Optimization of FCCU Expansion Joint Application, System Design and Reliability Considerations
Expansion Joints in FCCU Application

Basic Considerations

- Expansion Joints are the **Weakest Link** in the system
- **ELIMINATE**
- **OPTIMIZE** EJ by composite system design approach
- Consider effect of **refractory** on the **stiffness** of the system
- Implement Design & Fabrication **UPGRADES** of EJ’s
- **MONITOR** movement during Dry-out and Operation
- Routine **INSPECTION** and **PREVENTIVE MAINTENANCE**
- **VENDOR SELECTION** is Key
- Hot Wall versus Cold Wall
- **Orientation** – Vertical versus Horizontal
Outline of Routine Inspection and Monitoring program
FCCU Expansion Joint
FCCU Expansion Joint
Systematic approach to Optimize FCCU Expansion Joints

- Composite System Design Approach
- Eliminate EJ
- Minimize EJ
- Design Upgrades
- Fabrication Upgrades
- Proper Installation
- Monitor EJ during dry-out and Operation
- Inspect EJ during shutdown
- Preventive Maintenance of EJ
FCCU Expansion Joint

DESIGN

COMPOSITE SYSTEM DESIGN APPROACH

• All disciplines working together, **NO “SILO” APPROACH**
• Series Versus Parallel Design
• Vessels / Structures / Piping working together
• Mechanical Design Diagram
• Construction and Lift diagram
• Refractory Dry-out Diagram
Primary Mechanical Design Consideration in an FCCU

- Layout, Thermal Growth, Structure, Equipment
- Large Diameter (Refractory Lined) Transfer Lines
- High Operating Temperature
- Cold Wall vs Hot Wall
- Effect of refractory lining on stiffness and loading
- Thermal Movement and Banana Movement in transfer lines
- Erosion
- Upsets and Abnormal Operations including SLUMP Case
- Refractory and Thermal Conditions during Dry-Out
- Expansion Joint Application and Optimization
Expansion Joints in FCCU Application:

Design Basis

- Preferred Orientation – Vertical with Downward Flow
- Normal, Upsets, including SLUMP Condition
- Thermal Movement and Banana Movement
- Equipment Fabrication and Construction Tolerances
- Avoid Torsion
- Consideration of Out-Of-Plane Movement
- Stability of Bellow
- Support of Center Spool
- Use of Pantographic Linkage, Gimbal ring, slotted Hinge Bar
DESIGN (cont’d)

Expansion joint application and Design Optimization

• Consider the effect of refractory lining on stiffness of duct.
• Perform FEA to determine vessel nozzle flexibility
• Perform structural analysis to determine restraint flexibility
• Determine effective modulus of elasticity of duct, $E_{eff}$.
• Calculate equivalent duct thickness, $teq$
• Use $teq$ to calculate reduced flexibility factor, $K_{eff}$, of bends
• Perform analysis based on nominal $t$, $CA$, $E_{eff}$ and $K_{eff}$
• Perform FEA of nozzle based on load, stress and distortion
Effect of Refractory Lining on the Stiffness of Steel Pipe;
(Ref – PVP- Vol. 53)

\[ I_r = 0.6 I_1 + 0.4 \left( \frac{I_2 + I_3}{2} \right) \]  

(Fig. 3 Variation of \( \frac{I_{eq}}{I_{iso}} \) with Lining Thickness)
Regenerator Flue Gas Nozzle FEA

Flue Gas Outlet Nozzle & Plenum

LOAD CASES:
# 1: (Thermal + Pressure + Weight)
# 2: (Pressure + Weight)
# 3: Weight only
# 4: Pressure only
# 5: Thermal only @ "Normal" operating condition

DESIGN BASIS:
- Pressure: 20 psig @ Regen head
- Differential Pressure = 3 psig for plenum design
- Temperature = 1400 F
- Ambient: 90 F & 3 mph wind
- # of fatigue cycle = 200 (min)

Finite Element Model

FCCU Regenerator
EJ Fabrication

Upgrades and Consideration

- Vendor selection is key.
- Use of 2- Ply testable bellows
- Centerline of bellow and Line Seal to coincide
- Gimbaled pantographic linkage to provide center spool support & accommodate movements without binding
- 2- Thermocouples per bellow to measure bellows skin temperature in service.
- Hot Blankets to provide heating in those unique circumstances where the bellows will operate below the acid dew point in service.
FCCU Expansion Joint

Fabrication (cont’d)

BELLOWS

- 2-Ply Testable Bellows and Hot Boxing
- Materials Selection and Corrosion consideration
- Condensation Protection
- Forming
- Attachment to Body
- Purging versus Packing
- Use of telescopic liner to coincide with center of bellow
Fabrication (cont’d)

- Provisions for a future clamshell. Put in bands and have room under the hinge for this. Not all current designs have the room for a clamshell.

- Sealable covers. This is a backup to the clamshell in case everything goes wrong you can box the leaking bellows in online.

- Cr-Mo weld inlay.
FCCU Expansion Joint

STANPIPE EXPANSION JOINT HARDWARE

PANTOGRAPHIC LINKAGE

CENTERSPOOL GIMBAL

SLOTTED HINGE

COVER
Design / Calculations

• EJMA & ASME B31.3 Design Basis
• FEA’s – Bellow Temp
• FEA – Liner to Spool Intersection
• FEA – Pressure Retention and Local Stress
• FEA – Floating Ring Design
• Clearance – Internal Sleeve to Spool
• Clearance – Slotted Hinge Bar
• Bellow Movement Calculation using field data
Monitoring during Construction and Refractory Dry-Out

• Minimize Fabrication and Construction Tolerances
• Monitor Proper Installation and Field Fit-Up of EJ
• Add thermocouples at critical locations to monitor system temperature during refractory dry-out.
• Monitor Thermal Operation during field dry-out and verify to be same as “system design” basis
• Monitor and verify Expansion Joint, spring hanger and system movement as “designed”
Routine Monitoring of Expansion Joint during OPERATION

• Monitor Bellows movement on routine basis to verify any sign of excessive actual movement over Design limit.

• Monitor 2-ply testable bellows for any leaks

• Monitor bellow temperatures using installed thermocouples. Keep between (400 – 800) deg F range or as per Spec.
**FCCU Expansion Joint**
*(Bellows Movement Monitoring)*

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**Elevation Looking West/North-West**

<table>
<thead>
<tr>
<th>Location or Date</th>
<th>Operating Condition</th>
<th>Expansion Joint Measurements</th>
<th>Indicator Reading</th>
<th>Calculated Results</th>
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<tbody>
<tr>
<td></td>
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<td>Lower Bellows</td>
<td>Upper Bellows</td>
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<td>SHIP BARS REMOVED</td>
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<td>DURING DRY-OUT</td>
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<td>START-UP/OPTION</td>
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FCCU Expansion Joint
(Bellow Temperature Monitoring)

TAG (1): UPSTREAM THERMOCOUPLE
(1): DOWNSTREAM THERMOCOUPLE

USE S/S TIE WIRE TO BAND EXCESS LEAD WIRE OF THERMOCOUPLE.

SEE DETAIL 2/9
Routine Monitoring of Expansion Joint during OPERATION

- Watch for bellow temperature rise over time. This will indicate if the internal pillows or braid seal may be damaged or external insulation over bellows require any changes.

- Look for limit rods that have bottomed out. This is a sign of attempted over-movement.

- Look for any binding hardware such as a non-gimbaled pantograph that is trying to move in out-of-plane lateral.
• Calculate Axial Movement

• Calculate Lateral Movement (in-plane and out-of-plane)

• If exceed design basis, calculate / verify liner clearances & seal clearance

• Calculate, Slotted Hinge Clearances and verify design basis.
Optimization of FCCU Expansion Joint
(2-ply testable bellows monitoring)
Common Failure Areas of expansion joint to inspect

- The common failure areas are the bellows inner ply leaking. Routinely monitor testable 2-ply bellows using the test port.

- Bellow Attachment welds

- Internal liner to duct weld joint failure due to stress / vibration

- Loss of refractory due to mechanical & thermal reasons.
Common Failure Areas of expansion joint to inspect (cont’d)

- Braid seal hose and inner pillow failure.

- Routinely monitor bellow temperature to watch for excessive temperature rise of bellow over time as indication of damage to pillows or braid seal.

- Mechanical failures due to movement surprises

- Hot spots and metal distortion due to excessive heating.
Routine Inspection of Expansion Joints during Shutdown

- Perform leak test for 2-ply bellows and verify sign of leak.
- Look for evidence of cracks on hardware and distortion of hardware such as pantographs.
- Perform interior inspection of refractory and liner gaps. Determine that insulation pillows are still in place. Look for evidence of bottoming out, denting of overlapping surfaces.
- Look for evidence of vibration.
- Look for evidence of hot spots, discoloration, loss of refractory.
Inspection of Expansion Joints during Shutdown (cont’d)

- Inspect the refractory at the hot wall liner to cold wall refractory transition to determine if the liner weld at that point is cracked. That is a very high stress area.

- If needed, contact EJ Vendors such as SFI, EJS and others to perform hot & cold inspections, issue of inspection report and follow-up to track changes in the future.
FCCU Expansion Joint Optimization, Monitoring and Life Improvement

**DESIGN**
- Avoid or Optimize Application
- Design & Fabrication Upgrade
- Consider Normal & SLUMP
- Refractory Dry-out & Operation

**FABRICATION**
- Select Vendor Carefully
- Design, Fabrication & Testing
- Bellow Attachment
- Refractory Installation

**EXPANSION JOINT OPTIMIZATION, SAFETY & OPERATIONS RELIABILITY**

**FIELD MONITORING AND PREVENTIVE INSPECTION**
- Bellow Movement
- Bellow Metal Temperature
- Inner Ply Testing
Thank You
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