Non-Destructive Examination of Kinetic Sleeves

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Introduction

Sleeves may be installed in steam generators to bridge damaged areas in the original (or parent) tube. Sleeving is preferred to plugging as a repair in plants that operate close to their design capacity because sleeving essentially maintains the heat-exchange surface area.

The most challenging non-destructive examination (NDE) areas of the steam generator are the parent tube wall behind the sleeve ends where the tube still serves as the pressure boundary between the primary and secondary side coolant, and the joint area proper. The parent tube area is shielded from the NDE sensor by the sleeve. Inspection in this area is further complicated by geometry signals from the sleeve end and the joint, which are ordinarily many times the amplitude of the target flaws to be detected. The sleeve joint presents a different set of challenges to confirm absence of flaws in the parent tube or sleeve, and to examine for a gap or lack of bond that would permit primary-to-secondary leakage if the parent tube were violated.

Sleeve inspections fall into two classes: process verification and code inspection. The process verification is usually performed only once after the sleeve is installed. This examination confirms sleeve position, expansions, heat treat, and weld quality. The code inspection must assure the pressure boundary integrity, which includes both the sleeve region between the welds and the parent tube region above and below the weld area. A baseline code inspection is usually performed after the initial installation. This inspection, however, must be performed periodically throughout the life of the sleeve to monitor the pressure boundary integrity of the sleeve area.

Inspection methods have been developed for the kinetic sleeve developed by the B&W Nuclear Service Company (BWNS). This sleeve design is particularly challenging for NDE due to the geometry changes, the number of process and geometry parameters to be measured, and the need for rapid examination and analysis consistent with the overall goal of a rapid process. Even though the joint has been qualified by process rather than NDE verification of the bond, an ultrasonic inspection method has also been developed to evaluate the weld. The primary installation and code flaw examinations, however, are based on a rotating eddy current probe technique. This paper describes the BWNS kinetic sleeve and the NDE systems used for its inspection.

Sleeve Description

The kinetic sleeve is designed to be an easily and quickly installed, low cost, minimal flow restriction, sealed sleeve. The sleeve is available to bridge any tube support plate (TSP) elevation except the top TSP, or to bridge the top of tubesheet (TS) region for most standard nuclear steam generators.

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The key to the sleeve installation is the kinetic weld. A charge is loaded in the sleeve end so that when fired, the sleeve OD impacts against the parent tube ID. During the impact, a metallurgical bond occurs that forms the fluid seal. The sleeve has been designed so that if the metallurgical bond does not form, the joint is extremely leak resistant due to the tight interference fit between the sleeve and parent tube. This tightness precludes the need for UT to confirm the metallurgical bond. Following the kinetic weld, the expanded area is heated to relieve any stresses that could lead to stress corrosion cracking (SCC) in the tube.

The entire sleeving process involves:

- Inspection to confirm tube ID for sleeve installation clearance (usually this may be done using existing bobbin probe inspection tapes).
- Cleaning the weld area.
- Inserting and detonating the sleeve.
- Heat treating the expansion areas.
- Rolling of the tubesheet area (if applicable).
- Performing eddy current inspection to confirm the installation parameters and establishing a baseline signature.
- Inspecting the weld by UT to confirm the metallurgical bond. (Optional)

Pre-Sleeve Installation Bobbin Eddy Current Examination

Ordinarily, annular bobbin coil examinations are performed on steam generator tubes to detect flaws or loss of metal that may weaken the tube or permit a primary-to-secondary leak. The bobbin coil diameter approaches the tube inside diameter. The coil is centered within the tube as the probe is pulled through the region of interest to minimize the signal from changing liftoff separation between the coil and the tube wall. Impedance changes in the coil resulting from eddy current interaction with a flawed tube wall produce detectable signals on a computer display screen. Such an analysis is performed on all tubes to be sleeved to confirm the condition of the parent tube in the sleeve-bond area. The kinetic sleeve must be positioned so that the bonds form in a defect-free region of the parent tube.

The same bobbin coil may also be very sensitive to liftoff or diameter changes in a tube. This principle is used to evaluate the tube for dents, skip rolls, and other changes that may affect the sleeve installation.

Post-Sleeve Installation Rotating Cross Wound Coil Flaw Inspection

The task of inspecting the parent tube pressure boundary required a coil that would emit a strong far-reaching field, thereby exhibiting a relatively large response from the target flaw size. The coil, acquisition system, and analysis system must also minimize the geometry influence on the signal that complicates the flaw analysis. Assessments of conventional centered bobbin coils and conventional rotating pancake coils showed insufficient sensitivity to the critical parent tube flaws of concern. A rotating, surface riding, crosswound coil seemed to offer several design advantages over conventional coil designs for this inspection.

Under the conditions found in this sleeve, a surface-riding rotating bobbin coil somewhat smaller than the tube ID produces a larger response than a pancake coil traversing the same flaw. This is principally caused by the relationship among coil diameter, optimum coil frequency, and skin depth effects. The theory and equations describing the performance of small pancakes, centered bobbin coils, and surface riding bobbin coils are found in References 1 and 2.

Crosswound coil probes have traditionally been used to suppress uniform 360° asymmetric variable signals while enhancing asymmetric variable signals. The crosswound probe must be well centered in the tube to achieve the desired circumferential signal suppression. Coils are analyzed as a differential pair so that any tube characteristic equally affecting both coils has no effect on the differential coil response. Any asymmetrical flaw affects the response of the two coils sequentially so that the response is similar to the classic figure eight that may be analyzed in the normal manner.

The kinetic sleeve crosswound coil is not particularly designed to suppress uniform circumferential indications. Rather, the coil is mounted in a head to press the coils radially against the tube wall. As the head is rotated and translated through the tube, a helical scan of the tube is developed. The terrain map image of any flaw uses the characteristics of the cross would coil to enhance the flaw's visibility. (Figure 1) The characteristic signature of a flaw terrain map is an axial progression of:

1. A peak bordered circumferentially by somewhat shallower valleys.
2. The signals (peaks and valleys) pass through null or zero.
3. A valley bordered circumferentially by peaks and appearing as an inverse presentation of the signal discussed in (1) above. Points 1 and 3 are separated axially by approximately the spacing between coils.

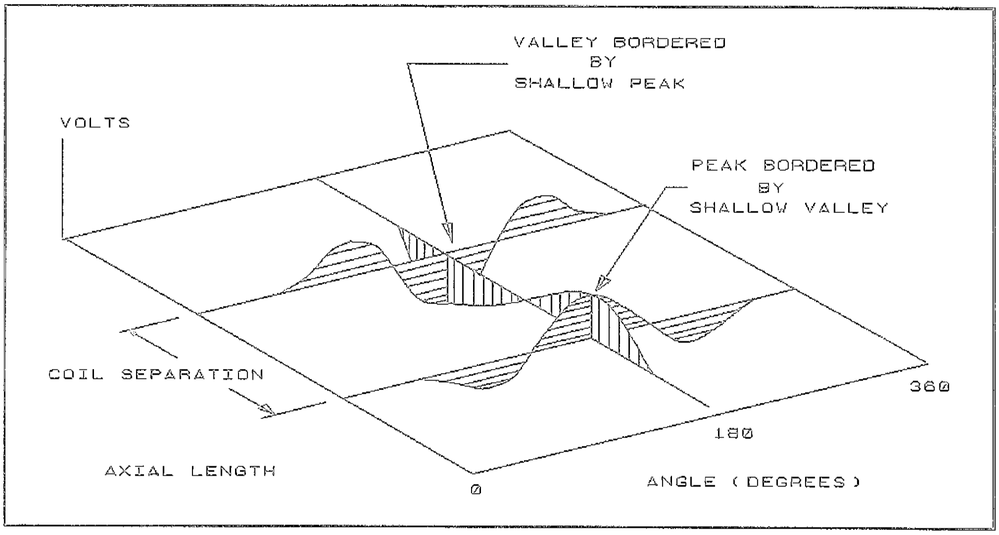


Figure 1: Terrain Map Presentation of Rotation Crosswound Coil Response to a Flaw Enhances Visualization of the Indication

Geometry-based signals do not tend to affect the coils in the same way as flaws, thereby creating a different type of signal. Some of the geometry signals may be several times the size of the smaller target flaws; however, much of the disturbing geometry signal may be removed by mixing, filtering, and using other signal processing tools available.

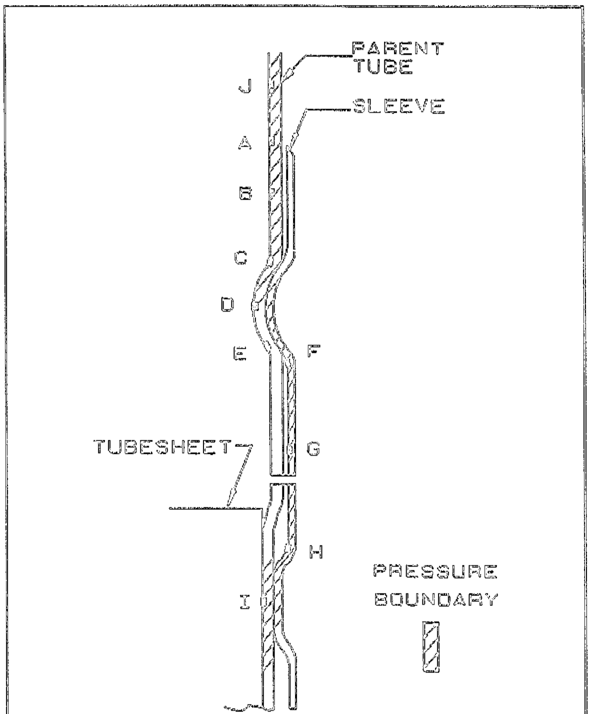
Based on these methods, the kinetic sleeve may be inspected throughout its length. The flaw sensitivity as characterized by response to the ASME standard .187-in. (4.7 mm) diameter flat bottom hole is 20% through-wall depth (TWD) or better (Figure 2).

Due to severe geometry changes, the most difficult area to inspect is the parent tube near the sleeve end. Response to a 20% through-wall hole is shown for this area in Figure 3.

Bobbin coil defect sizing and determination of ID or OD flaw initiation is ordinarily performed using a phase angle versus ASME flat bottom hole defect depth calibration curve. Phase angle discrimination using the rotating probe may be sufficient in the kinetic sleeve design to determine whether the flaw is ID-(sleeve) or OD-(parent tube) initiated; however, defect sizing is subject to a substantial error due to the expansion and sleeve end geometry influence on the signal. Amplitude calibration curve methods have been found to offer improved sizing for the flaw samples examined during qualification testing. Sizing practice for defects with the rotating probe system is, therefore, based on an amplitude calibration. Typical calibration curves are separate and distinct for parent tube and sleeve flaws. Selecting the appropriate amplitude curve is based on the phase angle indication (sleeve or parent). Note that amplitude response of a flat bottom hole may not correlate well with actual flaw mechanisms. This is ordinarily acknowledged in common eddy current examination practice and the data is interpreted accordingly.

Rotating Crosswound Verification of Sleeve Position and Geometry

The rotating cross wound coil is also tasked with sleeve position and expansion geometry verification. One of the differential coils is matched with a reference coil outside the tube much like a reference coil used in ordinary bobbin coil analysis. In addition to the low frequencies used to detect and characterize flaws, a very high-frequency signal is imposed on the coil to measure the sleeve and tube geometry. The front side of the coil is not sensitive to tube diameter or geometry effects because the coil rides the tube surface, thereby maintaining a constant liftoff between the sensor and target material. The back side of the coil, however, is sensitive to the distance to the tube wall opposite the contacting surface. Sleeve profiling software was incorporated into the analysis system to facilitate the position and geometry expansion analysis task.



ALL FLAWS ARE 0.187-INCH DIAMETER 20% TWD FLAT BOTTOM HOLES.

Figure 2: Flat bottom holes > 20% TWD may be detected throughout the B&W kinetic sleeve region.

Automated Eddy Current Analysis

A computer macro or series of keystrokes has been set up, which pre-calculates the landmark and expansion cursor positions, selects the appropriate calibration curve and prepares an expansion geometry and position verification table. The analyst must then either accept the computer's assessment of cursor locations and table values, or manually override the computer's assessment (Figure 4).

A similar computer screening is available for flaw analysis. The computer automatically performs the appropriate filtering and convolution to minimize any geometry effects. A threshold is established above which any signals are further examined for characteristics of genuine flaws. Any signals passing the screen criteria are presented to the analyst for confirmation. Otherwise, the largest signal from the sleeve is presented and/or the analyst is permitted to scroll through the data before final flaw disposition.

UT-360 Bond Integrity Examination

An ultrasonic inspection method was developed to evaluate the degree of metallurgical bonding present in the kinetic weld. The principal engineering challenge for the kinetic sleeve was to develop a UT head capable of tracking the sleeve geometry and adapting it to the BWNS UT-360 system (Reference 3). The bond measurement is based on a focused zero degree surface riding head.

An ultrasonic pulse generated in the transducer travels through the water path into the sleeve. If a metallurgical bond is present, the pulse will

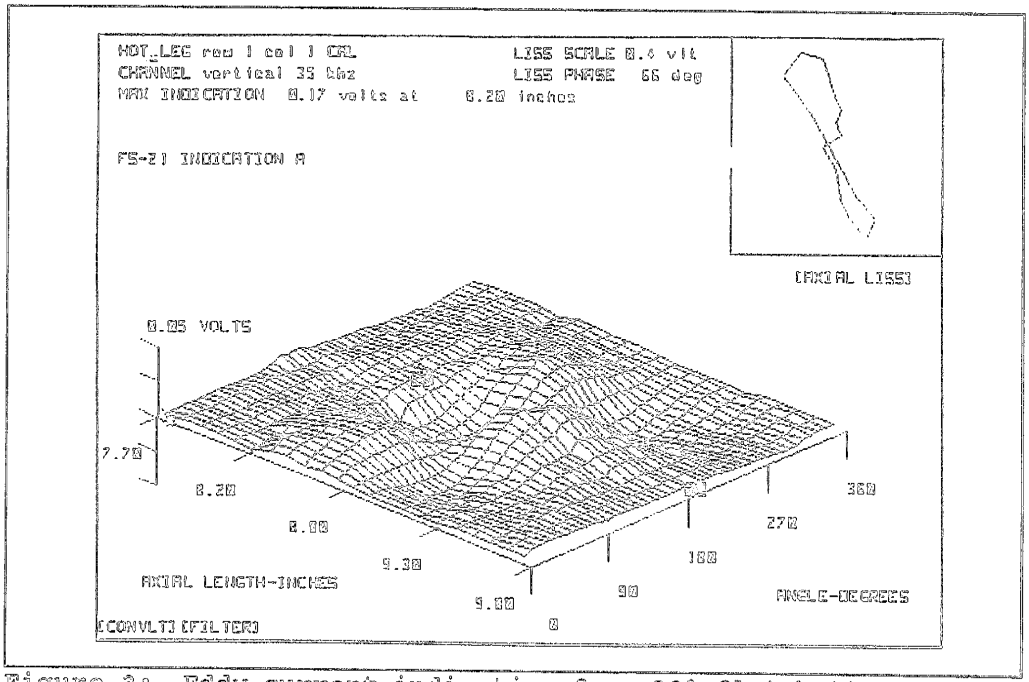


Figure 3: Eddy current indication from 20% flat bottom hole at sleeve end.

continue through the sleeve into the parent tube, reflect off the parent tube back wall, and return back through the sleeve and water to the transducer. The combined wall thickness of the sleeve and parent tube may be measured by the time delay between interface echoes as received by the transducer. If no metallurgical bond is present, most or all of the UT energy will be reflected from the sleeve OD back to the transducer. A thin wall will be recorded indicating absence of a sleeve/tube bond.

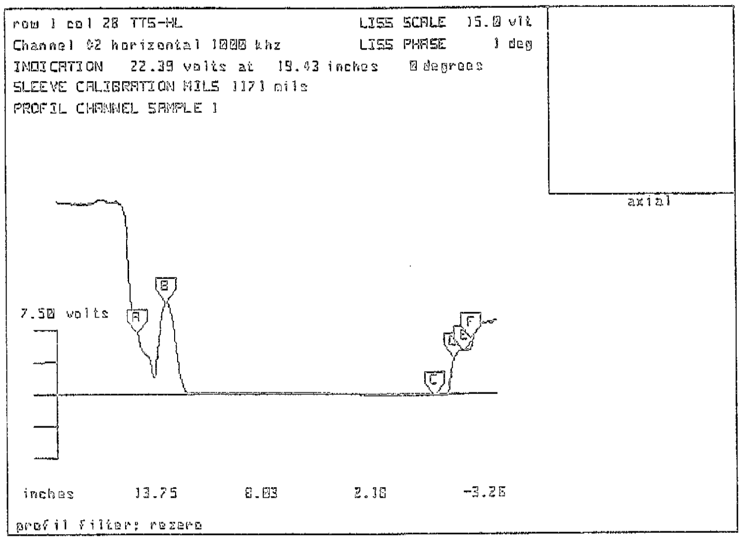
Laboratory UT examinations have been instrumental in developing the kinetic sleeve. Hundreds of UT examinations have been performed in the field on a sample basis to confirm the weld quality. The qualification process, however, does not require a UT examination to be performed. Although it would be possible to examine all kinetic welds by UT, this process is less than half as fast as the eddy current examination. UT is still available as an option.

Summary

The BWNS kinetic sleeve is designed to be easily and quickly installed. NDE methods were specially developed for this sleeve to support the installation process, and the code pressure boundary examination. Application of these NDE techniques is an integral part of the sleeving process.

Prior to sleeving, conventional bobbin coil analysis methods are applied to determine whether a tube is suitable for sleeving. Specific criteria are the absence of a flaw near any sleeve joint; and the absence of denting, skip rolls, or tube end geometry changes that could hamper sleeve insertion.

Once a sleeve has been installed, a single-pass rotating eddy current method is used to characterize (1) expansion geometry, (2) position in tube, and (3) presence of flaws in the sleeve or parent tube. This examination must be performed as part of the sleeve installation program.



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row 1 col 28 TTS-HL                     LISS SCALE  15.0 vlt
Channel #2 horizontal 1000 khz          LISS PHASE     1 deg
INDICATION   22.39 volts at  19.43 inches   0 degrees
SLEEVE CALIBRATION MILS 1171 mils
PROFIL CHANNEL SAMPLE 1
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CURSORS 1st	CURSORS 2nd	1st MILS	2nd MILS	DELTA MILS	AXIAL INCHES	
A	B	654	767	113	1.526	TOP SLV TO WELD
A	C	654	545	109	15.437	TOP SLV TO TTS
C	F	545	644	99	1.906	TTS TO BTM SLV
D	F	609	644	35	0.957	ROLL LENGTH
A	F	654	644	10	17.343	TOP SLV TO BTM
C	B	545	767	222	13.911	WELD EXPANSION
C	E	545	621	76	1.504	ROLL EXPANSION

Figure 4: Automated sleeve analysis software selects cursor labels and annotates the profile for analyst concurrence or editing.

A UT method has also been developed to verify the sleeve-to-tube bond quality. Application of the UT test has been used for sampling, but is not required to demonstrate satisfactory sleeve installation.

References

1. C. V. Dodd, "The Use of Computer Modelling For Eddy Current Testing," Research Techniques in NDT, Vol. III, edited by R. S. Sharpe, Academic Press Ltd., London (1977).

2. C. V. Cecco, G. Van Drunen, and F. L. Sharp, "Eddy Current Manual Volume 1 Test Method," Chalk River Nuclear Laboratories, Chalk River, Ontario (1981, revised 1983).

3. S. W. Glass, and S. W. Shackelford, "Development of a Rotating UT Inspection System," Proceedings of the 7th Annual EPRI Steam Generator NDE Workshop, (1988).