Acoustic Emission Monitoring of Fossil High Energy Piping

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Sixth EPRI Piping & Bolting Inspection Conference
Recent HEP Seam Weld Failures

<table>
<thead>
<tr>
<th>Power</th>
<th>Unit</th>
<th>Year</th>
<th>Hrs</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alabama Power</td>
<td>Gaston Unit #2</td>
<td>1993</td>
<td>156,000 hrs</td>
<td>Through-wall leak</td>
</tr>
<tr>
<td>Monongahela Power</td>
<td>Ft. Martin Unit #1</td>
<td>1995</td>
<td>205,000 hrs</td>
<td>Through-wall leak</td>
</tr>
<tr>
<td>East Kentucky Power</td>
<td>Spurlock Unit #2</td>
<td>1996</td>
<td>125,000 hrs</td>
<td>Through-wall leak</td>
</tr>
<tr>
<td>Virginia Power</td>
<td>Mt. Storm Unit #1</td>
<td>1996</td>
<td>200,000 hrs</td>
<td>Catastrophic</td>
</tr>
<tr>
<td>Kansas City Power &amp; Light</td>
<td>Hawthorne Unit #5</td>
<td>1998</td>
<td>225,000 hrs</td>
<td>Catastrophic</td>
</tr>
<tr>
<td>Alabama Power</td>
<td>Gaston Unit #4</td>
<td>2001</td>
<td>~225,000 hrs</td>
<td>Through wall leak</td>
</tr>
</tbody>
</table>

Mt Storm, June 1996

Mt. Storm Unit 1 SH Outlet Lead “B”
20"OD x 3.5" wall
ASTM Gr. B
Rupture: 6.5’ L x 7.5” W

Hawthorne, Aug 1998

Mt. Storm Unit 1 SH Outlet Lead “B”
20"OD x 3.5" wall
ASTM Gr. B
Rupture: 6.5’ L x 7.5” W
Typical double-vee Weld Preparation in a Hot Reheat Pipe
J-Groove Weld Preparation in a Link Pipe Section
Failure Mechanisms for LSW Piping

• The mechanism of failure is creep cavitation
  – Cavities initiate at discontinuities in the microstructure, i.e. inclusions, carbides
  – Multiple initiation sites that are very localized at some microstructural feature such as grain size, weld fusion lines or weld centerlines
  – Very little local deformation at crack location thus no global pipe deformation
Cavitation (creep voids) at the Cusp in a Double-vee Weld of a Hot Reheat Pipe

Magnification: 500X
Failure Mechanisms for LSW Piping (cont.)

- The time from microcrack formation to final rupture can be very short (1-5 years) that lies within normal inspection intervals
- The prevention of pipe rupture depends upon detection of damage at the cavity stage
  - This presents are very large challenge for the NDE
Historical Perspective
AE Development Program

- 1985, 86 Mohave and Monroe failures spur start of EPRI investigative program
- 1986-1990--Initial EPRI investigative program for AE (RP1893-4)
- 1990-1995--Joint investigative program with PG&E (RP1893-20)
  – Revised AE Guidelines for AE testing of seamed HRH piping (Nov ‘95)
  – Successful full scale test on PG&E Potrero HRH piping
- 1994-2002--EPRI Guidelines testing of >75 HRH & SH lines shows good correlation with other NDE methods and advanced cryo-cracking metallography
Purpose for AE Testing of HRH Seamed Piping

• Improve economics of inspection
  – Find active flaws during operational conditions
  – Direct additional NDE (ultrasonics, magnetic particle, radiography)
  – Reduce effort to evaluate inactive sources

• Provide global inspection
  – Detect active flaws in entire volume of piping
Key Elements of AE Testing

• Waveguides required for temperature isolation ---spacing 15-18 ft
• Sensor design and filtering to reduce influence of background (flow) noise
• Active linear source location to identify active emission sites
• Correlation with plant parameters to identify AE source behavior
AE MONITORING OF REHEAT LINES

Waveguide and Sensor

Coax cabling

Computer-based AE System

Time Difference of Arrival

Threshold

Near-field Signal

Threshold

Far-field Signal

Chan. 1

Source Location

Chan. 2
Advantages of AE Testing

• Minimal insulation removal
• Performed online—no outage required
• Real time detection of growing flaws
• 100% volumetric inspection
• 2-5 times less expensive than UT inspection
• Distinguish seam weld creep sources by response to pressure
• Detect creep or thermal fatigue problems in other structures:
  – Closure welds
  – Hanger supports
  – Drains and vents
  – Dissimilar metal welds
Case Histories

- SH link piping seam weld
- HRH clamshell seam weld
- HRH welded batwing hanger
- SH piping drain line socket weld
- SH piping dissimilar metal thermowells
Example of Waveguide installation on SH link piping

East SH Lead

Penthouse Roof
Kentucky Utilities Brown #3 West SH Link--Mar 98 Online

AE location profile during online monitoring similar to June 97, but broadening

Sources show sensitivity to pressure during online conditions
Kentucky Utilities Brown #3
West SH Link--EPRI Evaluation

Phased array automated UT scan finds scattered indications in weld centerline over 24” length of weld--matches AE location data

3” plug sample is taken from suspect area for metallography
Metallographic and cryo-cracking analysis by M&M Engrg (Austin, TX) finds evidence of early stage creep cavitation in weld centerline

- a  Fine grained intraweld zone 1/3 from OD
- b  Fine grained intraweld zone at mid-wall
- c  Weld center near ID and OD intersection
- d  HAZ near ID/OD weld cusp
- e  HAZ near mid-wall of pipe
- f  HAZ near fusion line at mid-wall of pipe
- g  Weld near fusion line at ID root pass

Kentucky Utilities Brown #3
West SH Link--EPRI Evaluation
Activity during online 4 days after 5/7/98 startup

- Clusters 4, 5 show pressure sensitivity
- Much reduced activity from startup condition
Intradose Weld LSW4I 53.5"
Extradose Weld LSW4E 110"
Girth Weld GF-10
Girth Weld GS-11
CS Hanger (U-bolt clamp)
Focused Array UT Inspection
Centerline distance WG #14 to WG #15 = 192"

Illinois Power Baldwin Unit #1 Elev 553 Clamshell Elbow

Spool HR8
Seam Weld LSW8
Elbow HRF4
Intradose Weld LSW4I 53.5"
48-50" from GF-10
Girth Weld GS-11
101-103" from GF-10
Spool HR9
Seam Weld LSW9

#15
Baldwin #1 HRH Elev 553 Elbow
UT Inspection Results

• No significant TOFD indications or FATS indications at elbow seam weld locations selected by Structural Integrity
• Significant TOFD indications in spool HR9 over 6’ section
  – FATS 0 & 45 deg inspections show this is due to plate laminations
  – Inconclusive results on presence of creep damage
• FATS indications of early stage creep damage in extradose elbow seam weld location selected by AEC
  – Isolated cavitation or disbonded inclusions near midwall cusp
• Material sampling recommended—not pursued
• Cryo-cracking metallography only reliable method for early stage creep analysis
Illinois Power Baldwin #1 Elev. 553 Elbow
Midspan Extradose Weld Focused Array UT Scan
(48-50” downstream of GF-10)

FATS scan shows isolated cavitation or disbonding at midwall position on one side of the weld. Pattern is consistent with early stage creep damage.
HRH Line Batwing Hanger

- HRH line shows elbows and batwing hanger position with pressure-sensitive sources (creep-related)
- Manual UT inspection confirms mid-wall indications in 1st elbow
- Magnetic Particle inspection confirms multiple indications on batwing hanger weldments
- Both pipe side and hanger side indications
Batwing hanger inspection report identifies multiple cracks on both the hanger and pipe side of welds.
• SH Link Piping, Two Leads
• 7 AE Waveguide positions on each
Hanger and drain line location show high emission rate during online testing.
Hanger/drain location show higher activity rate with higher pressure. Data located continuously during monitoring period. Profile indicates drain line problem.
SH Drain Line Failure

- AEC recommends drain line inspection
- Utility performs thermal analysis of drain line at pipe, but finds no evidence of leakage (no insulation removal)
- Drain line fails 9 months after AE test
Main Steam Line—Thermowell Dissimilar Metal Welds

- Activity detected at four thermowells with dissimilar metal welds during startup
- Utility removes thermowells
Conclusions

• AE has reached field maturity
  – Requires online testing with peak loading
  – >75 full scale tests
  – >20,000 ft of piping tested

• Early detection of creep damage at cavitation stage
  – More sensitive than TOFD or manual UT to early damage development

• Advanced UT and Metallographic techniques required for verification

• All high energy piping could benefit from AE monitoring