ABSTRACT

It is a very important issue to operate nuclear power plants (NPP's) safely and steadily. On the other hand, fuel damage can become a serious issue affecting plant reliability and radiation levels. Thus we have carried out several cleaning activities and visual inspection for RPV component, aiming to enhance the continuation of the operating nuclear power plants. Fuel damage can occur if loose debris inside the reactor vessel flows through the fuel, therefore, removing the small debris or soft CRUD on the bottom head is significant activities in NPP’s. While it is difficult to remove small debris or soft CRUD on bottom head of RPV because of many Control Rod Guide Tube (CRGT), the cleaning device which has capability to deliver the cleaning nozzle widely on the bottom head is essential.

This paper presents the new cleaning tool on the bottom head of RPV underwater. The tool is mainly composed of vacuum hose and swinging nozzle mechanism at the tip of the hose, and camera for visual test (VT). In order to obtain the wider cleaning coverage such as the bottom surface among Control Rod Drive (CRD) stub tubes with a few disassembled CRGTs, the cleaning nozzle can be manoeuvred remotely by control wires with an operation lever. In addition, it provides a cleaning picture by CCD camera set on the nozzle. By applying to this cleaning tool to the bottom head, the wider inspection coverage and reducing critical pass can be acquired.

INTRODUCTION

The supply of electric power from nuclear power plants is expected to serve as one of the pillars of the country’s electricity generation system. Safe and steady operation of nuclear power plants is essential. On the other hand, fuel damage can become a serious issue affecting plant reliability and radiation levels. Fuel damage can occur if loose debris inside the reactor vessel flows through the fuel, therefore, TOSHIBA has carried out several cleaning activities and visual inspection for RPV component, aiming to enhance the continuation of the operating nuclear power plants [1], [2]. Removing the small debris or soft CRUD on the bottom head is significant activities in nuclear power plants (NPP’s).

While it is difficult to remove small debris or soft CRUD on bottom head of RPV because of many Control Rod Guide Tube (CRGT). To carry out cleaning and inspection on the bottom head widely, many CRGT should be removed. Then the much time and great deal of labour would be unavoidable. Owing to the top guide and the core support plate the unobstructed view from above is limited. It is difficult to deliver the cleaning nozzle or inspection camera widely on bottom head. And the surface of the bottom head has highly bank in the periphery area, it is difficult to send the nozzle or camera between Control Rod Drive (CRD) stab tubes on the bottom head.

In this paper, new cleaning tool on the bottom head of RPV underwater is mentioned. This tool aims to deliver the cleaning nozzle or inspection camera widely on the bottom head in short time, by applying to this tool wider inspection coverage would be realized without expending much time and a great deal of labour.
EQUIPMENT FOR CLEANING AND INSPECTION

Figure 1 shows the cleaning areas which have carried with conventional method. In these areas, bottom head of RPV is especially difficult to access. For the cleaning and inspection work in the bottom area, we already have the following tree types of tool and applied to the existing NPPs.

Straight Nozzle Vacuum Cleaning Tool

Figure 2 shows the tool configuration. This tool is the conventional TOSHIBA cleaning tool for the horizontal surface in various areas shown in Figure 1. This tool only consists of vacuum hose and long poles, hanged down from bridge of fuel handling machine. Workers grab the poles directly, locate the tip of the vacuum hose by checking the image of observation camera. Hose inner diameter is 25mm, length is approximately 40m, and by way of example suction flow rate is approximately 4m³/h. Figure 3 shows the cleaning coverage on the bottom head of RPV.

Flexible Nozzle Vacuum Cleaning Tool

Figure 4 shows the tool configuration. Flexible nozzle vacuum cleaning tool can clean the bottom head surface among CRD stub tubes and in-core monitor housing (ICM housing) widely. Generally, this tool is installed in the CRGT removed location and the nozzle is pushed into the area between CRD stub tubes or ICM housing and CRD stub tube with flexible rod operation. Thanks to the stiffness of the flexible rod, the nozzle is delivered not only lower area but also upper area on the bottom head. The cleaning coverage applied to existing RPV bottom head is shown in Figure 5. Specifications of the flexible nozzle vacuum cleaning tool are listed below.

- Vacuuming flow: approx. 4m³/h;
- Operation place: on the bridge of fuel handling machine (FHM);
- Hose inner diameter: 25mm;
- Hose length: approx. 40m;
Swing Nozzle Vacuum Cleaning Tool

This tool was developed to clean and inspect wide area on the bottom head among CRD Stub Tubes. Applying the flexible nozzle vacuum cleaning tool, many CRGT need to be disassembled. Then risk of the fuel damage would rise in proportion to the number of the setting location of tool. It is better to reduce the number of the disassembled CRGT. Therefore this tool was developed to be applied only to remove the periphery CRGT. Figure 6 shows the tool configuration. The tool was developed to consider the following feature:
1) Utilizing the gravity to deliver the nozzle head;
2) Swinging the nozzle to widen the cleaning coverage;
3) Use guide plate located in front of nozzle, which makes the nozzle to follow the surface declination;
4) Use guide rod located on the tip of the tool, which makes the nozzle to insert smoothly among CRD Stub tubes;
5) Use overhead camera to observe the tool maneuverability;
6) Use Camera and light to inspect any foreign material around the nozzle.

![Figure 2 - Straight nozzle vacuum cleaning tool](image)

![Figure 3 - Cleaning coverage](image)

![Figure 4 - Flexible nozzle vacuum cleaning tool](image)

![Figure 5 - Cleaning coverage](image)
Specifications of the flexible nozzle vacuum cleaning tool are listed below.

Vacuuming flow: approx. 4m³/h;
Operation place: on the bridge of fuel handling machine (FHM);
Hose inner diameter: 25mm;
Hose length: approx. 40m;

The tool was applied to existing plant in Japan. Figure 7 shows the cleaning coverage at that time. The green colored area was cleaned completely by this tool. Additionally the area around the CRD Stub tubes of the tool installation location was cleaned by the straight nozzle tool.
FLEXIBLE SWING NOZZLE TOOL

Tool Concept

In order to diminish the risk of fuel damage and inspect the weld line of such as CRD Stub Tube, we have applied above mentioned tools to the bottom head of RPV. Although each cleaning and inspection was successful, some improvement was learned about cleaning coverage or operation capability and so on. Therefore we are improving a vacuum cleaning and visual inspection tool. Requirements are listed as below:

a) Cleaning the wider area only to disassemble the periphery CRGTs;
b) Cleaning the narrow area around the ICM housing;
c) Delivering the vacuum nozzle in highly banked periphery area;
d) Inspection of the foreign material or in-core components in the bottom area;

Accordingly new clean and inspection tool has developed to consider the following feature:

1) Utilizing the gravity to deliver the nozzle head to the bottom center;
2) Bending the tip section with nozzle to go round to the CRD stub tubes;
3) Also bending the tip section manually for sending the nozzle to intended position;
4) Use Camera and light to inspect any foreign material around the nozzle;

Tool Configuration

Figure 8 shows the tool configuration. The tool is mainly composed of vacuum hose and swinging nozzle mechanism at the tip of the hose, and camera for visual inspection. At the tip section, four control wires are arranged around the vacuum hose in equal interval. Control wires are operated manually by control unit on the floor. Relative length of each wire is changed, then the tip section is bent in all direction. This swinging mechanism is attached to nozzle base equipped with wheels. The camera with lump is mounted on the nozzle base, it can observe the cleaning status and furthermore inspect the in-core component on the bottom surface of RPV.

Specifications of the flexible swing nozzle tool are listed below.

Vacuuming flow: approx. 4m$^3$/h;
Camera: 380,000 pixel color CCD
Lamp: LED
Operation place: on the bridge of fuel handling machine (FHM);
Hose inner diameter: 25mm, 31mm;
Total hose length: approx. 56m;

System Application

Figure 9 shows the system application. The tool is installed to the bottom area with auxiliary hoist, binding the vacuum hose to the operation poles. The height of the tool is adjusted on the auxiliary bridge with monitoring the view of the observation camera.

The vacuum flow of the nozzle is send to the pump unit, and then returned to the well of RPV through the filter.

The expected cleaning coverage is shown in figure 10. Central area means the area which angle of gradient is less than 30 degrees. As an example, 12 periphery CRGTs would be disassembled, the cleaning coverage is estimated approximately 70% of the central area which tend to accumulates small debris and approximately 43% of the total area. It can obtain wider coverage by using the straight nozzle to the tool installation location.
Figure 8 - Flexible swing nozzle tool

Figure 9 - System configuration

Central area; Under 30 degrees of Angle of gradient

Figure 10 - Expected cleaning coverage
TESTING AND RESULT

In order to confirm the applicability of this cleaning and inspection work for the reactor bottom area, functional test was conducted using full-scale mock up facility at TOSHIBA, in which remote maintenance work in RPV could be simulated. The partial mock up are shown in figure 11. Two kind of mock up were installed in bottom of large tank.

The vacuum retrieving capability was confirmed with the prototype nozzle. Figure 12 shows the retrieving region. Small diameter wires (diameter: approx. 0.5mm length: approx. 6mm) are sprinkled on the 10mm grid and then the 45mm width nozzle was placed on it. The vacuum flow was approximately $4m^3/h$. According to the figure 12, it was confirmed the retrieving region was approximately 70mm width. Figure 13 shows the accessibility on partial mock up. It was confirmed the nozzle could be delivered to the center of RPV between CRD stub tubes. The tool installation time was approximately 30minutes same as the removal, and it took approximately 35minutes for delivery, cleaning and visual inspection in each installed location. According to the figure 13, it was confirmed the nozzle was delivered round to the CRD stub tube on the peripheral mock up and could be reach to hatched region. Consequently the wider cleaning coverage compared to the existing region could be obtained. The image of the mounted camera is shown in Figure 14. The simulated weld line of CRD stub tube could be confirmed clearly. The visual inspection work can carry out with cleaning work in parallel. Currently the mounted camera is fixed on the nozzle base, it can obtain wider inspection coverage by using pan tilt camera for instance.

The results of these functional tests showed that this tool was useful and effective for underwater cleaning and inspection work for the bottom surface of RPV.
CONCLUSIONS

This paper mentioned the new cleaning and visual inspection tool on the bottom head of RPV underwater. In order to confirm the applicability of this tool to the cleaning and inspection work for the reactor bottom area, a series of functional tests was conducted.

The testing showed the nozzle and the camera could be delivered successfully between CRD stub tubes on the bottom surface of RPV. It was confirmed this tool was useful and effective for the cleaning and inspection work for the bottom area of RPV.

Based on the above-described results, in the bottom area of RPV the cleaning and inspection work that previously had been difficult to access was realized without expending much time and a great deal of labor.
REFERENCES


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