Simple and Novel Solutions to Countering Uneven Density Variations in Microfocal Radiographs

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Abstract

The tube to tube sheet (TTS) welds of steam generator of Fast Breeder Reactor is the most critical joint. This is because, sodium flows on shell side and water on tube side. Any failure would thus be catastrophic. Microfocal radiography is an established technique that is being used for the evaluation of such welds. Using microfocal radiography pores of the order of 25 microns could be detected. Microfocal radiography of TTS joints is primarily accomplished using a backward throw rod anode. Such an arrangement however is beset with its own problems. The angled beam results in uneven beam intensity across the weld. During actual weld radiography, the trailing edge of the beam where intensity is minimum, traverses a longer distance than the leading edge which compounds the problem of density variation. This results in uneven radiographic density and contrast. It is a well-known fact that sensitivity achievable in radiography is a function of radiographic contrast and definition. Radiographic contrast in turn is affected by subject and film contrast. Uneven radiographic contrasts make interpretation complex and sometimes result in unacceptable density variations. To overcome this problem, the authors devised a novel solution. Using appropriately designed and fabricated filters and image processing techniques, authors have successfully developed procedures for ensuring uniformity in radiographic density. This has also resulted in improved effective sensitivity. A 32 /25 micron wire could be clearly resolved through a wall thickness of 2.3 mm. More than 600 welds have been examined successfully. This paper dwells on the criticality of the problem and the solutions that have been successfully developed and applied in the shop floor.

1.0 Background

India has embarked on the program of building 500 MWe fast reactors. Compared to conventional pressurized heavy water or light water reactors, a fast reactor uses sodium as the coolant. In the steam generator (SG) of fast breeder reactor of 500 MW(e), the transfer of heat from secondary sodium to water generates steam. Since the sodium-water reaction is exothermic and generates hydrogen, which produces high-pressure leaks in the sodium system, the integrity of weld joints separating sodium and water/steam and the overall integrity of steam generator is of paramount importance. A fast reactor has eight SGs. The tube to tubesheet (TTS) welds in the SG are thus the most crucial joints as they separate water and sodium. Typical configurations of the tube-to-tubesheet welds in conventional heat exchangers shown in Fig.. 1 a, b and c involve a fillet weld to the face side and are not desirable because of the following reasons:

1. The existence of crevice between the tube and tubesheet may lead to failures by crevice corrosion and stress corrosion cracking
2. The weld configuration is not amenable for NDT inspection.

In fact, world over many failures have been reported in this weld configuration. At the Indira Gandhi Centre for Atomic Research, the technology developer for the fast reactor program, the design of the TTS configuration was modified to overcome the disadvantages of the conventional configurations. The modified configuration shown in Fig. 1(d), envisaged a machined nipple of length of about 30mm from the tubesheet to which the tube (23 m long) is butt-welded. Due to restricted access from outside, the welding is carried out by pulsed TIG welding utilising a rotating electrode placed on the boreside. Visual examination, dye penetrant testing, replica and dial gage measurements reveal the external features such as concavity, convexity, undercut or other surface defects. However, the detection of internal defects

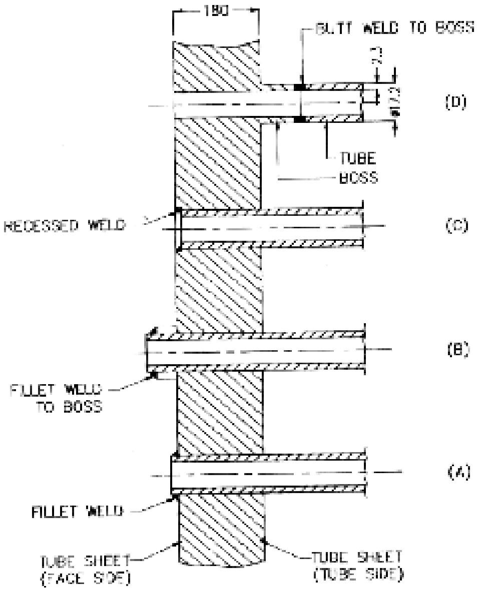

Figure 1: Typical joint configurations of tube to tubesheet welds

requires the use of other NDT techniques. Due to the typical joint configuration, conventional ultrasonic testing or X-radiography are ruled out due to problems of access. Hence, gamma radiography using a very small thulium source (size 0.1 mm) or microfocal radiography using a rod anode tube are the only other alternative. Theoretical and experimental analysis revealed that gamma radiography is not an appropriate choice leaving only microfocal radiography as the possible technique [1]. The challenge in the inspection of these TTS joints is that all linear indications and micropores of the order of 50µm need to be detected. As part of technology development program, procedures based on microfocal radiography have been successfully developed by IGCAR and L & T and applied in the shop floor for the reliable detection of microporosities of the order of 25 microns, cracks and wall thinnings[2-4].

2.0 The Problem

Microfocal radiography of TTS joints is primarily accomplished using a backward throw panaromic rod anode of diameter 10 mm since the ID of the tubes is 12.7 mm. In this probe, a flat tungsten target is used. Ideally a conical target is preferable as this would give a radial panoramic beam. However, due to problems in fabrication, a flat target configuration probe was only available. In this probe, the X-ray beam is emitted as a cone in the backward direction with the beam angles being – 5° x – 50° x 360 (w.r.t vertical). Such an arrangement however is beset with its own problems. The angled beam results in uneven beam intensity across the weld. The result is an unacceptable film since the density variations are more than what has been prescribed in the standard and even if the film becomes acceptable, problems in interpretation due to uneven radiographic contrast. Fig. 2 shows a typical film with the density variations. The longer arrow denotes a high density region due to the beam angle. Micropores can also be seen.

3.0 Experimental Approach

It was first thought that image processing can be adopted for removing the density variations. However, considering the manufacturing time schedules involved, it was decided to explore the feasibility of using appropriate compensation wedge. The essential pre requisite for the design of a compensating wedge was the beam profile and density variation profile. The following experimental steps were then undertaken

1. Radiography on a film at the same equivalent distance as being used in actual conditions but without the TTS weld or any other material. This was taken to judge

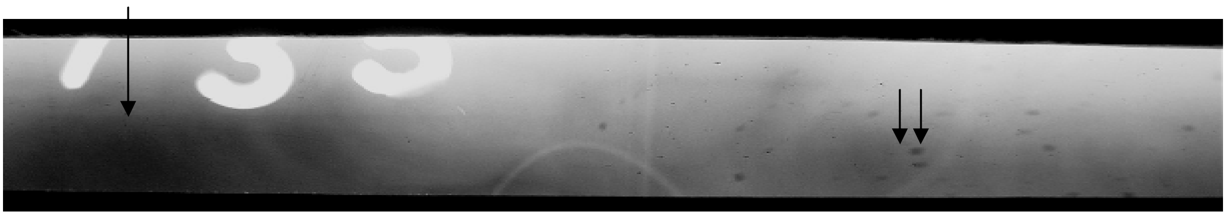

Figure 2: Uneven density variations introduced because of the varying beam angle. Note the density variations along and across the weld region.

the beam spread and also the beam intensity variations. This radiograph would also serve as the base line radiograph for background subtraction in case of image processing.

2. Radiography of the actual tube to tubesheet weld.

Density measurements were taken in the second case also and compared with the first one. It was observed that the density variations were similar except for minor variations which can be attributed to the variations in the weld thickness caused by cumulative effect of inside outside convexity / concavity of weld profiles and also the statistical fluctuations in the radiation beam intensity. Based on the density profile across the weld, coupling it with the characteristic curve of the corresponding film and using the fundamental equation for attenuation

$$I = I_o e^{-(\mu x)} \quad \text{--------------} \ (1)$$

where I is the transmitted intensity and I_0 is the incident radiation intensity, a intricate compensating wedge was designed. The choice of material for the fabrication of the wedge was quite important. Since higher the density of the material, then higher would be the kilovoltage that has to be used which is not advisable. Hence based on careful analysis, an optimum deisgn was arrived atan appropriate low density alloy was chosen and the wedge fabricated. The compensating wedge had very intricate profiles and was ultimately finalized on the basis of practical trials and experiments. The typical photograph of the wedge is given below.

Table - 1: Radiographic parameters employed

Voltage	105kV
Exposure	35 µA min
Wall thickness of tube	2.3 mm
Technique employed	Single-wall Single-image
Source to object distance	6.35 mm
Probe used	Backward throw with a beam angle -5°x -50°x360
Projective magnification	3x
Film used	Agfa D2
Penetrameter	Wire type
Processing conditions	Automatic
Sensitivity achieved	A 32 micron wire could be resolved corresponding to 1.39% of the wall thickness

Radiography of the TTS welds was then carried out without and with the compensating wedge in position. The typical radiographic parameters employed are given in Table – 1. In the case of compensating wedge, a marginal increase in the tube current was resorted to obtain the required density as per the standard. However, kV employed was same.

4.0 Results and Analysis

Radiographic density measurements were carried out on both the films. The positions on which the readings were taken is indicated in fig. 4. The results obtained for three typical TTS welds are summarised in Table – 2.

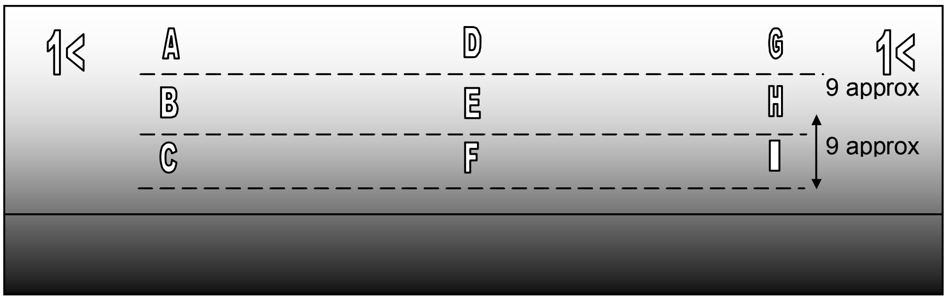

Figure 4: Typical locations on the radiographic films for density measurements.

Table – 2: Summary of radiographic densities before and after compensation using a wedge

FILM	BEFORE COMPENSATING									AFTER COMPENSATING								
	DENSITY AT									DENSITY AT								
	A	B	C	D	E	F	G	H	I	A	B	C	D	E	F	G	H	I
381 R7H33	1.38	2.84	3.47	1.06	1.94	3.71	1.62	2.67	2.68	2.89	3.50	3.78	1.78	3.16	3.27	2.91	3.40	2.67
381 R7H37	1.66	2.53	3.30	1.04	1.94	3.39	1.47	2.21	3.07	3.25	3.39	2.66	1.96	2.78	2.61	2.45	2.95	2.26
381 R7H15	2.12	3.10	3.45	1.20	1.96	3.57	1.55	2.30	3.16	2.73	3.49	2.70	2.07	2.90	2.75	2.25	2.75	2.30

It can be clearly observed from table 2 that the introduction of the compensation wedge has resulted in

(a) reducing the density variations in the radiographic film. While in the case of uncompensated beam the density varies across the weld by more than 68 %, this variation has been clearly reduced with the use of compensating wedge to less than 25 %

(b) It can also be observed from the table that the compensating wedge has increased the latitude. Thus densities less than 1.8 have improved and overall density on the radiographic film falls within the acceptable range of 1.8 to 4.0 as stipulated in the standards.

Apart from decreasing the density variations, the result of using the compensating wedge was improved radiographic contrast. It is well known that uneven radiographic contrasts make interpretation very difficult. The use of the wedge has made it possible to achieve a even radiographic contrast thus making film interpretation convenient and easy. It should also be highlighted here that while in the case of uncompensated radiographs, two exposures had to be taken to take care of the requirements of density as per standard, the use of compensation wedge provided in a single acceptable radiograph this density resulting in huge savings of time and cost.

5.0 Conclusions

In this paper, a novel and effective solution to the problem of uneven density variations introduced by the beam angle variations during microfocal radiography of the tube to tubesheet welds has been presented. Based on a combination of theory and practical experimental trials, a novel compensating wedge with intricate variations following the beam density variations has been designed and successfully applied in the shop floor. The application of this wedge has not only resulted in improved radiographic contrast and reduced density variations but also increased the latitude thus enabling the weld to be radiographed in a single exposure. Considering the fact that roughly about 4000 welds are to be examined, this novel experimental approach will also result in huge cost and time savings.

6.0 References

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