ARCHER – Advanced System for RPVH Inspection and Repair

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ABSTRACT

The reactor pressure vessel head (RPVH) is an integral part of the reactor coolant pressure boundary. Its integrity is important for the safe and reliable operation of the nuclear power plants (NPP). After detection of the leakage and cracks on the RPVH in a French NPP, followed by another that occurred in a NPP in the USA, methods and frequency of inspections were defined, and are strictly regulated by the US NRC Order EA-03-009 (substituted lately by ASME Code Case N-791-1) since 2003.

ARCHER, INETEC’s new manipulator, is designed to provide full scope inspection of the RPVH, by using various test modules and by performing the surface repair action on J-groove weld. It is adjustable to work with different types of penetration nozzles and thermal sleeves on both VVER and PWR types of NPPs.

The paper describes the system’s capabilities and features, and its advantages compared to other systems for performing the RPVH inspection and repair activities on PWR and VVER reactors.

1 INTRODUCTION

The reactor pressure vessel head (RPVH) has penetration nozzles for instrumentation systems and control rod drive mechanisms (CRDM). A typical configuration of the reactor vessel head penetration nozzles, used in most of the PWR’s worldwide, is shown in Figure 1. The joint between the RPV head and a penetration nozzle is achieved by the so called J-Groove weld. It ensures the mechanical fixture and sealing of the pressure boundary.

Operating conditions of PWR plants and primary coolant water can cause cracking of the nickel-based alloys through a process called primary water stress corrosion cracking (PWSCC). The susceptibility of RPVH penetrations to PWSCC appears to be strongly linked to the temperature of the RPVH and the operating time. Problems related to PWSCC therefore increase as plants are operating for a longer period of time.
The discovery of leaks and nozzle cracking at an US NPP and some other PWR plants [1] has made clear the need for more effective inspections of RPV heads and associated penetration nozzles [2, 3].

Usual scope of inspection from inner side of RPVH comprises of:

- Visual inspection of the surface,
- Ultrasonic testing (UT) and eddy current testing (ET) of the penetration nozzle
- Eddy current testing (ET) of the J-groove weld and nozzle outside surface below the weld.

In order to perform the needed in-service inspection per procedure, the ARCHER manipulator has been developed. The base manipulator has interchangeable modules (End effectors) that allow different inspection methods. The schematic representation of the entire ARCHER system concept is given on Figure 3.
HARDWARE

The manipulator has 7 axes that can be moved independently. The first 4 axes are the manipulator axes used for positioning of the modules under the selected penetration, while the remaining 3 are used for driving the module’s axes.

Maximum velocities of the manipulator are 20 °/s for the main rotation axis and 100 mm/s for the horizontal and vertical axes. Because the electronics are sensitive to radiation exposure, the absolute position of the axes is measured with the resolvers.
The motor control box is located outside of the manipulator, and is connected to it in such a way that the motor (power) and the data (resolver and data) wires are physically separated to minimize the interference and ensure the best quality of the data signals. Cable management has been conducted inside the manipulator – there are no wires hanging for the operator to think about while operating the manipulator.

In comparison with the older system, the number of cables between the and the outside of the containment area has been significantly reduced. All control, video, audio and tester signals go into one communication box located inside the containment. From there they are connected to the outside of the containment communication box with only two optical cables. The first one is used for the tester instruments (MIZ and DYNARAY), while the other one carries everything else (video, audio, control…).

3 SOFTWARE

The RPVH manipulator is controlled by a new version of the Manipulator Control (MC) software, which utilizes the possibilities given by the next generation of motion controllers.

Previous versions of the MC and firmware (FW) used the Modbus communication that made sending complex commands difficult to implement. To solve that, a standard TCP/IP server has been implemented on the controller side. In addition, the whole communication is formatted in the JSON format which further simplifies and standardizes the communication.

Using this approach, complex commands and data (error descriptions, configuration files, status data…) can be easily sent to the controller without the need for additional tools and restarts. For example, the axis configuration file can be sent to the controller which can then reconfigure its parameters and structure on the fly.

Communication between the controller and drives (status and command data) is performed over the CAN protocol. The schematic of the control section of the system is given on Figure 5.

![Figure 5: ARCHER control system schematic view](image)

Commonly used manipulator commands (e.g. enabling and disabling of the axes, driving the axes …) have been mapped to the keyboard which allows for a simpler and faster control of the manipulator. A 3D model of the manipulator has been added to the program to simplify the process of positioning the manipulator under the selected penetration. Also, a double click on a penetration automatically drives the manipulator to the selected penetration, reducing the complexity of driving the multi-axis system.
While driving the manipulator, the user can select between the axis coordinate system (each axis is operated independently) and the tool coordinate system, where the rotation and translation of the first two axes have been transformed to the X and Y tool translations which makes positioning easier for the user.

4 MODULES

Due to complex geometry, each module is specially designed for particular type of examination. Modules are exchanged through the docking system without need for personnel to enter under the head region, thus reducing the personnel’s exposure to the ionizing radiation. Three different module types are used in the RPVH inspection and repair procedure.

4.1 GAP module

The GAP Module is used to determine the surface flaws or cracks on inner diameter surface of penetration nozzle gap. It guides a slim sword-like probe (Figure 7) which carries a pair of Time-of-flight diffraction (TOFD) transducers for detection and sizing of circumferential and axial cracks, an eddy current cross-wound coil, and a zero-degree UT probe through a gap between the penetration nozzle and thermal sleeve. In the case of a non-sleeved penetration nozzle, an open housing module is used.

Figure 7: Pro Ultra Sabre probe
The Gap Module, shown in Figure 8, guides the described eddy current and ultrasonic probes into the gap (approximately 3 mm) between the inner surface of the penetration nozzle and the thermal sleeve. It also manipulates the probes to scan the inner surface area.

![Figure 8: Gap module](image)

### 4.2 J-Groove module

The J-Groove module (Figure 9) is designed to fit the geometry of the J-groove weld of the penetration nozzle, vent pipe and funnel guide. The whole weld area (2” on shell side and ½” on nozzle side) is covered by two specially designed arrays of eddy current probes.

![Figure 9: J-Groove module](image)

### 4.3 ASR module

Surface flaws that were discovered by eddy current examination of the J-groove weld define the scope of the grinding for the automated surface repair module (ASR module).

A specially developed grinding procedure, based on the surface probing and UT results, ensures that the treatment does not affect the originally designed structural integrity basis. When compared with the other repairing methods, the ASR module significantly reduces the inspection time and radiation exposure of the personnel, and does not introduce residual stresses into the structural material.
The grinding is performed with a grinder head that is powered remotely via a flexible shaft. The holder for grinding head is fixed on the ASR module. The ASR module has three axes of movement which ensure the position and remote drive of the grinding head. The C-axis is rotational and it is used to position the grinding head angularly around the penetration axis. The Linear X-axis is used for the radial positioning of the grinding tool head with respect to the penetration axis. The Z-axis positions the grinding tool head by height (measured from penetration’s bottom surface).

Figure 10: ASR module

5 CONCLUSION

To obtain safer functioning of nuclear power plants for longer periods of time the various inspection methods of the reactor pressure vessel head need to be performed. This article presented the ARCHER system - INETEC’s solution for efficient and quick PWR’s RPVH inspection and repair. Modules available for the ARCHER manipulator cover the full scope of inspection and repair methods for the RPVH.

REFERENCES


