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ADVANCED APPROACH OF REACTOR PRESSURE VESSEL HEAD INSPECTION AND REPAIR of CRDM J-WELD

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ABSTRACT

The reactor pressure vessel head (RPVH) of Pressurized Water Reactors (PWR's) is an integral part of the reactor coolant pressure boundary. Its integrity is important to the safe operation of the plant. RPVH has penetration nozzles for instrumentation systems and control rod drive mechanisms. The discovery of leaks and nozzle cracking at the US NPP and some other PWR plants has made clear the need for more effective inspections of RPV heads and associated penetration nozzles. Alloy 600 RVHP nozzles & corresponding J-welds cracking and leaking phenomena have been strictly regulated by NRC Order EA-03-009 since 2003. Some additional events on this component (Canopy Seal welds, Thermal sleeve, Control Rods Drive Mechanism…) in nuclear industry have raised concerns about the structural integrity of RPVH and consequently increased extent of Non Destructive Examination employing new state-of-the art NDE and repair methods.

This article presents non destructive examination of Reactor Pressure Vessel Head (RPVH) Penetration by various methods. The scope of this examination and repair methods includes Eddy Current examination of RPVH J-weld surface, ultrasound examination of Penetration Tube from inner side and unique method of surface indications removal.

These article present details of examination techniques with focus on eddy current and ultrasonic examination, as well as details and approach on AST (Automatic Surface Treatment) method of the RPVH J-weld surface.

AST repair method represents new principal approach with combination of design basis justification and As-built measurements which provide to perform repair of J-weld indications without any welding.

1 INTRODUCTION

The reactor pressure vessel head (RPVH) of Pressurized Water Reactors (PWR's) is an integral part of the reactor coolant pressure boundary. Its integrity is important to the safe operation of the plant. The RPVH has penetration nozzles for instrumentation systems and control rod drive mechanisms.

A typical configuration of the reactor vessel head penetration nozzles is shown in Figure 1. It is used in most of the PWR's worldwide. Penetration nozzle made of Alloy 600 is fitted into the vessel head made of the low alloy steel. The joint between the RPV head and the penetration nozzle is achieved by the so called J-Groove weld. It ensures the mechanical fixture and sealing of the pressure boundary. The Alloy 82 or Alloy 182 is used as an equivalent filler material for the Alloy 600 [1].

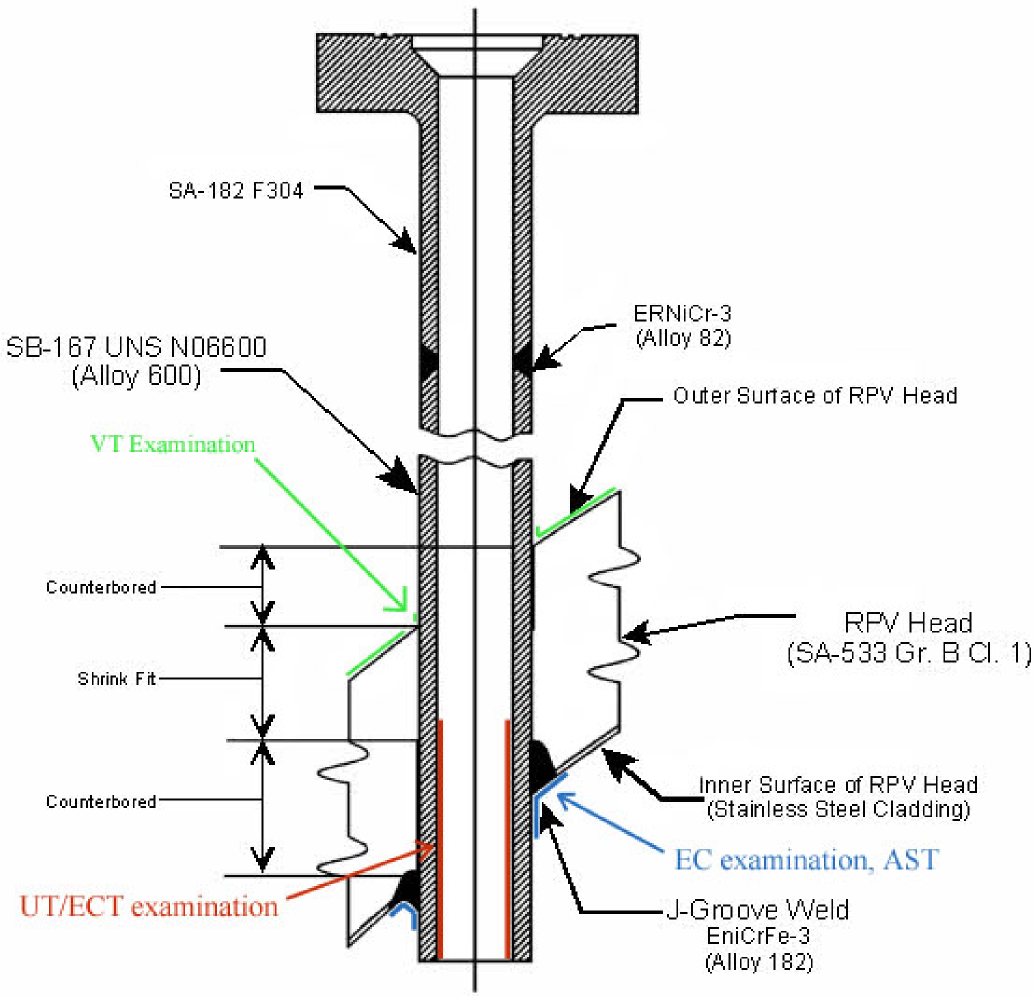

Figure 1 - Sleeved CRDM Penetration

Operating conditions of PWR plants and primary coolant water can cause cracking of these 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 are therefore increased as plants are operating for a longer period of time.

The discovery of leaks and nozzle cracking at the US NPP and some other PWR plants has made clear the need for more effective inspections of RPV heads and associated penetration nozzles [2].

NRC Order EA-03-009 (substituted lately by ASME Code Case N-729-1) defines several different inspections that must be performed on RPVH during refueling outage. Every plant has to determine in which PWSCC susceptibility category they belong by calculating value of effective degradation years (EDY). Depending on the category (High, Moderate or Low) different set of inspections are required from plant to perform during each refueling outage.

Usual scope of inspection from inner side of RPVH which is required by the most of utilities is:

- Visual inspection of 100% of RPVH outside surface,
- Ultrasonic and Eddy current (EC) testing of each RPV head penetration nozzle base material to at least 51mm above J-Groove weld to the bottom of the nozzle
- Eddy current (EC) testing of the wetted surface of each J-Groove weld.

2 RPVH INSPECTION TECHNIQUES

System that performs all RPVH inner surface and CRDM inspections has been developed. In addition, Inetec new module for automatic surface treatment, module for VT inspection of Control Rod Drive Mechanism (CRDM) Latching Tool Mechanism and module for VT inspection of Thermal Sleeve to CRDM penetration adapter surface has been developed and utilized. This chapter represents an overview of RPVH examination techniques and equipment.

2.1 UT/EC examination of RPVH penetration nozzle base material

To determine surface flaws or cracks on inner diameter surface of penetration nozzle UT and EC examination is performed. For that purpose, a slim sword-like Trinity probe (Figure 2) which has one pair of TOFD transducers for detection and sizing of circumferential and axial cracks, an eddy current cross wounded coil and one zero degree UT probe has been selected.

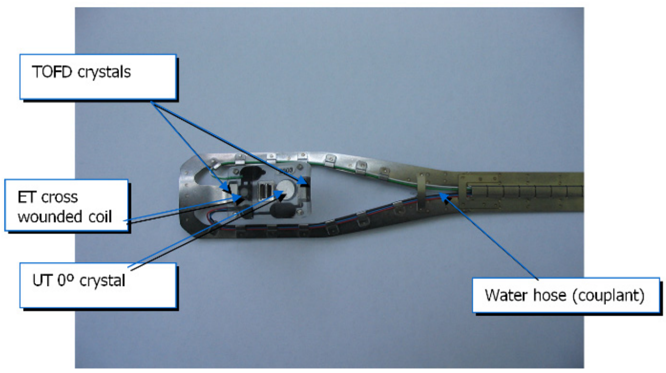

Figure 2 - Trinity probe

Special tool, called Gap End Effector (Gap EE) is designed to manipulate with this probes. The Gap EE, shown in Figure 3, guides the 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 inner surface area.

Figure 3 - GAP End Effector

2.2 EC examination of J-Groove weld wetted surface

EC examination is performed to determine the existence of surface flaws in the J-Groove weld shell side and nozzle side as well as to determine orientation of possible indication (radial, circumferential or volumetric). Because of the complex geometry of the J-Groove weld, examination is performed by utilization of two specially designed EC array probes which assure coverage of the whole weld area (50mm on shell side, and 12.5mm on nozzle side).

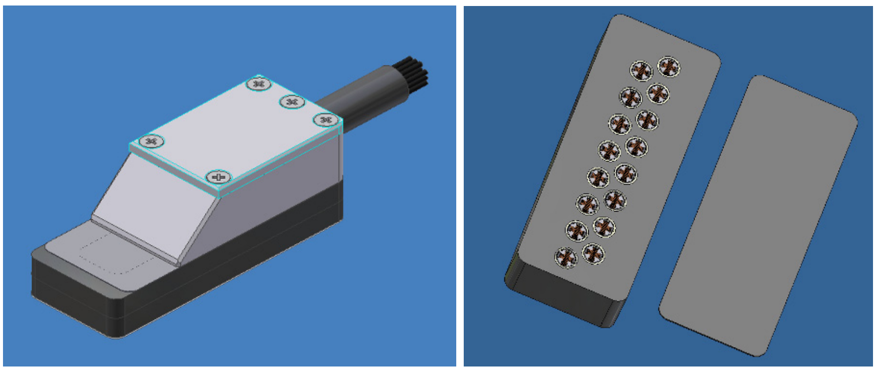

Figure 4 - EC array probe with 16 cross wounded coils

The first EC probe (Figure 4) is an array probe consisting of 16 cross wounded coils for examination of the J-Groove weld from shell side working in differential mode.

The second EC probe (for examination of the J-Groove weld from nozzle side) is also an array probe of same design but with 3 cross wounded coils mounted in flexible probe body.

For EC examination J-Groove EE (Figure 5) that caries both probes has been developed and utilized. The tool is designed to fit to the geometry of the J-Groove weld and to guide the EC probes to follow the contour of the assembly.

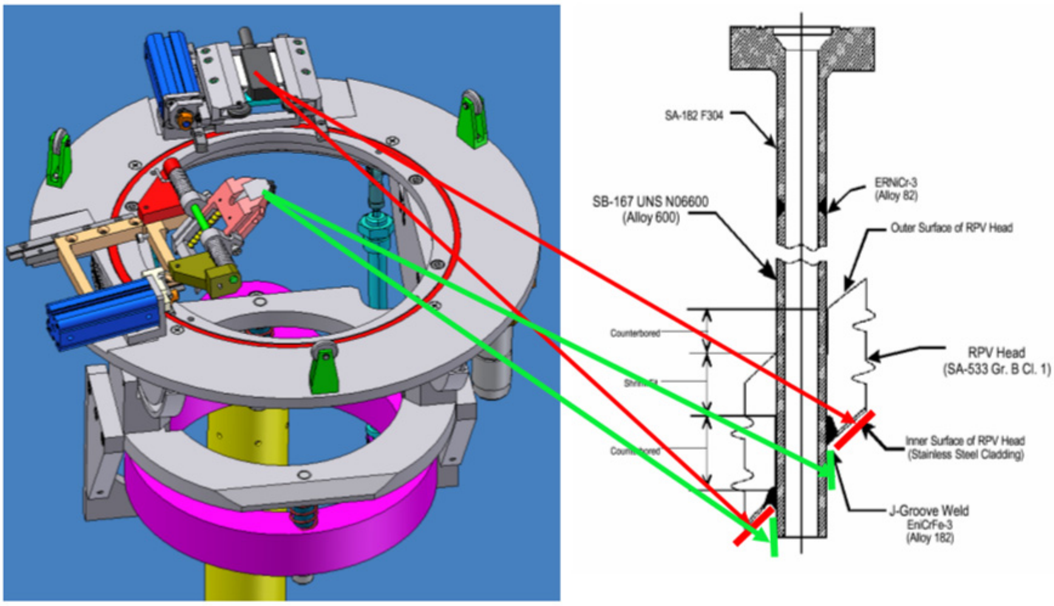

Figure 5 - J-Groove End Effector

Surface flaws discovered by EC examination of J-Groove weld wetted surface are the scope of the automatic surface treatment.

2.3 Automatic surface treatment of J-Groove weld wetted surface

In order to remove any abnormality in the areas of penetration nozzle J-Groove weld on reactor pressure vessel head, Inetec has developed automatic surface treatment (AST) system that provides efficient repair of the J-Groove weld. Purpose of the AST system is to remove indications that are discovered by EC examination from the J-Groove weld surface. Further propagation of surface flaw is prevented or slowed by removing from weld surface.

2.3.1 Impact on structural integrity of the RPVH

This chapter describes the design background for development of an automatic surface treatment system. It also proves that grinding process does not impact RPVH structural integrity.

The design of the RPVH J-Groove weld defines weld height minimal dimension of 0.94” inch (23.8 mm), as shown on Figure 7. During the UT inspection, exact (As-Build) data (Figure 7) of J-Groove weld height have been acquired, which were the input parameter for the surface treatment approach. The acquired and analyzed UT data indicated that the minimal As-Built dimensions of the RPVH penetration nozzle J-Groove welds are increased in respect to the designed minimal required dimension are not questionable.

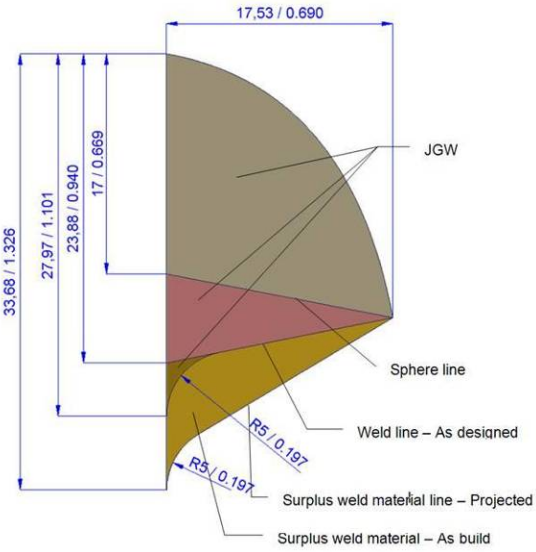

Figure 6 - Minimal J-Groove weld height, as per As-built documentation

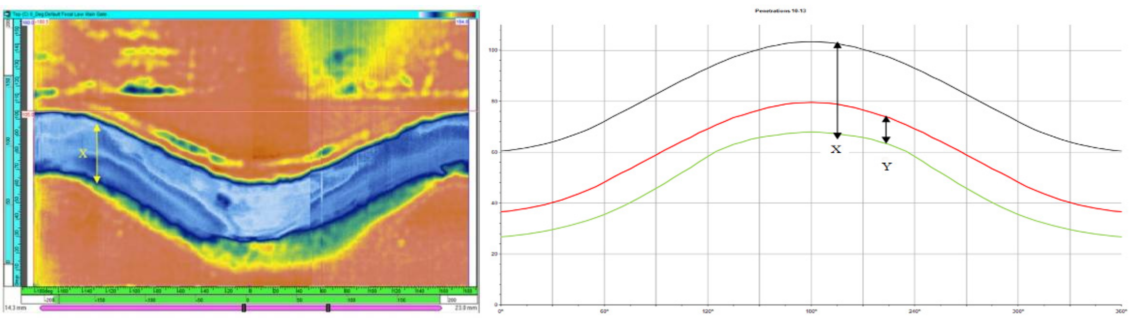

Figure 7 - Typical J-Groove weld acquired by 0° UT probe and maximal allowable grinding height

Nine typical penetrations of RPV head have been analyzed and measurements have been collected at each 5°. The exact UT data and weld heights for typical penetrations are presented in Table 1, where X represents actual weld height, and Y represents difference between actual and calculated (permitted) weld height. It can be concluded that the height of As-Built JGW exceed minimal designed dimension of 0.94" (23.8 mm) at all CRDM penetrations.

Table 1: NEK Typical Penetration J-Groove welds heights

Penetration	X max (mm)	X min (mm)	Y max	Y min
1	34.5	34.5	10.7	10.7
2-5	34.9	33.1	11.1	9.3
6-9	35	31.6	11.2	7.8
10-13	37.1	33.7	10.7	10.7
14-17	47.8	36.1	24	12.3
18-21	49	37.4	25.2	13.6
22-29	47.4	38.3	23.6	14.5
30-37	49.5	38.5	25.7	14.7
38-40	46	36.8	22.2	13

General approach of the surface treatment is based on minimal designed and calculated weld height. Qualification process for the NPP Krško has demonstrated surface treatment removal of the artificial flaws on the JGW mock up. It proved that surface treatment process will not influence structural integrity of the RPVH (minimal and calculated weld height will remain). Qualification also demonstrated that all grinding parameters are very well controlled including appropriate software & hardware safety hard-stops.

2.3.2 Description of the automatic surface treatment module

Purpose of AST module (Figure 8) is grinding of the J-Groove Weld wetted surface. The grinding is performed with a grinder head that is powered remotely via a flexible shaft. Holder for grinding head is fixed on the AST module. AST module has three axes of movement which ensure the position and remote drive of the grinding head. 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).

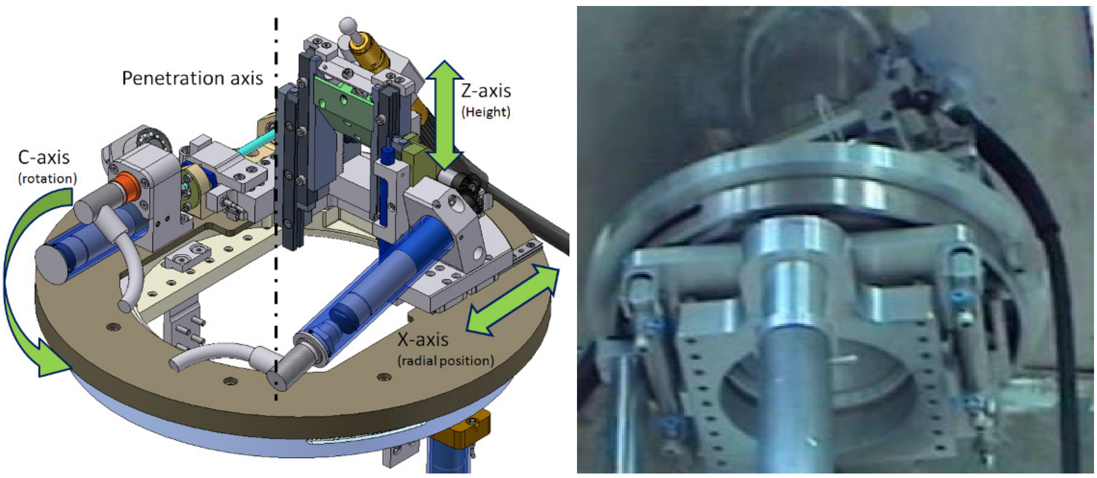

Figure 8 - AST Module

2.3.3 AST Working principle

Area of a J-Groove weld surface that has to be grinded is defined depending on the size and the position of a flaw. To obtain real (as possible) 3D “picture” of a weld surface geometry, “probing” process is developed. “Probing” is a process in which AST module automatically touches the weld surface with grinding tool head. Sensor on AST module recognizes the contact of grinding tool head and weld surface.

INETECs AST software memorizes coordinates of all “probed” points of weld surface. When sufficient number of probed points is obtained, “probing” is finished. These probed points represent 3D “picture” of the weld surface (Figure 9).

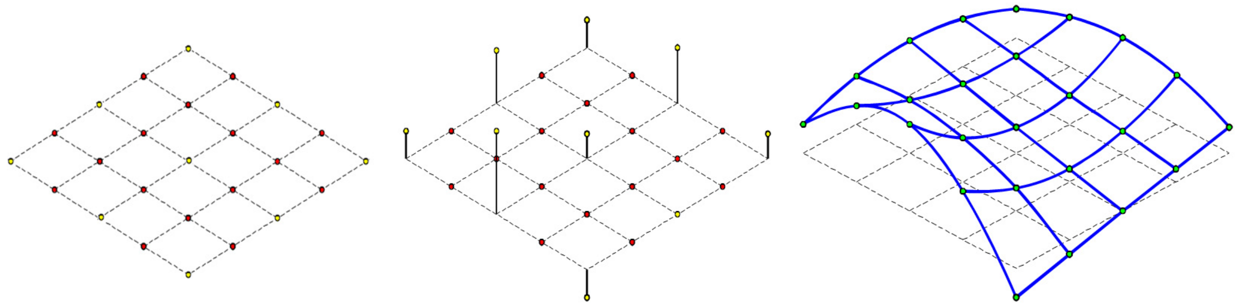

Figure 9 - Probing principle

Mathematical algorithm in AST software then modifies 3D picture of surface to achieve required depth of grinding at surface flaw position. It also blends ends of grinded surface with untreated area.

After grinding, “probing” process (post verification) is employed again to measure real amount (i.e. depth) of grinded material on the particular location of grinded area.

To verify that flaw is removed from the weld surface second EC examination of J-Groove weld is also repeated.

3 CONCLUSION

It can be concluded that various examination methods of Reactor Pressure Vessel Head are necessary to obtain safer functioning of Nuclear power plants for longer period of time. Additionally, advanced repair systems for RPVH are also necessary to achieve that goal. Inetec’s Automatic Surface Treatment system and new Visual examination modules are helping that cause.

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[2] NRC Order EA-03-009, United States of America Nuclear Regulatory Commission, Office of Nuclear Regulation, Washington, D. C. 20555-0001, February 20, 2004.