Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Development of the Tube Sheet Cleaning System of the Nuclear Steam Generator

Woo-Tae Jeong and Sung-Yull Hong
Nuclear Power Lab, Korea Electric Power Research Institute, Munji-dong, Yusung-gu, Daejeon, 305-380
wtjeong@ kepri.re.kr and syhong@kepri.re.kr

1. Introduction

When nuclear power plants are first introduced for generating electricity commercially in 1950s, the engineers didn't know that sludge will be accumulated in the steam generators. Therefore, some early steam generator models during the 1950s and 1960s even don't have hand holes for inspection and sludge removal. However, from the experience of operating commercial nuclear power plants, the engineers acknowledged that periodical removal of sludge from nuclear steam generator was necessary.

Sludge accumulation in the secondary side of nuclear steam generators may cause tube degradation. Soft sludge may be hardened when it is baked by hot temperature of primary coolant. Soft and hard sludge prevent heat transfer from steam generator tube to secondary side coolant, and hence may influence the electricity production in the power plants. Therefore, steam generator makers recommend that the secondary side of tube sheet and tube support plates should be cleaned during each outage cycle.

There are several ways for cleaning the nuclear steam generators. High pressure water jet is most often used to remove sludge. Ultrasonic transducers are used to soften the hard scale. Chemicals for selectively dissolving sludge without damaging the internal components of the steam generator are also available. High volume flushing is a way to remove sludge piled up on the upper region of the steam generators.

2. Tube Sheet Lancing

2.1 KALANS®-I Lancing System

KEPRI started the design of the lancing system for cleaning delta 60 steam generator of Westinghouse in 1999 and completed manufacturing and hot application on October 2000 [refer final report]. KALANS® (**K**epco **A**dvanced **Lan**cing **S**ystem) is the registered trademark of the KEPRI steam generator cleaning system. Korea Hydro & Nuclear Company (KHNP) wanted a new lancing system to be developed for cleaning the tube sheet of its replacement steam generator of Kori unit 1. High pressure of 250 bar water is supplied to the nozzle head of lancing robot as shown in Figure 1. High pressure water is ejected through 8 nozzles into the gap between steam generator tubes. The lancing robot is supported by the rail which is installed in no tube lane of the steam generator. By the rotation of a pinion gear which is connected to a servo motor with an encoder, the whole lancing robot moves along the rail in the steam generator. Another servo motor axis is directly coupled to the nozzle head for enabling rotation of the nozzle head. A video-scope is attached to the camera mount to provide video image to an operator [1].

2.2 KALANS®-II Lancing System

The previous lancing system for system 80 steam generator of Optimized Power Reactor (OPR-1000) was not very efficient in removing the accumulated sludge on the tube sheet: High pressure water was directed from annulus toward the center, therefore, sludge accumulation in the central area of the steam generator tube sheet, sometimes called kidney bin zone, was often observed to be increased after lancing. To remove sludge accumulated in the kidney bin zone, a very novel rail and a lancing nozzle head were designed.

The System-80 steam generators have economizer divide plate along the no tube lane. Furthermore, there is the stay cylinder in the center of the steam generator. The divide plate separates cold and hot side, and it is connected to the stay cylinder. To automate the operation of the lancing system, we designed a rail which can be installed along the no tube lane through the hand-hole. The rail is designed to be installed on the left and right side of the stay cylinder. The end portion of the rail is segmented into several parts so that it can be bent. The rail guide makes the rail to be bent at 45 degrees. Before installing the rail to the hand-hole of the System-80 steam generator, the hand-hole fixture should be attached to the hand-hole using several hex bolts.

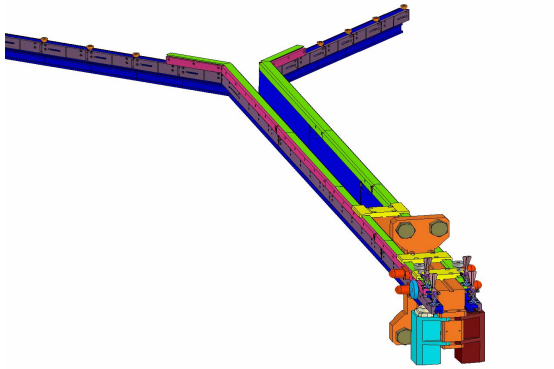

Figure 1. Lancing System (left) Installed in the System-80 Steam Generator

The gap between the divide plate and the tube bundle of the System-80 steam generators is about 33.2mm in average. The rail and the rail guide are designed to be installed along this gap, thus, the maximum width of the rail and the rail guide are limited to 33.2mm theoretically. The lances which eject high

pressure water are designed to move along the groove in the rail. The movement of the lance is controlled by a servo motor. Timing belt is attached to the lance, and it is controlled by a pinion gear driven by a servo motor. Timing belt is selected to drive the lance because it can be easily bent.

The other four lances just move along the linear portion of the rail. The eject angles with respect to the rail are set as 30 degree and 90 degree. To effectively remove shadow zone effect, two lances of the four have nozzles with 30 degree ejection angle. Whereas, other two lances have nozzles with 90 degree ejection angle with respect to the rail.

The hand-hole mount is designed for easier and quicker installation and removal. The hand-hole mount can be attached to the hand-hole only by joining 4 hex bolts. The rail guides are attached to the hand-hole mount by the grooves of triangular shape built on the guides. Total 3 guides are attached along the stem of the hand-hole mount. The rails are attached to the rail guides by the grooves built on the rail guides. The rails have rectangular shape grooves for guiding the movement of the lances.

2.3 KALANS®-III Lancing System

As the outage duration was becoming shorter every year, a new lancing system for removing the soft sludge and the hard scale at the same time was developed in 2004 for cleaning the tube sheet of the Westinghouse model F steam generators. The nozzle head assembly has 12 barrel spray nozzles and a rigid lance for removing the soft sludge and the hard scale respectively as shown in Figure 2. High pressure water of 650 bar from the rigid lance breaks the hard scale on the tube sheet or on the tube surfaces. The rigid lance was designed to be inserted into the gap between the tubes to transfer as large momentum as possible to the hard scales.

When the nozzle head assembly is inserted into the secondary side of the steam generator, the rigid lance is folded to enable to move through the hand-hole with inside diameter of 6 inch. Afterwards, the rigid lance is unfolded in the inside of the steam generator. The nozzle head assembly is attached to the locomotion robot which moves along the rail. The pinion gear on the locomotion robot is directly coupled to the rack gear of the rail. A servo motor with an optical encoder rotates the pinion gear, therefore exact positioning of the nozzle head assembly is possible.

Safety of the lancing system is the most important thing which should be considered during the design stage. The KALANS®-III Lancing System has several unique safety features. Firstly, the two bevel gears transmitting the rotational motion of the servo motor of the lancing robot was designed to be mechanically disengaged. This feature enables the operator to remove the nozzle head assembly from the inside of the steam generator when the lancing robot was stuck during the steam generator lancing. Secondly, the operator can rotate the nozzle head assembly mechanically using a special tool when the assembly is stuck between the tubes during the hard scale lancing. The architecture of the control system is similar to that of KALANS®-II Lancing System.

Figure 2. KALANS®-III Nozzle Head Assembly

3. Conclusions

From March 1999, KEPRI has been developing various water-jet lancing systems for cleaning nuclear steam generators. The first lancing system in Korea, KALANS®-I Lancing System, was developed and successfully used in 2000 for cleaning the tube-sheet of the Kori Delta-60 steam generator. Sludge processing system was also developed for supplying high pressure water and removing solid ingredients of the sludge. KALANS®-I Lancing System has been used for lancing of Delta-60 and Model-F steam generator of Kori NPP #1 since 2000.

The project to develop steam generator lancing systems for Ulchin NPP #2 and YGN NPP #1 was started in 2001 and completed in 2004. KALANS®-II Lancing System of Ulchin NPP #2 was designed to effectively remove sludge accumulated on kidney bin zone of the tube sheet. The lance was designed to move along the rail which is installed between the divide plate and the tube bundle. KALANS®-III Lancing System of YGN NPP #1 was designed to be able to remove soft sludge and hard scale at the same time. This unique feature enables lancing in relatively short time of 1 day per steam generator. Therefore, steam generator lancing may be completed in 3 days by using KALANS®-III Lancing System.

REFERENCES

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[2] Woo-Tae Jeong, Seok-Tae Kim and Sung-Yull Hong, “Development of Sludge Lancing System for Younggwang #1, #2 and Ulchin #3, #4 Steam Generators,” Internal Technical Report, pp. 17 - 29, KHNP, 2004.