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Design of ultrasonic waveguide device for approaching to narrow space

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1. Introduction

Generally, ultrasonic cleaning is used frequently in industry. The objective of ultrasonic cleaning in industry is small parts in a tank with transducers. But the ultrasonic cleaning in industry cannot be applied to huge structures like heat exchanger and steam generators of nuclear power plants. Therefore the ultrasonic waveguide is designed for cleaning a steam generator or heat exchangers in this paper.

2. Design of ultrasonic waveguide device

Steam generators or heat exchangers are inserted into ultrasonic cleaning tanks because they are too huge to insert. For ultrasonic cleaning of them, steam generators or heat exchangers themselves are used to be ultrasonic cleaning tanks. And transducers have to be inserted or attached to steam generators or heat exchangers. In the case of steam generators, there are so many heat tubes in steam generators. The case is very severe environment to clean with ultrasonic transducers. Therefore the ultrasonic waveguide is designed for steam generator cleaning without inserting transducers.

2.1 Conceptual model and calculation

The ultrasonic energy level decreases in according to increasing distance from ultrasonic transducer because ultrasonic waves are propagated to all volume of water or liquid medium. The ultrasonic energy is transferred to remote place through waveguides. In this paper, special beam is considered as a ultrasonic waveguide in Fig. 1.

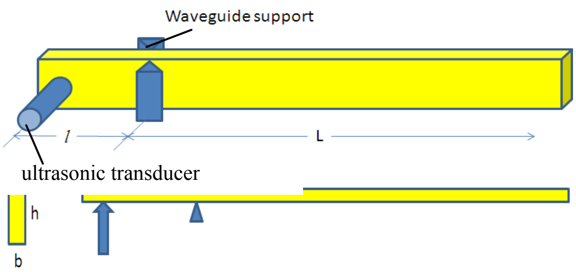


Fig. 1. Modeling of a special beam for waveguide

Fig. 2. Simplifying a beam structure

The modeling of Fig. 1 is simplified to Fig. 2. The waveguide is designed as being resonating with ultrasonic frequency for high effectiveness. The govern equation for bending force is given by,

$$\frac{\partial^4 y}{\partial x^4} = -\frac{\rho}{E\kappa^2}\frac{\partial^2 y}{\partial t^2} \qquad (1)$$

Where y, ρ, E and κ are respectively displacement, mass-density, Young's modulus and radius of gyration of the beam respectively. In the case of a rectangular beam, $\kappa = h/\sqrt{12}$ is possible from Fig. 1. The harmonic equation of the beam is given by

$$y(x,t) = Y(x)e^{-i\omega t} \qquad (2)$$

From (1) and (2)

$$\frac{d^4 Y}{dx^4} = 16\pi^4\mu^2 Y,\ \mu^4 = \frac{\rho f^2}{E\kappa^2} \qquad (3)$$

Where, f is the frequency from the ultrasonic transducer.

$$\begin{aligned} Y(x) &= C_1 e^{\mu x} + C_2 e^{-\mu x} + C_3 e^{i\mu x} + C_4 e^{-i\mu x} \\ &= A\cosh(\mu x) + B\sinh(\mu x) + C\cos(mx) + D\sin(\mu x) \end{aligned} \qquad (4)$$

Using the boundary conditions, the displacement and moment are zero at x=0 and the transverse force and moment are zero at x=L.

$$Y = 0,\ \frac{d^2 Y}{dx^2} = 0,\ x = 0 \qquad (5)$$

$$\frac{d^2 Y}{dx^2} = 0,\ \frac{d^3 Y}{dx^3} = 0,\ x = L \qquad (6)$$

From (4), (5),(6),

$$\begin{aligned} A + C &= 0 \\ A - C &= 0 \end{aligned} \qquad (7)$$

$$\begin{aligned} B\sinh(\mu L) - D\sin(\mu L) &= 0 \\ B\cosh(\mu L) - D\cos(\mu L) &= 0 \end{aligned} \qquad (8)$$

From (8),

$$\tanh(\mu L) = \tan(\mu L) \qquad (9)$$

The solutions are obtained by numerical method because the equation (9) is implicit. Fig. 3 shows the solutions of the equation (9) in the intersections of graphs.

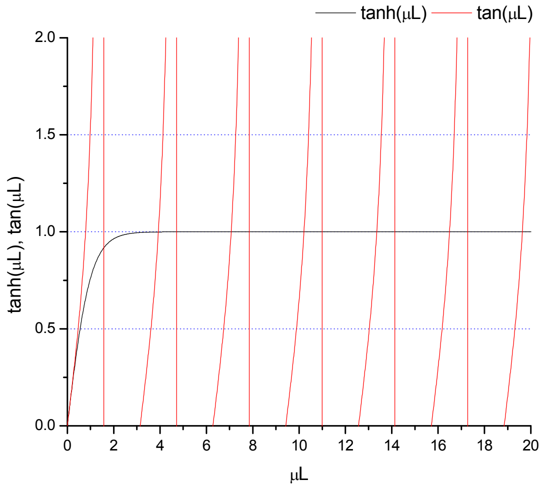
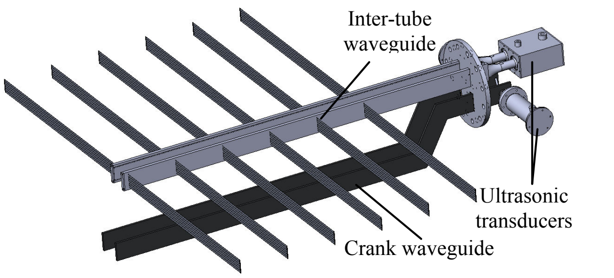


Fig.3. The graphs for tanh(μL), tan(μL) and μL

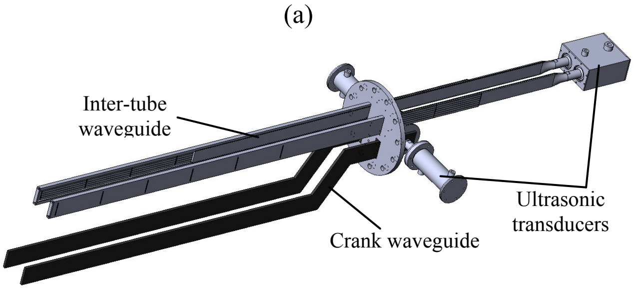
If the f, E and ρ of the carbon steel are respectively 20kHz, 205GPa and 7850kg/m^3, $L_n = \frac{\sqrt{h}\,(3.93+\pi\times(n-1))}{3.7}$ (L_n=0.34, 0.60, 1.14, 13.35, 16.49, 19.63,…) is driven from equation (3) and Fig. 3. If radius of a KSNP steam generator(about 2m) is considered, the value of 1.68m is decided as the length of beam.

2.2 Specific design of ultrasonic waveguide device

In this section, more specific device will be designed with result of section 2.1. The device has two kinds of waveguides. One of two is crank type of waveguide and the other is inter-tube waveguide.



(a)



(b)

Fig. 4. The ultrasonic waveguide device

The inter-tube waveguide can fold itself up with flexible metal beam as shown in Fig 4(a) and (b) and reach gap of tubes of a steam generator. These waveguides are designed as resonating with the frequency of the ultrasonic transducers.

2.3 Application of the ultrasonic waveguide device to steam generators

The ultrasonic waveguide device in this paper is applied to steam generators. Fig 5 shows the application of the ultrasonic waveguide device folded and unfolded to a KSNP steam generator and Fig 6 shows the application of the device unfolded to a W-F steam generator.

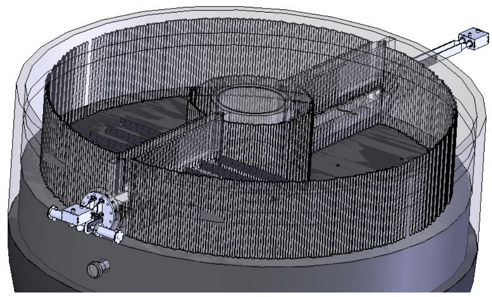


Fig. 5. Application of the device to a KSNP steam generator

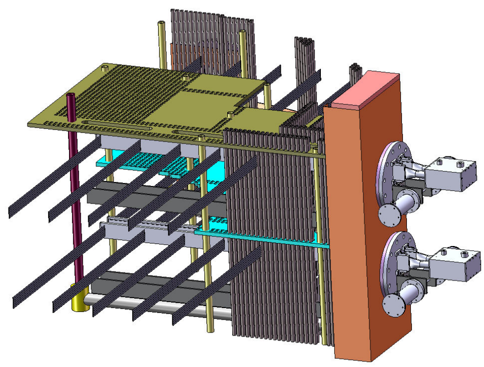


Fig. 6. Application of the device to a W-F steam generator

3. Conclusions

In this paper, the ultrasonic waveguide device is designed for approaching to narrow space. Especially, a KSNP steam generator has too narrow central space in it to insert any powerful ultrasonic transducer like a magnetostrictive transducer for ultrasonic cleaning. Therefore the ultrasonic waveguide device designed in this paper is applied to a KSNP as well as a W-F steam generator.

REFERENCES

[1] Seok-Tae Kim, "2010 Final report of overseas training in Georgia-Tech", KEPCO Research Institute technical report, 2010.