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Cleaning of OPR1000 Steam Generator by Ultrasonic Cavitation in Water

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1. Introduction

In this paper, we present ultrasonic cleaning technology for removing sludge or scale accumulated on the tube sheet and surface of the tubes of a nuclear steam generator using ultrasonic cavitation in water with micro bubbles. Twelve push-pull ultrasound transducers were inserted into steam generator through hand-hole, and positioned at the annulus which is the space between SG tubes and shell. Magnetic wheels are attached to the transducers to prevent tube damage which may be caused by wear between the transducers and SG tubes. To remove heat generated by transducers, we used water to water heat exchanger. Sludge removed from tube sheet area of the steam generator was pumped to filtering station for removing impurities in it.

2. System Design

2.1 Ultrasonic Cleaning System

Ultrasonic cleaning system is composed of twelve push-pull ultrasonic transducers, a water resonance system, and a water treatment system.

We selected push-pull transducer of Martin-Walter cooperation because it is small enough to be inserted through the hand-hole. The chosen transducer PP05.40.183 is 338mm long with maximum diameter of 48mm. The transducer has 40kHz of resonance frequency with 500 watt power consumption. Six transducers are inserted through each hand-hole. There are two hand-holes in OPR1000 S/G. Therefore, twelve transducers are inserted through hand-hole, and positioned in annulus area. Space between S/G shell and tubes are called annulus.

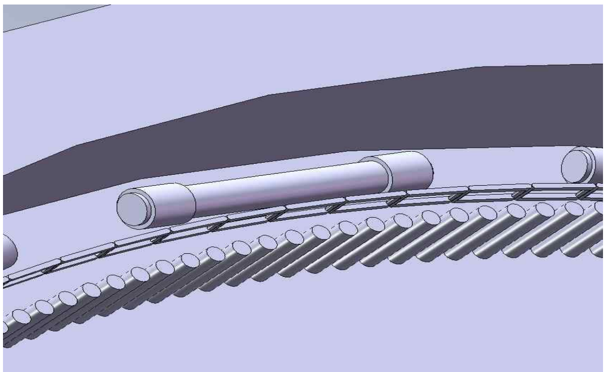

Fig.1 Transducers Located in Annulus of S/G

A water resonance system (WRS) is chosen to send ultrasound energy from annulus to central cavity area where sludge accumulation is dominant. We selected WRS of Kaijo cooperation with model number of WRS-F. WRS-F is 415mm (W) x 400mm (D) x 1,030mm (H) in size and 80Kg in weight. Electrical conductivity of supplying water to the WRS-F is 10 MΩ·cm with pressure between 0.2 and 0.4MPa. It could process 5 to 40 liters of water per minute and maintain 3mg/L of dissolved oxygen content. Operating temperature of the WRS-F is 10 to 40 degrees Celsius.

Water treatment system is composed of two circulating pumps, three water reservoir tanks, a filtering system, and a chiller.

A diaphragm pump is used to send water containing sludge from inside of S/G to filtering system. The filtering system is composed of two stage filtering stage. The first stage filter removes relatively big impurities of larger than five microns. The second stage filter removes small impurities between one to five microns. Three water reservoir tanks can hold one ton of water respectively. Each tank is serially linked for supplying three tons of water to S/G in ten minutes. Therefore, a pump which could send 18 tons of water in an hour is selected.

The total heat generated by the twelve ultrasonic transducers is 6kW per hour. Therefore, we selected a chiller with 8,500Kcal/hour capacity manufactured by Samjung ENC.

2.2 Transducer and Generator Design

We selected commercially available push-pull transducers. The shape of the transducer is shown in Figure 1. To avoid possible damage by collision between the transducers and S/G tubes, we designed a protective guide and the magnetic wheels. The protective guide is made of many plastic components which are serially linked by stainless steel wire. Flexibility can be adjusted by changing tension of the wire. Protective guide prevents metal to metal contact between the transducers and the S/G tubes.

Magnetic wheels are designed as shown in Figure 2. Four permanent magnetic wheels are attached at each end of the transducer. These magnetic wheels are coated with very soft material such as Teflon to avoid possible damage to S/G tubes by these wheels.

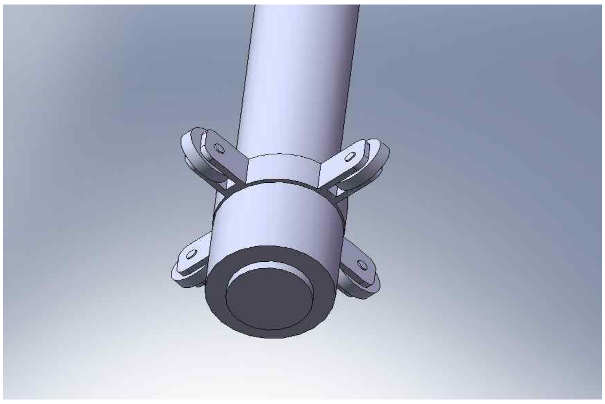

Fig.2 Magnetic Wheels Attached to Transducer

A generator rack was designed as shown in Figure 3. The generator rack is composed of three generator modules with five generators. Therefore, 15 push-pull transducers may be connected to the generator rack. The number of the transducers in normal operation is 12. However, we can increase it up to 15 to increase ultrasound energy density if necessary.

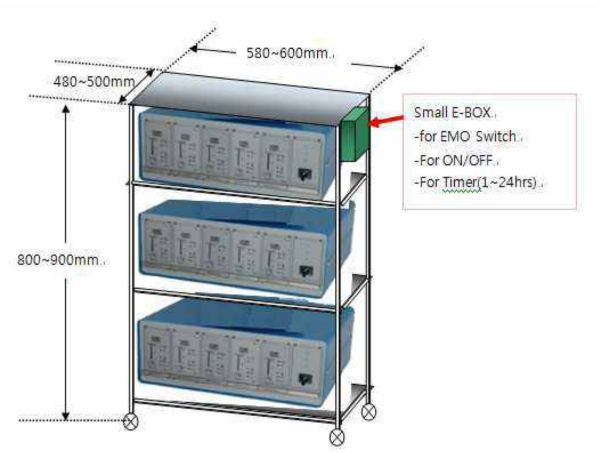

Fig.3 Generator Rack

2.3 Cleaning Experiment Using S/G Mock-up

We designed and manufactured a full scale S/G mock-up for ultrasonic cleaning experiments of OPR1000 S/G. We measured ultrasound energy strength in the S/G mock-up by a push-pull transducer in the annulus. Figure 4 shows a researcher measuring ultrasound energy in the mock-up. The experimental results revealed that sufficient energy level could not be measured at stay cylinder area. However, water resonance system was very helpful to enhance ultrasound energy level. In this experiment, we used only one push-pull transducer in the full scale S/G mock-up. Therefore, energy flux in the mock-up was not enough to generate sufficient cavitation at stay cylinder area. If we apply 12 push-pull transducers, we expect that ultrasound energy flux in cleaning water to be strong enough for cleaning.

Fig.4 Full Scale OPR1000 S/G Mock-up

3. Conclusions

We designed an ultrasonic cleaning system for application to OPR1000 S/G. The technology was developed for removing sludge in OPR1000 S/G. However, the technology could easily be applied to other types of S/Gs.

For cleaning OPR1000 SG, we designed an ultrasonic cleaning system with 12 transducers, 15 generators, a WRS, and a water treatment system.

An experiment with a single transducer and the full scale OPR1000 S/G mock-up did not show very satisfactory result in ultrasound energy level. However, we expect sufficient effects if we apply 12 or more transducers in this case considering our previous experimental results as shown in the references.

The ultrasonic cleaning system will be ready in August this year for performance test. After several experiments and the experiments followed, we are planning to apply this cleaning system for removing sludge in Korean OPR1000 S/Gs.

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