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Design of segmental ultrasonic cleaning equipment for removing the sludge in a steam generator

Seok-Tae Kim [a*], Woo-Tae Jeong [a], Min-Suk Byeon [a], Ho-One Lee [b]
[a]*KEPCO Research Institute, NuclearPower Research Lab., 65 Munji-Ro Yusung-Gu, Daejeon 305-760, Korea*
[b]*Sae-an ENG.CO. Technical support Division, Rm 910, Byucksan Digital Valley Ⅱ, 481-10, Gasan-Dong, Geumsheon-Gu, Seoul, 153-783, Korea*
[*]*Corresponding author: dimbar@kepco.co.kr*

1. Introduction

In nuclear power plants, the water in the coolant system is managed to be clean but metallic sludge is accumulated on the top of tube-sheet in a steam generator. The sludge causes the corrosion of the tube-sheet. The electric utility company in Korea removes the sludge with a lancing system for every outage of nuclear power plants. But the sludge is not perfectly removed with lancing system because the pressurized water of the lancing system cannot reach all area in a steam generator. Therefore the steam generator cleaning system with ultrasonic energy has been developed in KEPCO Research Institute. In this paper, the ultrasonic cleaning system is designed for removing the sludge on the steam generator.

2. Design of Segmental ultrasonic cleaning equipment

The ultrasonic cleaning technology for a steam generator was applied to the steam generators in Japanese Tomari nuclear power plant. In this application, Push-pull transducers(rod type transducer) set inserted into central no-tube lane in F51 steam generator emitted ultrasonic energy to water or liquid. But the ultrasonic energy does not propagate to remote tubes. In other words, remote tubes cannot be cleaned with the technology. Therefore, the segmental ultrasonic cleaning equipment is designed in this paper.

2.1 Conceptual Model

In this paper, the ultrasonic energy propagates through the surface of tube-sheet in a steam generator. The sludge on the top of tube-sheet is removed effectively with this method. As below Fig. 1, ultrasonic transducers set as special angle to the tube-sheet are inserted into a steam generator and they are arranged in the annulus inside a steam generator. The transducers in the water generate locally plane waves and the waves turn the longitudinal waves from the transducer to Rayleigh surface waves in the substrate material. One important characteristic for surface waves is that the displacement (wave energy) decays exponentially with distance from the free surface. Therefore, the energy stays only near the surface. Moreover, even in the case that the Rayleigh surface waves are scattered by tubes in the tube-sheet, the most ultrasonic energy of surface waves still remain near the surface of the tube-sheet.

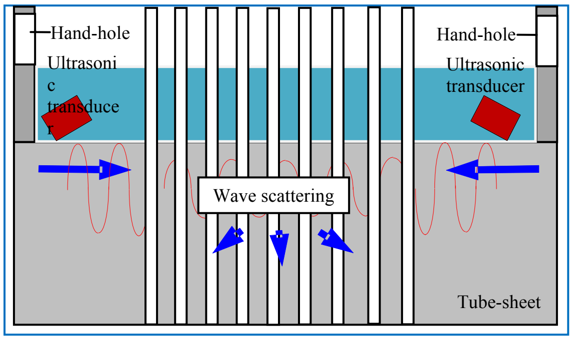

Fig. 1. Conceptual modeling of the segmental ultrasonic cleaning equipment using Rayleigh surface waves

2.2 Generation of surface wave

The tube-sheet is made of carbon steel (s45c) and we assume that it is elastically isotropic and the waves generated by transducers are homogeneous plane waves. As the Snell's law, ultrasonic waves generated by transducers are reflected as shown Fig. 2.

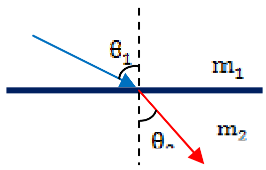

Fig. 2. The reflection of wave from Snell's law

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{C_1}{C_1}$$

Where, "c" is wave speed in the corresponding medium and "m_1" is water and "m_2" is tube-sheet made of carbon steel. From Fig. 3, the angles are determined as below.

$$\theta_1 = \theta,\ \theta_1 = 90^\circ$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{\sin\theta_1}{1} = \frac{C_1}{C_2} = \frac{C_{LW}}{C_R}$$

$$\theta = \sin^{-1}\left(\frac{C_{LW}}{C_R}\right)$$

Where, C_{LW} is the longitudinal wave speed in water and C_R is the Rayleigh wave speed in carbon steel(s45c).

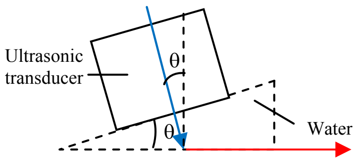

Fig. 3. Application of Snell's law to generating surface wave

Rayleigh and transverse waves are given by

$$C_R = \frac{0.862 + 1.14\nu}{1+\nu} C_T \quad , \quad C_T = \sqrt{\frac{\mu}{\rho}}$$

Shear modulus is given by

$$\mu = \frac{E}{2(1+\nu)}$$

Table I: Properties for calculating the special angle

Properties	value
Young's Modulus of Carbon steel, E	205Gpa
Poisson's ratio of Carbon steel, ν	0.29
Density of Carbon steel, ρ	7850kg/ m^3
Longitudinal wave speed of water, C_{LW}	1480m/s

From Table I, the special angle is calculated as below.

$$\theta = \sin^{-1}\left(\frac{C_{LW}}{C_R}\right) = \sin^{-1}\left(\frac{1480}{2941}\right) = 30.2^{\circ}$$

2.3 Feasible experiment of cleaning with surface wave

In this section, the experiment of measuring the ultrasonic energy was executed to be compared with previous ultrasonic cleaning technology. As shown in Fig. 4, ultrasonic energy level in ultrasonic cleaning method with surface wave is very higher than previous method. Therefore this method with surface wave is very effective to transfer ultrasonic energy to remote place.

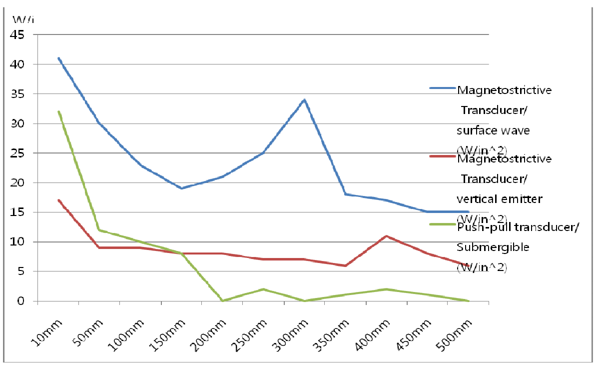

Fig. 4. Comparing surface wave method with previous methods

2.4 Specific design of the segmental ultrasonic cleaning equipment

For application of the ultrasonic cleaning equipment to steam generators in nuclear power plants, transducers mount on the segmental rail to be installed into annulus of a steam generator through its hand-hole as Fig. 5. The plate emitters of transducers are set as special angle 30.2° as Fig. 6.

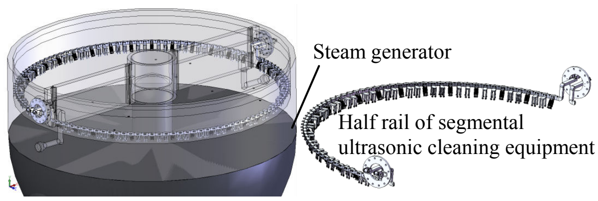

Fig. 5. Installation of the segmental ultrasonic cleaning equipment into a steam generator

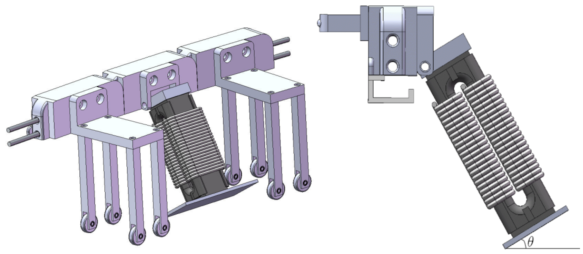

Fig. 6. Module of the ultrasonic cleaning equipment and special angle

3. Conclusions

In this paper, the segmental ultrasonic cleaning equipment can transmit ultrasonic energy to remote place or tubes through the surface of tube-sheet in a steam generator. This method with surface wave is very efficient to clean s steam generator in compare with previous method of simply inserting submersible push-pull transducers into a steam generator as shown in Fig. 4.

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