools cannot be used to monitor such obstacles because liquid sodium is optically opaque. As an alternative, ultrasonic sensors have been employed to monitor obstacles as well as for the visual examination of in-vessel structures in liquid sodium.

Two types of sensors (immersion and waveguide-based sensors) have been developed and employed for under-sodium viewing and telemetry (Lions et al., 1973; Spanner, 1977; Watkins et al., 1982; Barrett et al., 1984; Karasawa et al., 2000; Baqué, 2005; Griffin et al., 2009; Sheen et al., 2010; Joo et al., 2011; Wang et al., 2012; Sylvia et al., 2013; Kim et al., 2014). Immersion sensors are submerged in liquid sodium and placed close to the targets. This short propagation distance gives a chance to use high frequency ultrasounds providing high resolution images. However, further efforts are still needed to improve their life span because active parts of the sensor are directly exposed to hot sodium and intense radiation. On the other hand, waveguide-based sensors have a better life span by installing the ultrasonic transducer far from the sodium coolant. Although they give relatively low resolution results caused by the use of low frequency ultrasound due to the long propagation distance, the installation and maintenance of the ultrasonic transducers are much easier than those of immersion sensors.

In relation to the waveguide-based sensor technology, a plate-type waveguide-based sensor, which employs a 10 m long thin strip plate as a waveguide and radiates the ultrasonic wave horizontally, has been developed for under-sodium telemetry (Kim et al., 2015). In this sensor, the ultrasonic wave generated by the transducer installed at the one end of the waveguide propagates along the waveguide and is radiated into the surrounding liquid at the other end of the waveguide. Unlike

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