International Conference
Nuclear Option in Countries with Small and M
Opatija, Croatia, 1996
HR9800023

REVIEW OF DAMAGES OF NUCLEAR POWER PLANTS STEAM GENERATOR'S TUBES AND WAY OF DETECTING BY USING EDDY CURRENT METHOD

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ABSTRACT

Steam generator tubing integrity is very important factor for reliable and safe operation of NPP. Several different types of tube degradation mechanisms were experienced in SG operation. To avoid possible tube rupture and primary-to-secondary leak, the EC examination of tubing should be performed. Different eddy current techniques may be used for detecting defects and theirs characterization. A comparison of the data analysis results with pulled tube destructive metallography results can provide valuable insights in determining the capability of existing technology and provide guidance for procedure or technology improvements.

1. INTRODUCTION

Worldwide experience has shown that the steam generator is one of the most critical components in nuclear power plants. Damages to the tubes and tube walls may result in unplanned shutdowns, prolonged maintenance and even replacement of steam generator. In order to determine steam generator tubing condition, eddy current testing should be performed. Scope of inspection is in accordance with National Regulative which are based on results of previous inspections as well as on the worldwide experience for particular type of steam generator. In comparison with other methods such as ultrasonic inspection or leak testing, there are many advantages of eddy current examination such as:

- fast data collection
- absence of contact media
- remote controlled process
- high reliability of the system
- permanently stored results
- low radiation doses for working personnel

Variety of degradation mechanisms requires advanced eddy current techniques to be applied in order to assure reliable detecting and sizing of defects. Confirmations of EC data analysis results may be obtained by performing destructive metallography on tubes pulled out from steam generators.

2. DEGRADATION MECHANISMS ON SG TUBES

Steam generator operation has experienced several types of degradation mechanisms that can be divided as follows:

CHEMICAL MECHANISMS	*MECHANICAL MECHANISMS*
IGA/SCC	Wear
Pitting	Fatigue
Thinning	Impingement
PWSCC	

IGA/SCC - Intergranular corrosion is degradation occurring under symbiotic actions of a susceptible material, corrosive environment and stress. The corrosion process is generally a function of temperature. Intergranular corrosion assumes different forms with several major morphologies having been characterized

Intergranular attack is a term used to describe a morphology characterized by a uniform or relatively uniform attack of grain boundaries over the surface of the tubing. For IGA, stress is generally not a strong contributor to its formation. It is often refereed to as volumetric IGA when it occurs over a relatively large extent exhibiting three dimensional features. If localized but three dimensional, it is sometimes refereed to as pocket IGA. IGA finger is a two dimensional form of intergranular corrosion in which stress is believed to play a strong role.

In stress corrosion cracking the morphology consists of single or multiple major cracks with minor to moderate amounts of branching. Cracks propagate for the most part intergranulary, i.e., along grain boundaries, in steam generator tubing.

SCC is typically modeled or described as a two dimensional discontinuity with a length and depth. The cracking can be axial, circumferential or bi-axial depending on the stress state of material. Simple SCC is used to describe the case where a single crack is present whereas multiple SCC describes situations where more than one crack is present. Many variations or hybrid forms can be imagined such as the case of multiple SCC with variable depth or the case of shallow volumetric IGA with SCC or IGA fingers.

IGA/SCC may be found on many locations in the tube: tube sheet crevice, expansion transition, sludge pile and tube support plates.

Pitting - It is corrosion process in which degradation is driven by local galvanic differences in the tubing. Pitting occurs by dissolution of surface material with no preferential grain boundary attack. Because pitting is driven by small and localized galvanic differences, a given pit does not trend to grow to the large volumes. Pitting has occurred on both legs of the steam generator and for the most part it is confined to the central region where sludge effect is more pronounced.

PWSCC - It is simply defined as stress corrosion cracking that occurs on the tube primary side. As with secondary side SCC, it requires a susceptible material and a source of stress. It typically occurs at changes in tube geometry such as expansion transitions, dents, or sections of tubes that have been stressed (i.e., inner row U-bends)

Thinning - It may be defined as volumetric loss of tube material. It is a surface attack which proceeds by the dissolution of the tube material. Thinning caused by all-solids phosphate secondary side water chemistry is often refereed to wastage. It can be found in sludge pile region as well as at lower support on cold leg side.

Wear - It may be defined as the volumetric removal of material caused by the mechanical action of one material in contact with another. Wear cuts across grains nondiscriminantly, leaving a surface similar in appearance to one formed by general corrosion. The forcing function for tube wear is generally secondary side fluid flow which causes one object to vibrate against other. Tube wear tends to assume somewhat regular and predictable shapes which are depend on the geometry of the object vibrating against the tube. It has been experienced at AVB's and at baffle plates in preheater section of SG.

Impingement - It is a form of erosion (material loss) caused by suspended solids and/or liquid droplets hitting a surface. Its occurrence is unique to once-through units and it is believed to be caused by flow-induced impingement of micronsized particles against the tube wall. The source of particles is debris left in manufacturing process and it is distributed throughout the SG secondary side

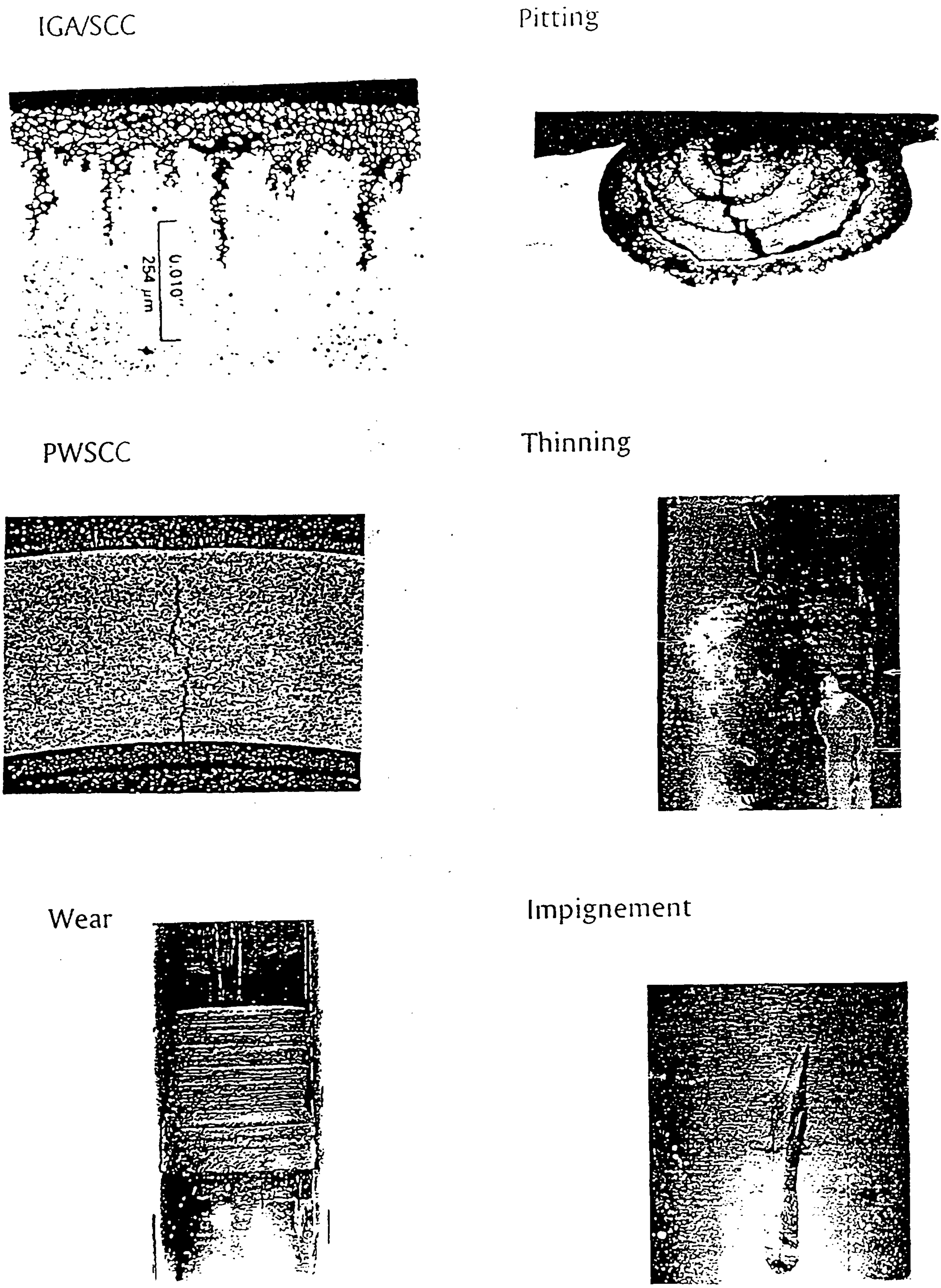


Figure 1. Degradation mechanisms on SG tubes

Fatigue - Corrosion fatigue is caused by alternating stress cycles produced by tube vibration often accelerated by corrosion processes occurring concurrently with the applied stress. Conditions contributing to the likelihood of fatigue cracking include: lack of adjancet AVB; tube locked at upper support and sufficient high secondary-side flow velocities.

The impacts of degradation mechanisms on plants of various NSSS vendors are presented in Figure 2.

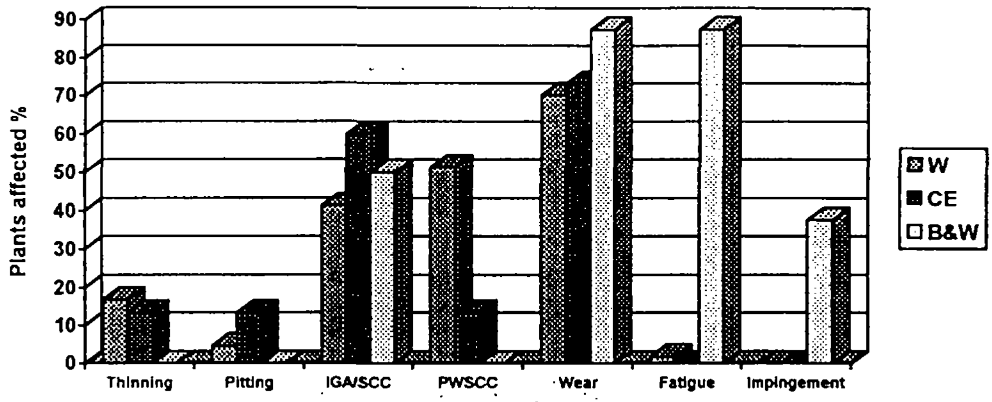


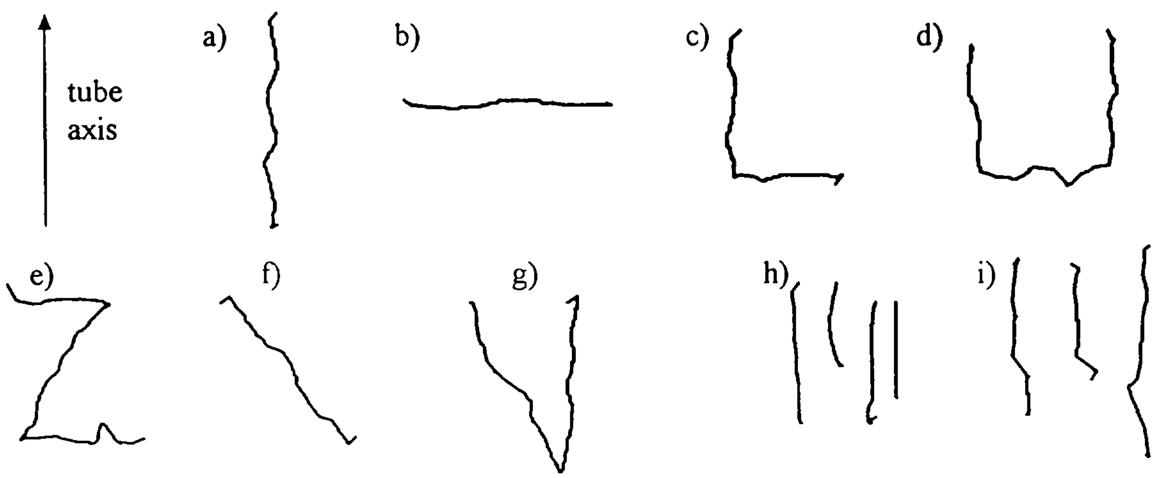
Figure 2. Tube degradation in PWR steam generators

Intensity of particular degradation mechanism acting depends of several factors such as:

- ◊ water chemistry
- ◊ operating conditions
- ◊ location of tube in tube bundle
- ◊ location of defect on tube
- ◊ tube material properties
- ◊ SG manufacturing process

Considering morphology, the defect may be recognized as cracks (IGA, PWSCC), volumetric loss of material (wear, thinning) or mixed defect (pitting). This classification is important from the analytical point of view, because depending of tube defect the most suitable method to evaluate structural integrity for damaged tube has to be used.

Shapes of cracks found on SG tubes:



3. *EDDY CURRENT EXAMINATION OF SG TUBES*

SG tubing are usually examined by eddy current method. The method is based on appearance of eddy currents in test object due to electromagnetic induction developed by alternating current flow in primary coil. Because of discontinuity in tube wall, the conductivity will change and affect the flow of eddy currents. Consequently, coil voltage and phase change will occur, providing determination the size of defect.

The most common eddy current technique applied for SG examination is standard bobbin coil technique. Bobbin probe consists of two coils wounded on probe body, electrically connected opposite to each other. Remote controlled manipulator is used to locate probe in front of desired tube, insert the probe in tube and withdraw by long flexible shaft. Data recorded during withdrawing are analyzed in order to find possible defect. Volume and depth of detected indication may be determined by comparison with artificial defects on calibration standards (Fig3.)

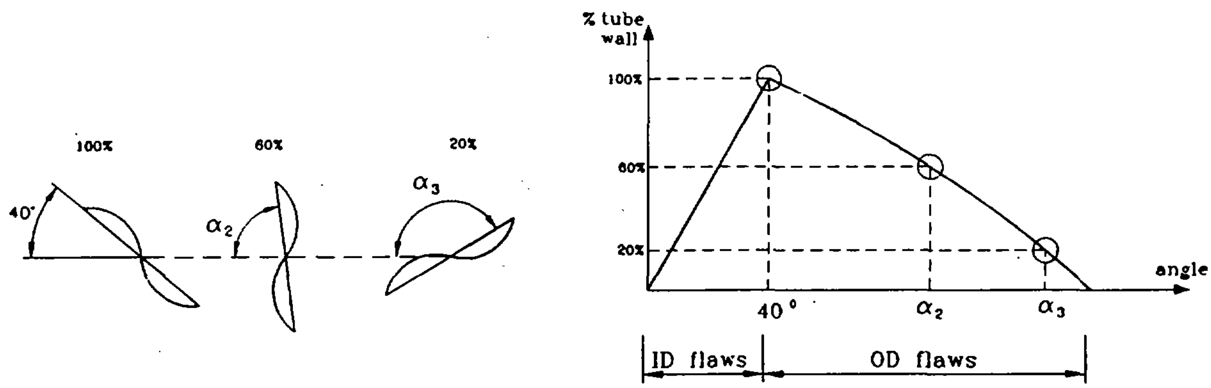


Figure 3. Determining the depth of detected indication

Besides standard tube's inspection by using bobbin coil probe, which provides limited amount of data concerning tube's damages, nowadays the other kinds of EC probes become also very interesting because in some cases these new probes enable additional information about parameters of degradation. These techniques provide a possibility to define shape and orientation of defect as well as it's sizing (length and width). This additional information that much more accurately describes nature of tube damage might be used :

- to confirm damage found by bobbin probe
- to enable new, better, less conservative plugging criteria
- to detect damages in tube areas where bobbin probe does not give satisfactory results

Especially, new techniques are sensible to circumferential cracking, which are hard to find with bobbin probe

These new techniques consider application of following type of probes:

* *rotating probe* - It may have 1, 2 or 3 coils of different orientations. Probe body is rotated while pulling so whole circumference is examined.
* *array probe* - It is probe with multiple coils (mostly pancakes) distributed around the tube interference. Each individual coil has a limited field of view, but composite array coil field provides complete circumferential coverage.
* *plus point probe* - It contains two coils wounded in shape of sign "+". It is used as rotating probe.

Advantages and disadvantages of mentioned eddy current techniques are given in Table 1.

EC	Advantages	Disadvantages
bobbin	• high speed of data collection • determining depth of damage • sensitive to axial cracks • durability of probes	• less sensible to circumferential cracks • found damage can not be sized • if there are more cracks on the same tube's axial location it can not be distinguished
plus point	• orientation of crack can be determined • high sensibility to circumferential cracks • possibility of detection more cracks in the same tube's axial location if applicable • good visual presentation of cracks	• slow data acquisition • depth measurement is not reliable • probes are not durable
array	• high data acquisition speed • sensibility to axial and circumferential cracks • orientation of crack can be determined • possibility of detection more cracks in the same tube's axial location if applicable	• less sensible to deep cracks which are not wide and long • depth measurement is not reliable • probes are not durable
3 coil MRPC	• orientation of crack can be determined • length and width of crack can be determined • sensibility to axial and circumferential cracks • possibility of detection more cracks in the same tube's axial location if applicable • good visual presentation of cracks	• slow data acquisition • depth measurement is not reliable • probes are not durable

Table1 Advantages and disadvantages of different eddy current techniques.

4. COMPARISON BETWEEN METALLOGRAPHY AND EDDY CURRENT RESULTS

Tubes removed from operating plants represent an extremely valuable resource for understanding of degradation mechanisms acting. A comparison of the original in-plant analysis results or a detailed review of the eddy current data under laboratory conditions with results obtained from destructive metallography can provide valuable insights in determining the capability of existing technology and provide guidance for procedure or technology improvements. Improvement of eddy current techniques may include: selection of probe types; selection of examination frequencies and establishing data analysis procedure for particular degradation. Knowledge derived from results of comparison provides direct feedback on the success of particular analysis practices and may be used as a good analyst training tool. Pulled tubes, by their very nature, include damage mechanisms grown under proto-typical plant conditions. There are no specimen credibility issues often associated with fabricating artificial defects in the laboratory. Of equal importance is the automatic inclusion of the effects of secondary-side environmental condition, such as interfering deposits, sludge, etc., which while often unknown, are almost impossible to replicate exactly under laboratory conditions. Since eddy current data used for correlation was acquired prior the tube removal, the detrimental effects of tube distortion caused by tube removal forces are also eliminated. In the case of significant discrepancy between eddy current data results and metallography results, reanalysis was done in order to define appropriate data analysis procedure. A scatter plot of eddy current measurements versus actual depth for different degradation mechanisms are shown on Fig. 4.

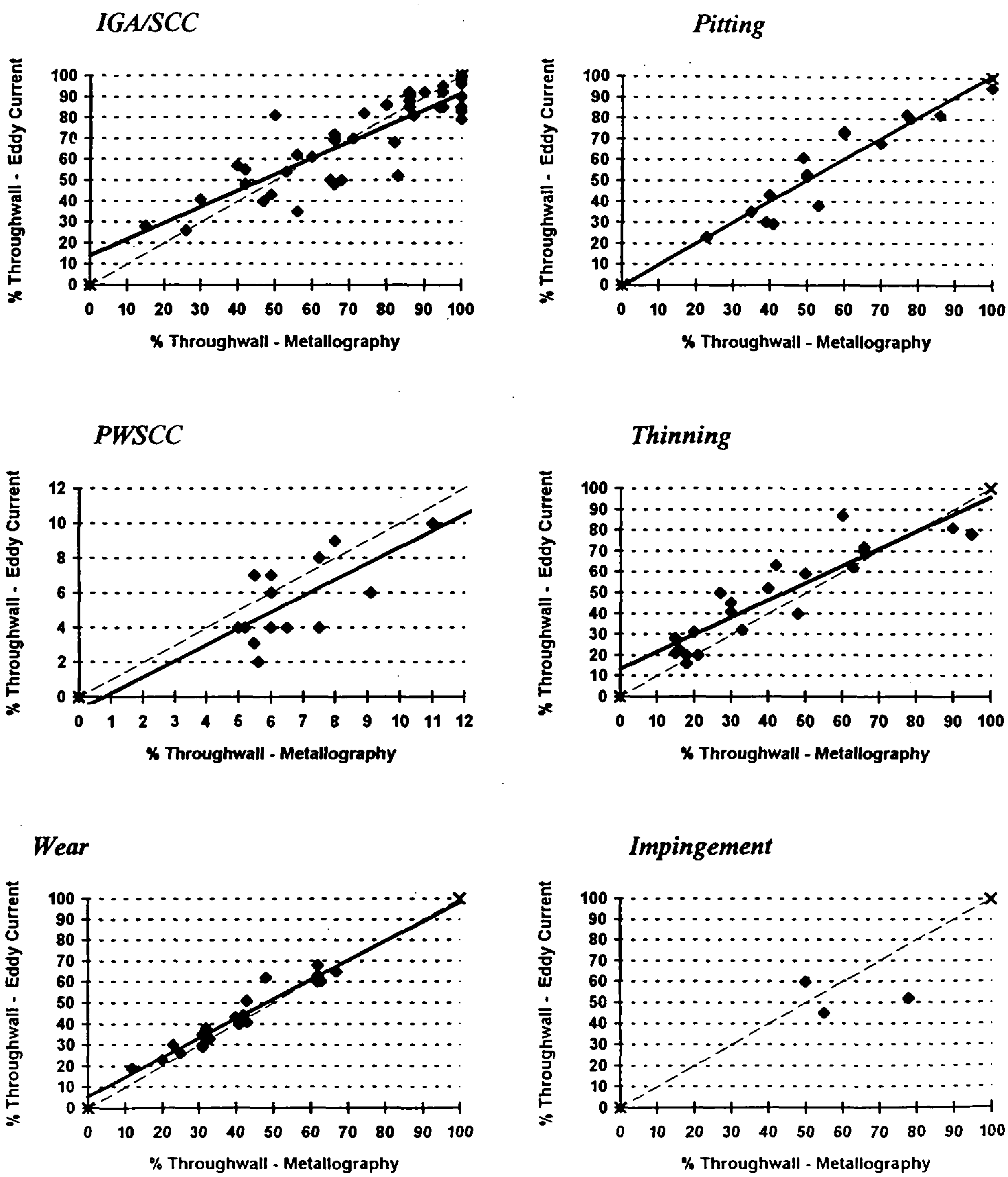


Figure 4 Eddy current accuracy for different degradation mechanisms

Recommendations for determining particular types of degradation

IGA/SCC Bobbin coil differential and absolute mode analysis techniques are used for detecting caused by this type of degradation. For expansion transition region the rotating probe should be used because of possible circumferential cracks.

Pitting Both conventional and special purpose bobbin coil technology has to be used to examine tubes for pitting. In presence of copper narrow groove bobbin coils used in conjunction with high frequency mixes have in some instances been shown to be effective in providing an improved detection and sizing capability.

PWSCC It is recommended to use rotating probe technique for diagnosing both axial and circumferential cracking modes. If bobbin coil is applied, the data should be very carefully reviewed because of possible occurrence of circumferential cracking.

Thinning This type of degradation mechanisms may be reliable detected by standard bobbin coil technique.

Fatigue The examination should be accomplished with 8x1 array probe because of U-bend length.

Wear Bobbin coil data acquisition and analysis techniques are normally used for wear scar detection. For sizing, special wear scar calibration standards are used with signal amplitude or voltage used to estimate wear scar depth.

Impingement Bobbin coil technique is appropriate method for determining this type of defects.

5. CONCLUSION

Considering SG operation experience related to tube bundle integrity, it is obvious necessity for better understanding of degradation mechanisms acting. This may be very useful in order to decrease the rate of tube deterioration and even avoid progress of new defects in further operation.

Examination of SG with different eddy current techniques may significantly help in determining the morphology of defects. Eddy current techniques are under permanent development with aim to assure the most accurate information about defect. This information provides possibility for performing different types of structural integrity evaluation (analytical, numerical and experimental) in order to improve reliable and safe SG operation.

Considering results of destructive metallography performed on tubes pulled out from SG the unvaluable knowledge may be derived. It may be used for further SG maintenance as well as for further improving of examination techniques.

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