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GENERAL ELECTRIC

WELD OVERLAY DESIGN FOR THE INDICATIONS IN THE PILGRIM JET PUMP INSTRUMENTATION NOZZLE

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Prepared By: B. J. Branlund
B. J. Branlund, Engineer
Mechanics Analysis

Reviewed By: H. S. Mehta
H. S. Mehta, Principal Engineer
Mechanics Analysis

Approved By: H. S. Mehta
for S. Ranganath, Manager
Mechanics Analysis

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1. SUMMARY

In September 1984, ultrasonic examination of the Pilgrim Jet Pump Instrumentation Nozzle revealed two indications in the 304SS heat affected zone next to the Alloy 182 weld butter (see Figure 1). The indications were circumferential with a maximum individual length of 1 inch.

Boston Edison has decided to repair the weld with an overlay made of Alloy 82 material. The weld overlay was designed to provide full structural reinforcement even with a postulated 360° through-wall crack while maintaining ASME Code safety margins. The recommended weld overlay thickness is 0.135 inch (excluding the first pass) and the width is 1.3 inches. The analytical basis for the design is described in this report.

2. INTRODUCTION

In September 1984, ultrasonic examination of the Pilgrim Jet Pump Instrumentation Nozzle revealed two indications in the 304SS heat affected zone (see Figure 1). The indications were circumferential with a maximum individual length of 1 inch.

It was subsequently decided to perform a weld overlay repair. The weld overlay consists of a continuous 360° band of weld metal applied to the outside of the surface of the pipe directly above the defect. The overlay weld metal is Alloy 82 (ASME SFA 5.14, ENi-Cr-3). deposited using a high quality gas tungsten arc welding technique (GTAW) with water inside the pipe. This process produces a very high quality, high toughness weld consisting of material resistant to IGSCC.

Due to the conservative assumption of a 360° through-wall flaw, the weld overlay thickness is independent of flaw size. Therefore, uncertainty in flaw sizing does not influence the weld overlay design. The overlay is designed to provide full structural reinforcement while maintaining the ASME Code-intended safety margins. This report provides the basis for the design of the weld overlay and the detailed geometric considerations.

3. WELD OVERLAY DESIGN ANALYSIS

This evaluation conservatively assumes that the flaws are fully circumferential and will extend through the original pipe wall. The overlay thickness is selected such that it provides the Code design margin for the applied loading without taking credit for the uncracked wall thickness. Also, no credit is taken for any beneficial compressive residual stresses that may be induced by the heat sink weld overlay process; compressive stresses would oppose crack extension through the thickness. The assumption of a through-wall crack also provides assurance that the overlay design is independent of the crack size as determined by the ultrasonic testing. Finally, the selection of IGSCC-resistant material like Alloy 82 weld metal minimizes the potential for IGSCC crack growth into the weld overlay material beyond the first layer.

3.1 Methodology for Determining the Minimum Required Weld Overlay Thickness

The minimum weld overlay thickness necessary to achieve full structural reinforcement of the flaw is that thickness which provides the appropriate factor of safety against net section collapse of the adjacent material for a postulated 360° through-wall crack. The crack depth at which net section collapse occurs is a function of the material flow stress, the overall wall thickness including the weld overlay, and the applied primary membrane and bending stresses. The primary membrane stress is produced by pressure, and the primary bending stress is the sum of the dead weight and seismic stresses.

Paragraph IWB-3642 of the ASME Code, Section XI (Reference 1), can be used to determine the allowable flaw size using a safety factor of 3.0 on applied loading. Assuming that the indications are fully circumferential, the method described in Reference 2 can be used. In this report a relationship between the applied loads, the flow stress, and the critical crack depth to thickness ratio is defined by Equations (1) and (2).

$$\beta = \frac{\pi \left(1 - \frac{a}{t} - \frac{P_m}{\sigma_f}\right)}{2 - \frac{a}{t}} \quad (1)$$

$$P_b = \frac{2\sigma_f}{\pi} \left(2 - \frac{a}{t}\right) \sin \beta \quad (2)$$

where

σ_f = Material Flow Stress = 3 S_m

P_m = Primary Membrane Stress

P_b = Primary Bending Stress

a = Crack Depth

t = Total Thickness (pipe wall + weld overlay thickness)

These equations cannot be solved directly for the allowable flaw depth to thickness ratio, so an iterative approach must be used. In the iteration scheme, a weld overlay thickness is assumed and the primary stresses are adjusted to the new total thickness. The iteration is performed until the minimum required weld overlay thickness is determined. A factor of safety of 3.0 is used in accordance with IWB-3642.

Conventional weld overlays on stainless steel piping welds have been made using high ferrite low carbon Type 308L stainless steel weld metal. Because of the difficulty of welding stainless steel over the alloy weld butter, Type 308LSS weld metal cannot be used in this case. Instead, Alloy 82 weld metal, which has shown excellent resistance to IGSCC (as evidenced by test data and field experience), will be used for the weld overlay. The strength of Alloy 82 weld metal, the associated flow stress at collapse, and the S_m value are much higher than the corresponding values for 308L stainless steel weld metal (S_m = 23.3 ksi for Alloy 82 vs. S_m = 16.9 ksi for 308LSS at 550°F). Therefore, a thinner overlay is required for Alloy 82 weld metal than for 308L stainless steel.

3.2 Applied Stresses at the Weld Overlay Location

Since the Pilgrim Jet Pump Instrumentation Nozzle stress report (Reference 3) did not contain information concerning the pressure, dead weight, and seismic loads, these were obtained from the BWR/6 report (Reference 4). The pressure is assumed to be 1050 psi and results in a primary membrane stress of 2.1 ksi. The primary bending stress is the sum of the dead weight and seismic stress. The dead weight stress is 2.2 ksi and the seismic stress is 4.4 ksi, giving a total $P_m + P_b$ value of 8.7 ksi.

3.3 Weld Overlay Thickness

The iterative calculations described in Section 3.1 were performed using the stresses described in Section 3.2. The thickness generated by this calculation is the minimum necessary for the overlay to maintain the required 3.0 factor of safety. Figure 2 shows the results of the iterative analysis to determine the overlay thickness. As shown in Figure 1, a minimum thickness of .135 inch is recommended. The conventional concept of dilution in the first layer and, therefore, increased susceptibility to IGSCC, as discussed in References 5 and 6, is not applicable for Alloy 82. The first layer can therefore be credited to the effective weld overlay thickness, providing an additional barrier to IGSCC. Assuming a first layer thickness of 0.09 inch, the total overlay thickness is 0.225 inch.

Weld Overlay Width

Unlike the thickness requirements for weld overlay designs, which are based on satisfying the safety margins of the ASME Code, there are no guidelines for determining the weld overlay widths. Former overlay design specifications recommended a conservative width of one attenuation length $\sqrt{Rt}$ on either side of the weld material (total width of $2\sqrt{Rt}$). General Electric has performed finite element studies which compared the stresses obtained when modeling pipes with weld overlay widths of $\sqrt{Rt}$ to those of $2\sqrt{Rt}$ for fully circumferential through-wall cracks. Results showed that there is no significant difference between the stresses obtained for the two widths and it was concluded that the additional material of the wider overlay contributed little to the overall structural reinforcement of the weld. Therefore, a minimum weld overlay width of $\sqrt{Rt}$ is used as the basis for the recommended overlay designs. The minimum width based on the criteria of $\sqrt{Rt}$ would be 1.3 inches. It is important to assure that the overlay covers the weld, heat affected zone, and flaw while considering the transition region.

3.5 Weld Overlay Design

The specific overlay design shown in Figure 1 was based on consideration of such factors as the relative thicknesses of the butt welding members, the weld crown geometry, the extent of the original heat affected zone, the proximity to transition area, and the consideration of ultrasonic testing. The slope of the overlay end was set to one-to-one (width-to-thickness) to reduce stress concentration effects. The weld overlay is positioned to cover the indication in the stainless steel spool piece and the adjacent Alloy 182 (ASME SFA 5.11, ENi-Cr-Fe-3) weld butter. However, the edge of the weld is at least 0.1875 inch from the low alloy steel nozzle to preclude hardening of the P3 material.

It should be emphasized that the issue of dilution in the first layer does not apply when using Alloy 82 weld overlay material. This implies that the entire weld overlay, including the first layer, constitutes a barrier to IGSCC. Therefore, the effective overlay thickness is 0.225 inch (instead of the .135 inch applied after the first layer). Therefore, the weld overlay design provides a conservative safety margin compared to the requirements for a typical Type I, full structural, overlay.

Figure 1. Pilgrim Jet Pump Instrumentation Nozzle Weld Overlay Design

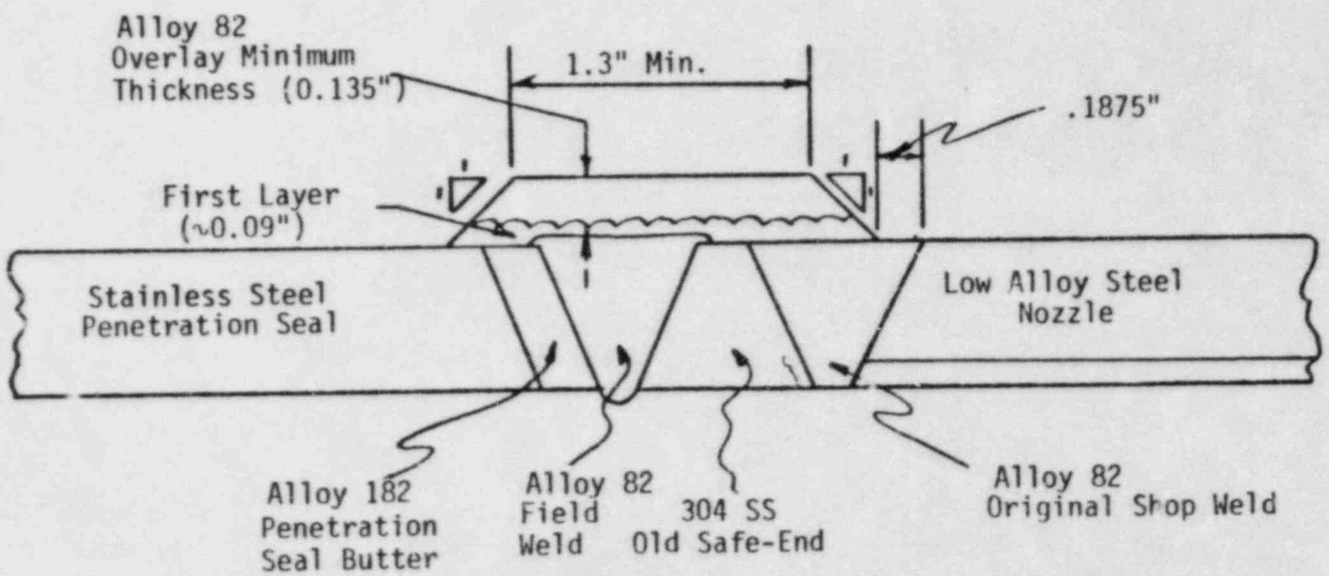

Figure 2.

Weld Overlay Calculations for Inconel 82

WELD ID: PILGRIM

PIPE THICKNESS = 0.64 INCH
PIPE DIAMETER = 5.1 INCH

PRIMARY LOADS (STRESS):
PRESSURE = 2.08 KSI
DEAD WEIGHT = 2.19 KSI
SEISMIC = 4.40 KSI

WOT	I / T+WOT	PM (KSI)	PB (KSI) ACTUAL	PB (KSI) CALC	PM+PB / SM (ACTUAL)	PM+PB / 3SM (CALC)
0.135	0.826	1.805	5.442	20.201	0.311	0.315

PRIMARY STRESS RATIOS (ADJUSTED):
PM/SM = 0.077
(PM+PB)/SM = 0.311

MINIMUM REQUIRED WELD OVERLAY THICKNESS = 0.135 INCH
MINIMUM REQUIRED WELD OVERLAY WIDTH = 1.3 INCH

4. REFERENCES

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5. Continued Service Justification for Weld Overlay Pipe Repairs (Final Draft), Prepared for BWR Owners Group and EPRI, May 25, 1984.

6. Letter from William J. Dircks, NRC to the Commissioners, NRC, "Staff Requirements for Reinspection of BWR Piping and Repair of Cracked Piping," November 7, 1983, SECY-83-267C.