BAFFLE BOLT ULTRASONIC INSPECTION
NEW DEVELOPMENTS FOR DIFFICULT TO INSPECT BOLT CONFIGURATIONS

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INTRODUCTION

Implementation of MRP-227 guidelines will require operators of Pressurized Water Reactors with bolted baffle-to-former joints in the Reactor Internals to perform a volumetric inspection of these bolts to assure structural integrity of the Reactor Internals assembly.

Most baffle-former bolts in Westinghouse reactors feature an external hexagon or round bolt head, with a slot for a welded lock bar traversing the bolt head (Figure 1). In this case, a contact ultrasonic probe may be placed on the exposed surfaces of the bolt head, and the bolt can be volumetrically inspected. However, in some reactors, the baffle-former bolt design features an internal hexagon socket. This bolt design presents two distinct obstacles for ultrasonic inspection:

Figure 1
External Hexagon/Round Baffle-Former Bolts (L), and Internal Hexagon Socket Baffle-Former Bolts (R)

1) The geometry of the bottom of the hexagon socket is not controlled or consistent: Internal hexagon socket bolts utilized in Westinghouse reactors are based on the ANSI B18.3 standard. This standard allows for various manufacturing methods of the bolt, and for subsequent variation in the profile of the bottom of the hexagon socket. Figure 2 shows that the bottom of the socket may vary from a shallow, completely flat socket, to a relatively steep cone with a sharp point. Furthermore, there may be other geometric discontinuities in the socket profile depending on the manufacturing technique employed. A forged socket is likely to have a smooth transition between the sides and bottom of the socket which mirrors the die used to make the socket. A socket formed by drilling and Electrical Discharge Machining (EDM) will have a discontinuity at the transition from the EDM'd hexagon socket to the drilled hole, which will vary depending on the relative depth of these features. Furthermore, evidence from inspections and removed baffle-former bolts shows that the bolt socket geometry may vary randomly among bolts found in the same internals assembly.

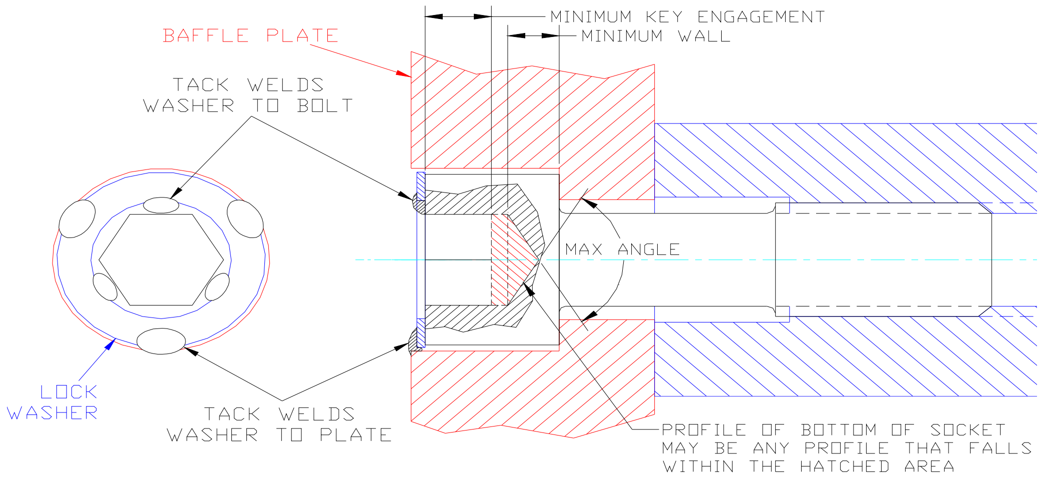

Figure 2
Potential Socket Geometry Variation allowed by ANSI B.13 Standard
(Lock Washer Style Bolt Shown)

2) The type of locking device employed: The locking device may be either

- a welded washer (this is found in (6) US 2-Loop plants)
- a welded lock bar which transverses the bolt head (this is found in (7) US 4-Loop plants.)

If an inspection cannot be performed, the plant operators may elect to replace a minimum required amount of these bolts. However, bolt replacement is time consuming and expensive which makes inspection the preferred method to verify bolt integrity.

The two different styles of locking devices found on these bolts have led WesDyne to develop two distinct inspection techniques for internal hexagon socket baffle-former bolts.

INTERNAL HEXAGON BAFFLE BOLTS WITH A WELDED LOCKWASHER

Technique Development

For bolts with a welded lock washer, the only accessible surfaces are the sides and bottom of the socket. WesDyne investigated two different approaches to this inspection; conventional ultrasonic inspection transmitting sound into the sides of the socket, and Phased Array ultrasonic inspection transmitting sound into the bottom of the socket. Two independent investigators designed prototype probes for each approach. The prototype conventional probe’s performance was hampered by mode converted signals, and did not interrogate very far down into the shank of the bolt. The prototype phased array probe showed the best initial results on test bolts, and could interrogate the full length of the bolt. For these reasons, WesDyne continued development of the Phased Array technique.

Test Bolts

A significant part of the technique demonstration and justification involved the specification of the test bolt set. Not only was an array of flaw configurations and sizes required, but a variety of socket geometries was also required to demonstrate the phased array technique.

Socket cone angles varied from nearly flat to the maximum allowed by the bolt manufacturing specification. Some bolts simulated the geometry of a forged socket with a smooth transition from the side to the bottom of the socket. Other bolts were fabricated to replicate the transitional geometries between the side and bottom of the socket that may be encountered with drilled/EDM'd bolts.

Flaw characteristics were based on both operational experience with removed baffle-former bolts, and published acceptance criteria. Flaws encountered to date in baffle-former bolts have all been very large flaws at the head-shank interface. In fact, all confirmed flaws in internal hex baffle bolts have been 100%. Most flaws also show some degree of tilt towards the bolt head. Detection of flaw sizes of 30% of the shank Cross Sectional Area (CSA) is an expected level of performance described in Reactor Internals Acceptance Criteria, so the sizes of most of the flaws introduced into the test bolts were in the range of 25%-35% CSA.

Many utilities expressed interest in their Requests for Proposals to develop Probability of Detection (POD) parameters for baffle-former bolt inspection. Although this is not specifically required in MRP-227 and MRP-228, WesDyne elected to construct a sufficient amount of samples to develop POD data. POD statistics would be developed for:

- a distribution of all flaws in all locations between 25%-100% CSA
- a distribution of flaws only at the head to shank interface between 25%-100% CSA

WesDyne did not develop separate POD data on flaws in the shank and thread region of the baffle-former bolts because this damage mechanism has not yet been observed in operating plants.

The range of combinations of possible flaw and socket geometries could produce an unwieldy number of test bolts to be constructed well beyond what would be required to develop POD statistics. To allow for a manageable population of test bolts, principles from Design for Six Sigma (DFSS), 2K Factorial Design of Experiments-were utilized. In effect, this approach emphasized that samples be constructed with combinations of parameters near the extremes of their ranges, and fewer samples be constructed with parameters near the middle of their ranges. Table 1 shows distribution of flaw sizes, location, and tilt for the sample set of bolts which ultimately consisted of 52 bolts with defects, and 12 non-defective bolts.

Table 1
Distribution of Flaw Characteristics for Internal Hexagon Socket Test Bolts with a Welded Lock Washer

Flaw Size Distribution		**Flaw Location Distribution**		**Flaw Tilt Distribution**	
0% (No Defect)	12	(No Defect)	12	(No Defect)	12
25%	7	Head-Shank Interface	38	-30°	1
27%-37%	38			0°	25
100%	7	Shank & Thread	14	5°	1
Total	64	Total	64	10°	3
				15°	3
				20°	3
				30°	9
				Spherical Rad.	7
				Total	64

Demonstration

Technique demonstration was conducted in two phases. First, all bolts were examined in a bench top test apparatus. This apparatus consisted of the probe holder and end effector from the manipulator to be used in the field application. After the bench test was completed, an integrated test with the NDE system and the actual probe delivery system was performed. The end effector was attached to the manipulator, and the test baffle bolts were installed in a full scale mockup representative of a two-loop baffle assembly. The mockup was then installed in a 25 foot deep tank of water at the Westinghouse Waltz Mill site. The manipulator used for the mockup tests was the MIDAS VI mini-sub (Figure 3), or ROV (Remotely Operated Vehicle). Calibration of the system was performed underwater, and the MIDAS docked the UT probe to the test bolts in the same fashion as would be done in the actual internals.

The technique achieved a POD of 94.1% at 90% confidence for head-shank flaws, and a POD of 95.7% at 90% confidence for all 52 flawed bolts in the test bolt set.

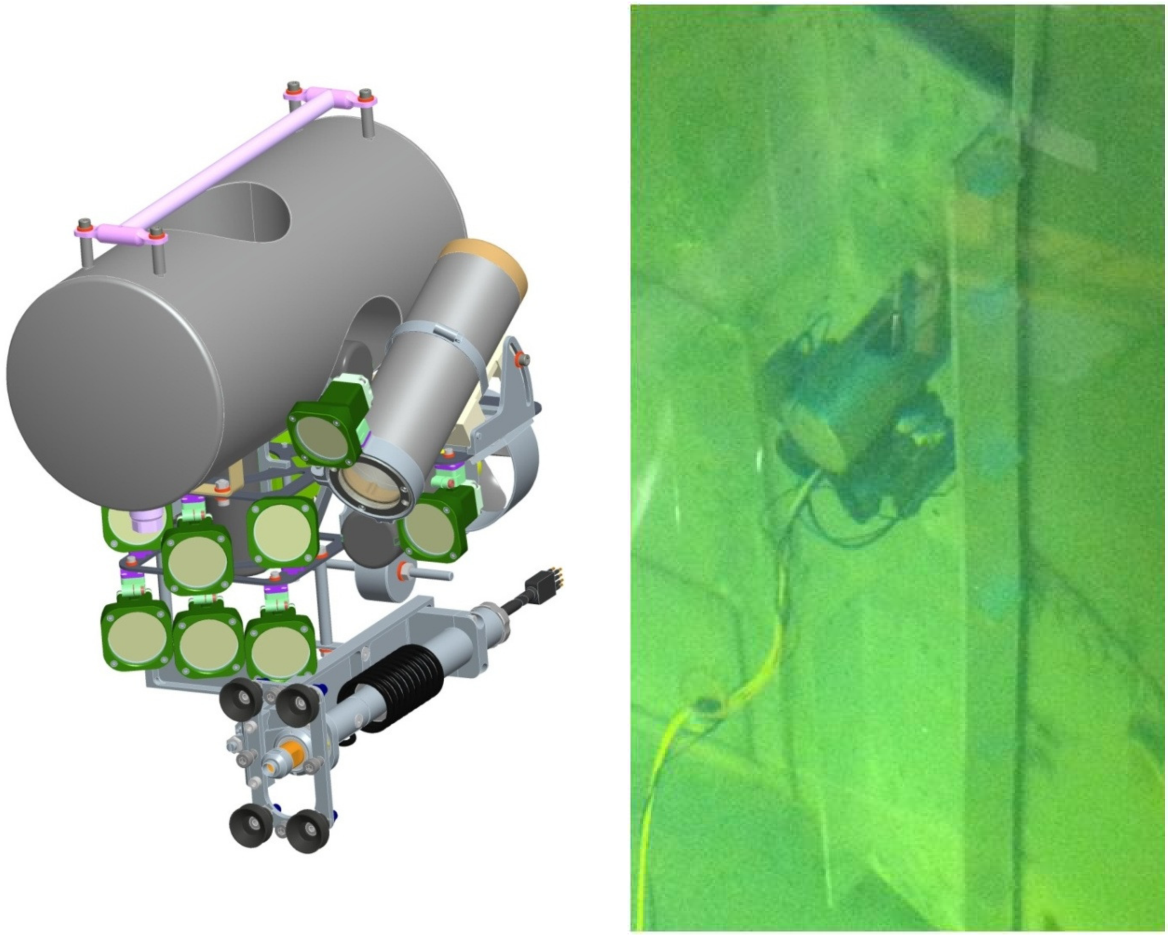

Figure 3
MIDAS-VI Remotely Operated Vehicle (L),
Shown Inspecting Baffle-Former Bolts in Two Loop Mockup (R)

INTERNAL HEX BOLTS WITH WELDED LOCKBAR

Technique Development

Another baffle-former bolt configuration also utilizes an internal hexagon socket bolt, but employs a welded lock bar instead of a lock washer. This configuration exposes portions of the top of the bolt head, but conversely blocks access to the center of the hexagon socket.

WesDyne evaluated 4 different prototype ultrasonic probes before arriving at the final probe configuration.

Test Bolts

Many of the existing test bolts from the lock-washer style bolts could be utilized to test the lock-bar style bolt inspection technique. In fact "movable" simulated lock bars enabled many bolts to provide 2 data points by rotating the orientation of the simulated lock bar. A small set of 10 additional test bolts exactly representative of the lock-bar style bolts was also fabricated for additional technique validation. This resulted in a total of 48 flawed grading units for technique demonstration, and 14 non-defective bolts.

Table 2
Distribution of Flaw Characteristics for Internal Hexagon Socket Test Bolts with a Welded Lock Bar

Flaw Size Distribution		**Flaw Location Distribution**		**Flaw Tilt Distribution**	
0% (No Defect)	14	(No Defect)	14	(No Defect)	14
25%	6	Head-Shank Interface	45	0°	18
30%-35%	29	1st/2nd Thread	3	15°	6
45%-50%	3	Total	62	20°	3
70%	1			30°	12
100%	9			45°	1
Total	62			Spherical Rad.	8
				Total	62

Demonstration

The demonstration of technique for the lock bar style bolts was conducted in the same fashion as for the lock washer style bolts. An initial bench top demonstration was conducted which was then followed by an integrated demonstration conducted in a full scale mockup using the MIDAS ROV. A POD of 95% at 90% confidence was obtained on the population of bolts with head-shank flaws, and a POD of 92.1% at 90% confidence was obtained for the entire population of flawed bolts. There were no false positive calls in an open demonstration.

Additionally, EPRI and Utility representatives proctored a blind demonstration on a limited set of 10 bolts, which was successfully passed.

CONCLUSIONS:

Technical Justifications as required by MRP-227/228 and supporting demonstrations are complete for inspection techniques for 2 styles of internal hexagon socket baffle-former bolts found in 13 US reactors.

- Demonstration of POD exceeds the level of rigor required by MRP-227, which requires Technical Justification only.
- Full scale integration tests of both techniques with the MIDAS-VI ROV have been completed.