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

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Optimization of FCCU Expansion Joint

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

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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

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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

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DESIGN (cont'd)

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

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DESIGN (cont'd)

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

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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, Eeff.
- Calculate equivalent duct thickness, teq
- Use teq to calculate reduced flexibility factor, Keff, of bends
- Perform analysis based on nominal t, CA, Eeff and Keff
- Perform FEA of nozzle based on load, stress and distortion

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Effect of Refractory Lining on the Stiffness of Steel Pipe;

$$I_r = 0.6\, I_1 + 0.4 \left(\frac{I_2 + I_3}{2}\right) \qquad (17)$$

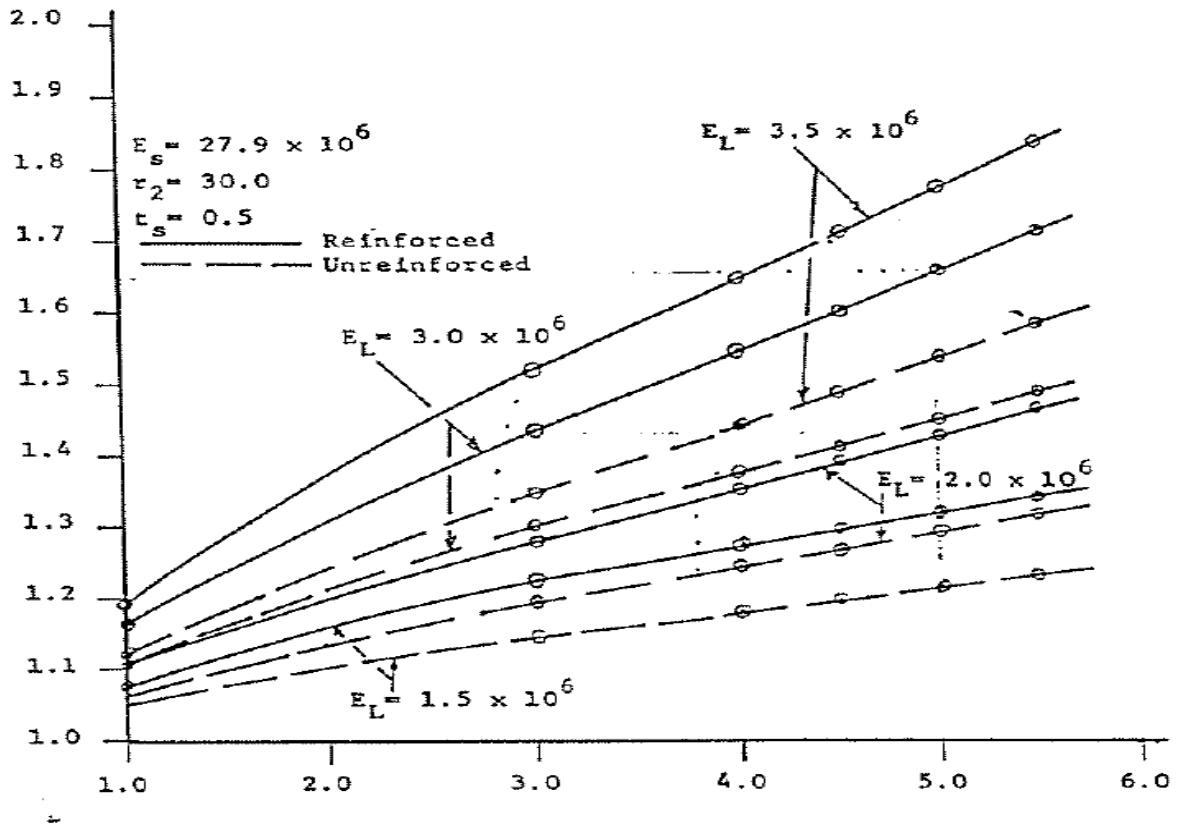

Fig. 3 Variation of $\left(\frac{I_{eq}}{I_{so}}\right)$ with Lining Thickness

(Ref – PVP- Vol. 53)

Regenerator Flue Gas Nozzle FEA

Flue Gas Outlet Nozzle & Plenum

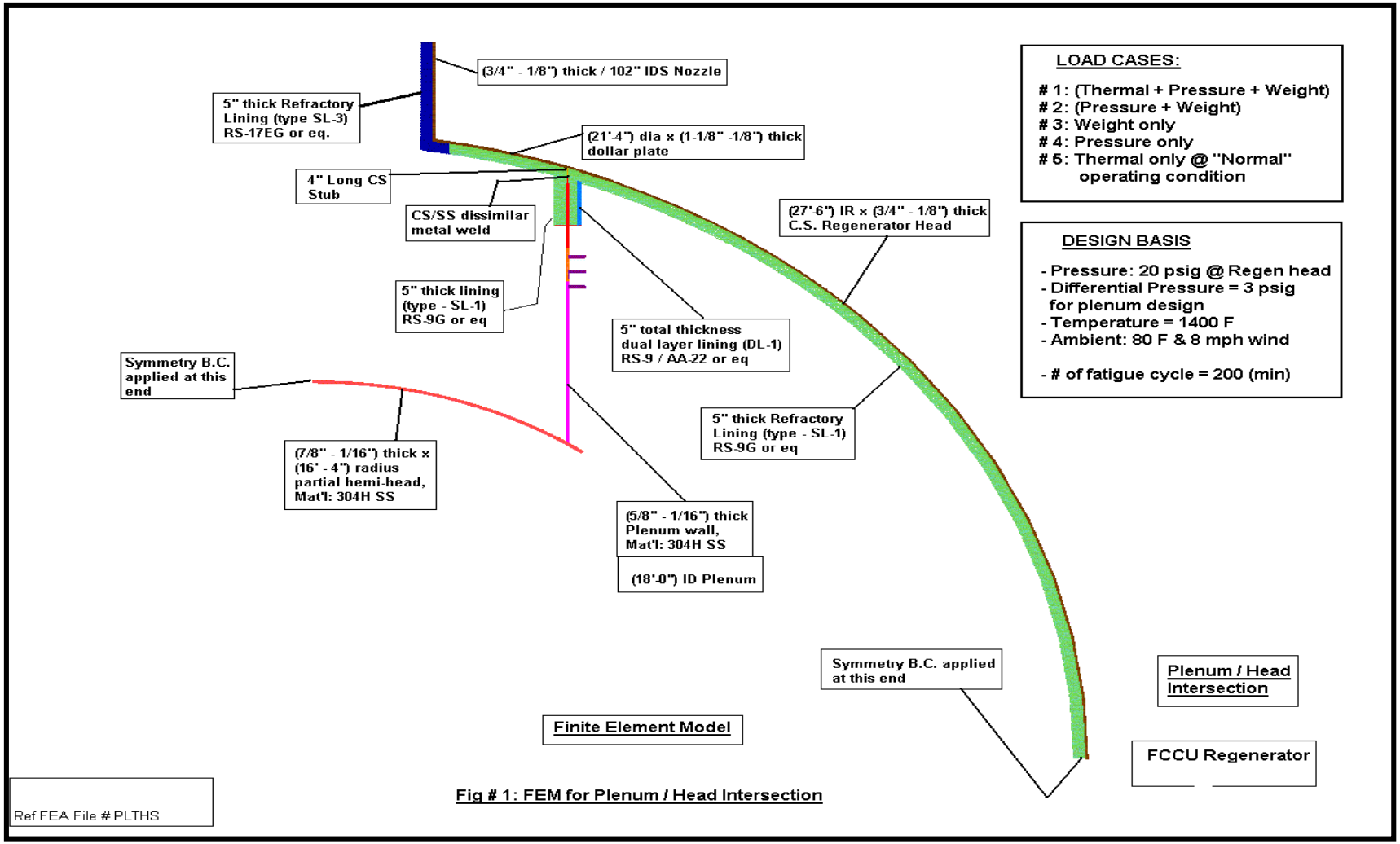

Fig # 1: FEM for Plenum / Head Intersection

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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.

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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

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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.

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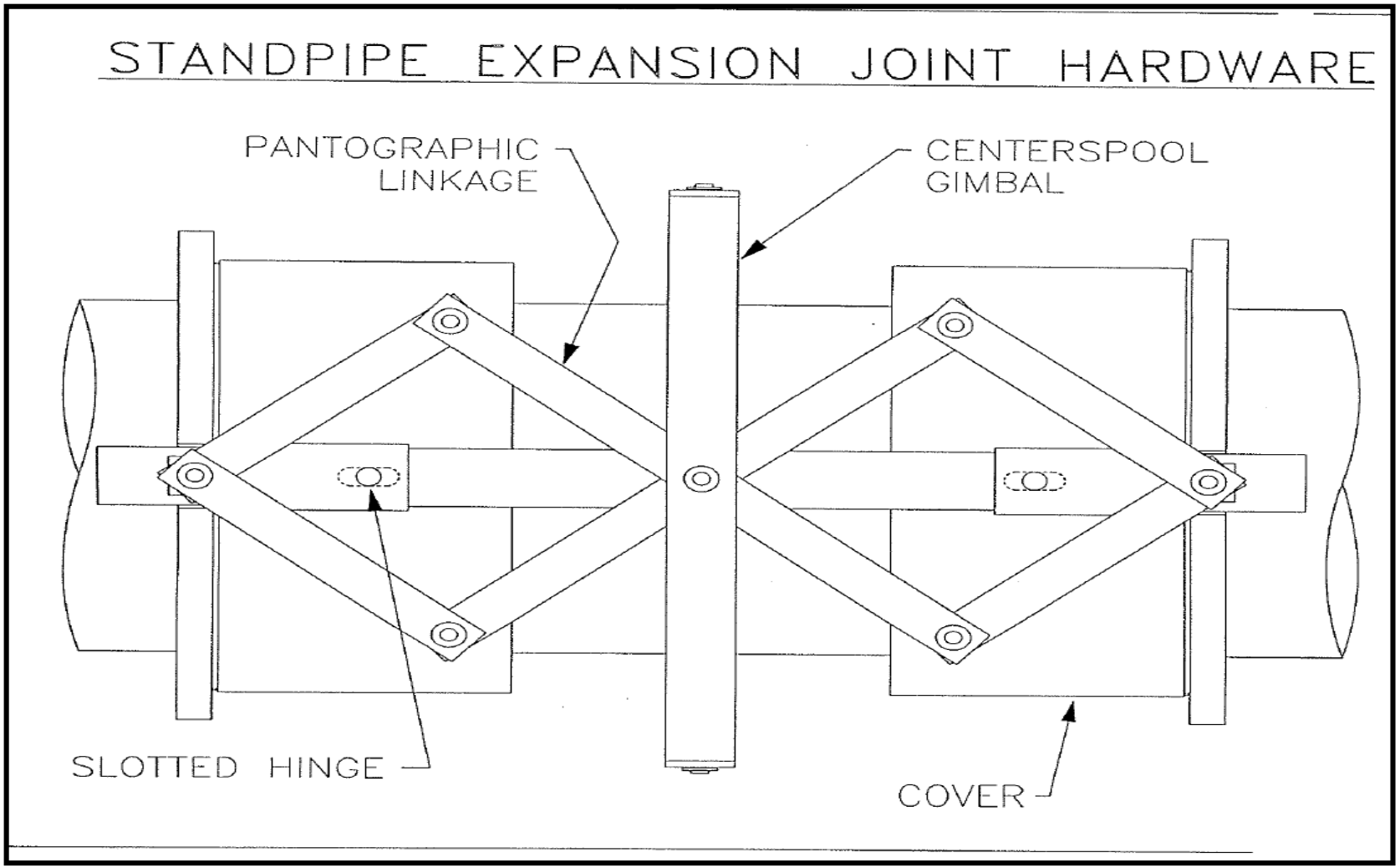

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(Fabrication & Vendor Data)

Design / Calculations

- EJMA & ASME B31.3 Design Basis
- FEA's – Bellow Temperature
- 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

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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”

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(On-line Monitoring)

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.

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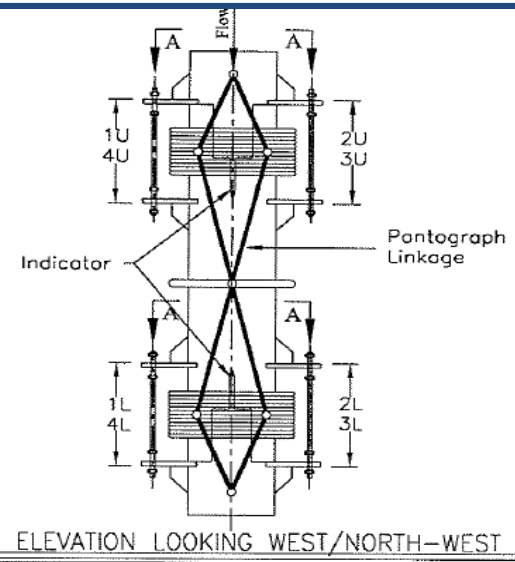
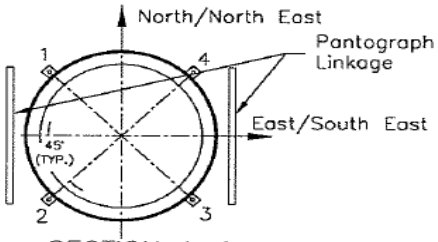
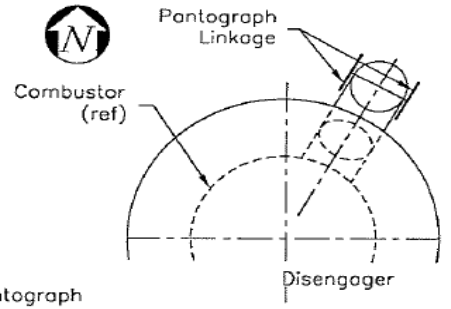
(Bellows Movement Monitoring)



ELEVATION LOOKING WEST/NORTH-WEST



SECTION A-A



PLAN

Location or Date	Operating Condition	EXPANSION JOINT MEASUREMENTS								INDICATOR READING				CALCULATED RESULTS					Remarks and Conclusions
		LOWER BELLOWS				UPPER BELLOWS				LOWER		UPPER		Resultant Axial Movement	Lateral Movement		Angular Movement		
		1L	2L	3L	4L	1U	2U	3U	4U	Axial	Angular	Axial	Angular		In-Plane	Out-of-Plane	In-Plane	Out-of-Plane	
	BEFORE OFFSET																		
	AFTER OFFSET																		
	AS INSTALLED																		
	SHIP BARS REMOVED																		
	DURING DRY-OUT																		
	START-UP/ OPERATION																		

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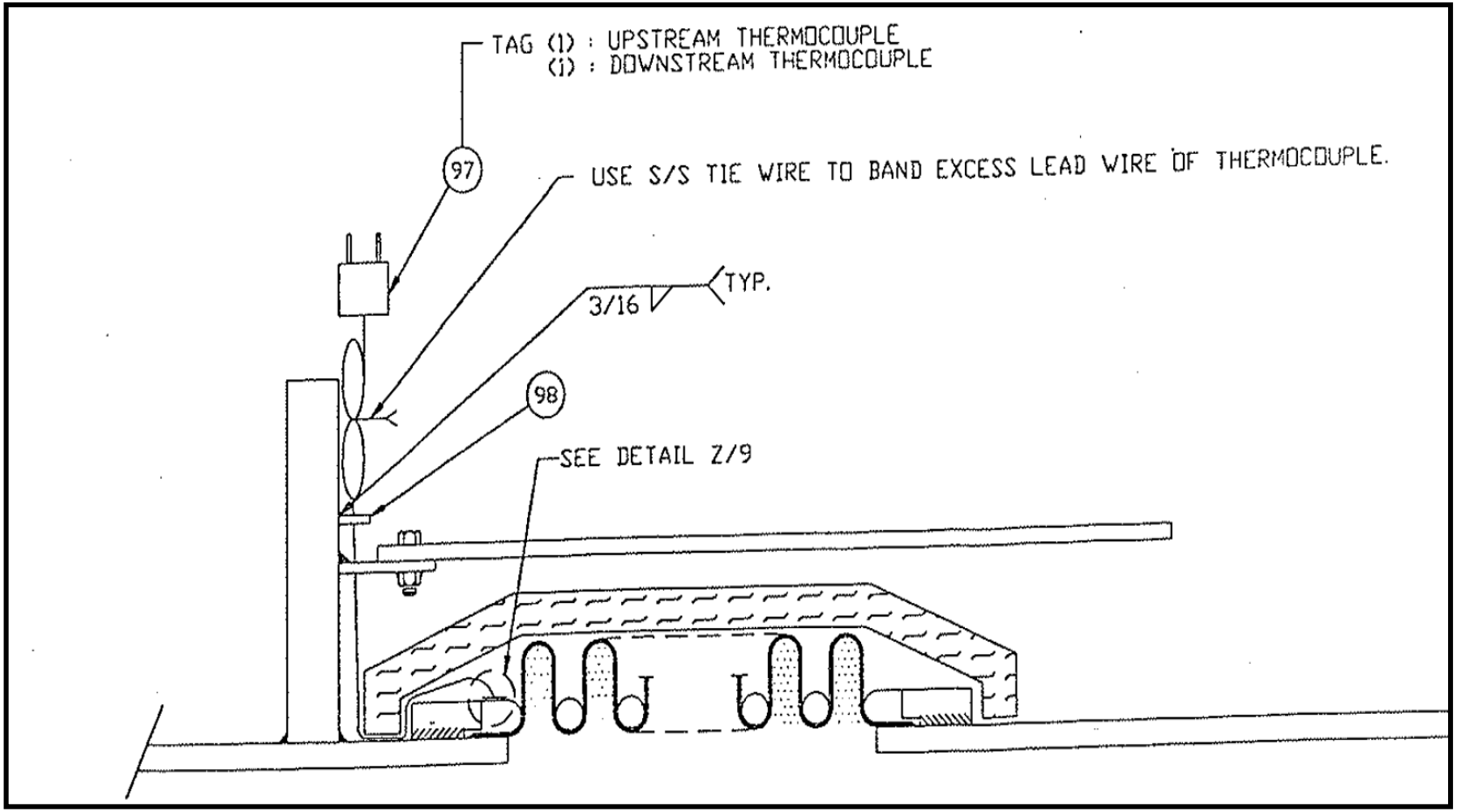
(Bellow Temperature Monitoring)



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(On-line Monitoring)

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.

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(Bellows Movement Monitoring)

- 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.

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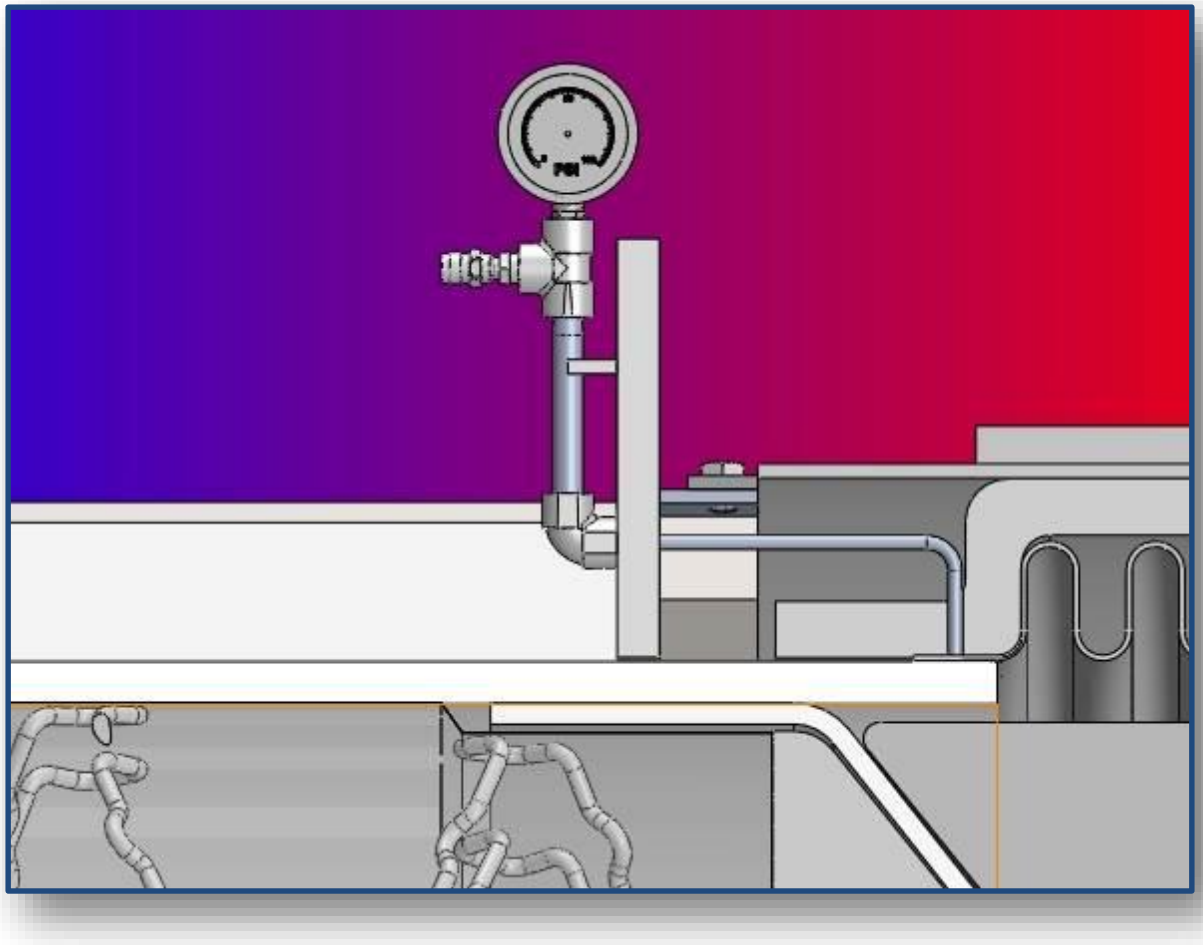
(2-ply testable bellows monitoring)



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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.

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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.

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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.

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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.

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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

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