EPR CRDM AND MSSS/MFWS INSPECTION TOOLING

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ABSTRACT
This paper describes the inspection tooling supplied by Phoenix Inspection Systems Ltd to China Guangdong Nuclear Power Corporation Inspection Technology Co. Ltd. (CITEC) for initial use on the pre service inspection of components for an EPR power plant in China. The contract was awarded to Phoenix in June 2011 for the supply of three machines for the inspection of the welds on the control rod deployment mechanism pressure housing standpipe (CRDM), the steam generator main steam supply system (MSSS/VVP) and the steam generator main feedwater system (MFWS/ARE). All three systems were delivered in January 2012 and have just been through site acceptance testing. Qualification will start in the third quarter of 2012 with the pre service inspections planned for 2013.

Control Rod Deployment Mechanism Housing (CRDM)

The EPR CRDM pressure housing is different in design to those of existing PWR units. On existing PWR reactors all the parts of the CRDM housings are manufactured from austenitic stainless steel with bolted connections. On the EPR the housings are made of austenitic and martensitic stainless steel. The housings have four welds, consisting of dissimilar and homogenous welds. The Phoenix manipulator was designed to perform ultrasonic inspections from the external surface of the housing on the welds 1, 2 and 3. Techniques have been developed by the client using both conventional and phased array techniques and these will be qualified in Q4 2012 before the pre service inspection in 2013.

CRDM inspection tooling

The CRDM This tooling was designed to inspect three welds on the housing of the control rod mechanism. The component is approximately 5.0m long and the welds are positioned approximately 4.7m and 4.0m along the length of the component on two different diameters, figure 2. Ultrasonic inspection procedures were developed by the client using conventional and phased array techniques and the scanner permits the use of either probe set. The manipulator was designed to allow the inspection of the component with the housing mounted on the RPV dome and also when removed. For the inspection when fitted on the dome the manipulator is to be lowered through the shielding grid using a winch arrangement. This lifting arrangement was not part of the Phoenix scope of supply but will consist of a four point winch and umbilical management system. A schematic of the proposed deployment mechanism is shown in figure 3.
Access Restrictions

The Scanner is lowered onto each of the housings via the shielding grid. The aperture of each segment of the grid consists of a square hole 290mm x 290mm with shielding block supports in each corner. To allow clearance on the grid the scanner had to be limited to a diameter of 275mm or a square profile of 275mm x 275mm with chamfers on each corner to reduce the diagonal dimension to 327mm. The design team opted for the square profile in the end to accommodate the couplant recovery, this also aids alignment of the tool. The length of the scanner also had to be kept to 1500mm because of limited head room in the cell above the shielding grid. Access for the ultrasonic probes is also restricted for the inspection of weld 1 when inspected in situ and low profile probes were developed in parallel with the scanner.
**Scanning Requirements**

For the inspection of Weld 1 the manipulator carries up to 6 probes and has to take into consideration the two circumstances under which the inspection will be carried out. The first is with the pipe insitu, where the mounting nuts and bolts are present and restrict access. In this case the probe emission point can be up to 38mm below the weld centreline and at least 80mm above it. The second circumstance is when the pipe is removed from the RPV Dome. In this case the scanner can position the probes at least 60mm on either side of the weld centreline.

![Figure 5](image)

Figure 5 shows the scanning limit for Weld 1 insitu

For Welds 2 and 3 the scanner carries 3 probes and scans them from 35mm below Weld 2 to 28mm above Weld 3, with the individual scan distances shown in figure 8 below depending on the scan direction.

![Figure 6](image)

Figure 6 scanning limits for Welds 2 and 3

**Description**

The CRDM scanner consists of three main components; Stator, Rotor and Couplant System.
Stator
The Stator section of the manipulator consists of four ring sections joined together by spacer rods. The upper section contains the locator device for the standpipe shoulder for referencing the position for weld 1, it also acts as a guide for the system during deployment. Between the middle rings are a set of radial pneumatic clamps which, when activated, secure the assembly onto the pipe. This locking system is designed to be fail safe as loss of air pressure allows the locking feet to retract so freeing the unit and enabling it to be withdrawn. A bore reduction insert with slave pads is used when the manipulator inspects welds 2 and 3 and clamps on the reduced diameter of the housing. The outer frame of the stator section is used to attach the guiding and locating feet, the couplant catchment device, the rotational orientation guide and the alignment reference camera. The top plate has a set of lifting eyebolts to attach the assembly to the crane mechanism for deployment and retrieval. The axial drive unit is attached to the lower middle ring section and is used to reciprocate a baseplate to which the circumferential assembly is attached.

Rotor
The Rotor section is attached to the lower baseplate with circumferential movement provided by the drive unit assembled to a stainless steel slide ring. Attached to the ring is a collar assembly for the cable.
management, umbilical attachment and the pneumatic probe holder toolposts. During insertion of the scanner the probes are held off the surface to protect them from damage. The probe housings have been designed to allow all the probes used for a particular weld inspection to be at the same axial position.

**Couplant System**

The system is supplied with a closed loop couplant supply and recovery unit. CITEC stipulated that a minimal amount of couplant was to be lost and to maximise the couplant recovery, rather than have individual recovery of couplant at each probe, it was decided that the most effective recovery arrangement would be to seal around the housing and to recover the couplant from this point. An inflatable bladder provides the seal whilst being retractable for insertion and removal of the tool. The system uses a combination of lift pumps and vacuum to ensure that a minimal quantity of water is left behind after the inspection.

![Figure 8 Couplant System](image)

**Location and Fixing Mechanism**

When the pipe is being inspected in the vertical orientation the scanner is lowered in to position using a hoist assembly. The couplant catchment unit includes cut outs for the hosing mounting studs and these provides a repeatable reference for the scanner orientation. Tests have proved that using the four point lifting the twist of the scanner is minimal and therefore it can be reliably located within one pitch of the studs. It will then use the top surface of the latch housing shoulder as the axial reference. Once in position it is then secured using the pneumatic clamping arrangement. A two axis inclinometer is fitted to the scanner to confirm that the system is vertical. The scanner also has guiding features top and bottom to ensure that it passes reliably through the grid. Installation can be achieved with an accuracy of ±2mm and once installed the scanner can be positioned with an accuracy of ±1mm.

**MSSS(VVP) and MFWS (ARE)**

The EPR Main Steam and feedwater lines are similar in design to those on the PWRs and CITEC required scanners to inspect the containment penetration welds for both systems. These welds are approximately 2000mm from the access point and the radial clearance between the pipe and the sleeve can be as little as 150mm. The Phoenix SAGE scanner was the obvious choice for this inspection which, with its modular
construction and low profile, could be inserted into the restricted envelope at the access point and also operate in the narrow gap between the vessel and the containment sleeve. Additional features were included with the scanners to adapt them for the inspections. These included an additional support ring behind the slide ring to make remote alignment easier, a mechanism to deliver the scanner to the weld area and surface polishing equipment.

MSSS and MFWS Inspection Tooling - SAGE
The ultrasonic inspection of the Steam Generator Feedwater and Main Steam line penetration welds are similar in their requirements except for the diameter of the pipework and the wall thickness. The Feedwater line is 508mm diameter and the Steam line 764mm diameter. The material is carbon steel and the inspection procedure adopted by the CITEC uses conventional UT probes, with the scanner required to carry up to nine probes in the case of the steam line. Within the scope of supply Phoenix provide the scanner, UT probes, couplant supply, surface finishing tools and vacuum debris extraction. The welds being inspected are on either side of the containment penetration approximately 2000mm from the access point and the minimum radial distance around each pipe is 150mm. Plant components limit the axial clearance to introduce the scanner to as little as 400mm around some sections of the pipe circumference. The scanning length for the Steam line is 300mm and for the Feedwater 250mm.
Description

The SAGE scanner is modified for this inspection to include the additional ring required to aid the alignment of the scanner, as shown in figure 12, and pneumatic clamping. Cameras, laser alignment and measuring and tilt sensors ensure that the scanner can be repeatably setup within the required accuracy of +/- 3mm. The system can be setup by two operators within 20 minutes.

![Figure 13 Scanner in position](image)

The ultrasonic inspection head can be replaced by a polishing unit designed to remove surface debris from the surface prior to the ultrasonic inspection. This tool uses a motorised height adjustment to control the polishing tool accurately and a camera monitors the unit to ensure that the removal of component material is minimised.

Circumferential Mounting and Drive

There are two circumferential mounting rings joined together by spacing rods. The inner ring consists of a hard anodised aluminium vee slide with an integral gear. The outer ring is made of anodised aluminium and its purpose is to maintain the inner ring square to the pipe. Both rings are split along their axes to allow mounting onto the pipe. Attached to each ring are a set of single acting pneumatic cylinders which, when activated, lock both rings onto the pipe. This locking system is designed to be fail safe as loss of air pressure allows the locking feet to retract so freeing the unit and enabling it to be withdrawn from the inspection area. The circumferential drive unit is left permanently assembled to the inner mounting ring allowing both the preload on the journals and the motor pinion mesh to be set at the factory. The drive operates at up to 70mm/s and is repeatable within +/- 1mm.

Axial Drive Unit and Probe Plan

This sub-assembly consists of a baseplate and a reciprocating probe pan. The unit is designed to allow rapid attachment to and removal from the main drive by locating with two dowels and fastening with an over centre clamp. The probe pan will hold up to nine probes using pneumatic toolposts. This allows the probes to be lifted clear of the surface during insertion and removal of the scanner. The probes can be reversed to allow for inspection in either direction. The speed of the drive is 40mm/s and is repeatable within +/- 1mm.

Deployment Mechanism

The deployment mechanism is designed to insert the scanner into the annulus around the pipe as far as the weld. It consists of a pair of rod sections with end fittings which connect to a latching mechanism on the outside of the mounting ring. Once the scanner is in position and locked pneumatically onto the pipe, the
tubes can be withdrawn.

**Tilt sensor, Camera and Lights**
The axial drive carries a tilt sensor which is used to position the scanner at top dead centre and to provide a circumferential datum. A camera is attached to the assembly and this has been mounted in a housing attached to the probe pan. The purpose of the camera is to locate the weld cap and to monitor the probes.

**Polishing System**
The assembly attaches to the axial drive in place of the probe pan. The unit consists of a pneumatic grinding tool with an abrasive wheel. The height of the abrasive wheel is controlled by a DC motor with an external display feeding back the height. The unit is designed to remove a minimal amount of material to ensure that no more than 0.5mm of material is removed. A vacuum collection unit removes debris produced by the polisher and a camera monitors the process continuously.

**Conclusions**
The CRDM, MSS and MFW systems have just undergone testing at the CITEC facilities and final engineering will be completed over the next few months to have them ready for the full qualification in Q4 2012. The systems offer versatile proven solutions to the inspection of these components for the latest generation of nuclear power plants.