Coke Drum Health Monitoring
And Reliability Improvement

- Headquartered in Houston with offices in Atlanta, Cincinnati, Chicago, Denver and New Orleans
- A professional engineering consulting company of approximately 170 personnel with more than 125 mechanical, electrical, civil and chemical engineers, 2/3 of which have advanced degrees with an average experience of 15+ years in industry.
- Extensive refinery experience in FEA, stress analysis, API 579 FFS, process modeling, CFD, materials engineering, failure analysis, acoustic emission testing, strain gage monitoring and vibration analysis of piping, pressure vessels, reactors, heaters and other refinery equipment.
Drums Over 20+ Years Old

- Not designed for Low Cycle Fatigue
- Operating on shorter cycles (16-12hr)
- High frequency of through wall cracks
- Foundation and concrete problems
- Many drums being repaired or replaced
  - Repair
  - Partial replacement
    - Keeping Top & Bottom Heads & Skirt
    - Replacing shell (CB&I vertical design)
  - Full replacement

Drums 5-10 years old - 2\textsuperscript{nd} Generation

- Not designed for LCF
- Through-wall cracks in shell after 7 years in 3 sets of drums
- Through-wall cracks in skirt region after 4 years in two set of drums
- Foundation and concrete problems and failures
- Not designed using "actual" measured thermal transients or stress ranges
Drums < 5 years old - Latest Generation

- Designed for LCF Shell & Skirt
- Designed using “actual” measured thermal transients, rates and strain ranges
- Designed for “Coke Crush” – Citgo Patent
- Conoco/Bechtel drums (3ea.) have SES Health Monitoring Systems installed
- Designed for 20-40 year life
Recent SES Coke Drum Projects
Monitoring and Assessment of 1500 Cycles and 46 + Coke Drums

- Design analysis of new drum skirts & shells and analysis of modifications to existing drums
- Health monitoring systems using strain gages, thermocouples and integration with DCS on existing and new drums
- Data reduction, analysis and optimization with plant personnel
- Acoustic Emission Testing of 44 Coke Drums
- Weld repair recommendations
- Materials consulting and failure analysis
- Crack Growth predictions, remaining life assessments and life extension recommendations

Current Issues being addressed by SES:

- Permanent AE monitoring to detect drum cracking
- Foundation and concrete repairs
- Operational optimization and yield increases with existing equipment through “BEST PRACTICES”
- Impact of Shorter Cycles and different feeds
- Detection of “hot drums” and drums with “water” prior to opening
Data acquisition when TC’s A and B (both well above 800°F)
4 AE transducers on each (W1, W2, W3, W4) welds at each drum.
Total of 24 AE transducers. Remotely calibrated AE
transducers.
Two TC's controlling data acquisition (TC-A, TC-B).
New TC's monitoring skin temperatures for thermal gradients.
Temperature distribution soon after Switching

Skirt is forced outward during Fill transient
High Temperature Strain Gage
with Intrinsically Safe
Instrumentation

Strain Gage Locations on Shell

Stress Engineering Services, Inc
www.cokedrum.com
Strain Gage Locations at Skirt Attachment

Structural Health Monitoring
Data Processing Tasks

- Review Recorded Data for
  - High Temperature Strain Gages
  - Thermocouples
- Correct Readings for Temperature Error
- Calculate each pair for Bi-Axial Principal Stress and Stress Intensity
- Determine Stress Range each Cycle
- Compile Histograms and Damage Accumulation
- Evaluate Process Cause and Structural Effect
- Compare Different Operating Procedures for resulting Structural Damage
SES combines their measurement experience with the latest engineering software tools and materials engineering knowledge to provide "Health Monitoring Technology" for fixed equipment, this enables plant personnel to solve daily engineering problems and improve plant integrity, safety and profitability.

- Structural Monitoring Systems Using Strain Gages
- Defect Identification and Assessment
- Crack Growth Prediction
- Bulge Analysis
- Drum Design and Modeling Using Actual Operating Transients
- Life Assessment and Extension Recommendations
- Metallurgical Consulting and Testing
- Heater Condition and Life Assessment
- Root Cause Failure Analysis
- Forensic and Litigation Support

Typical Coking Cycle for Process and Stress
Histogram of Stress Ranges and Damage for Low Cycle Fatigue

Example Histogram and Damage from High Stress Cycles

Calculation of Fatigue Damage for each Stress Component and Determine Cycle Life

Summary of Stress Range, Allowed Cycles, and Fatigue Damage

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Integration With SES
"DrumBeat" Analysis

DCS
Information

On-line Sensors

Critical Control
Factors

SES

Operator
Logs

↑ Outputs ↓

Observations

Operational Intelligence to
reduce fatigue damage

Remaining Life Assessments

Fatigue crack Growth Prediction
Low Cycle Fatigue Damage
Accumulation

SES Engineering Services to Owners, Operators,
and Designers of Delayed Coke Drums.....

- Health Monitoring Systems
  - Short and Long Term Strain Monitoring of Coke Drum Response to Daily Operation
  - Cause and Effect of Operation on Drum Damage
  - Integration into local DCS
- Defect Identification and Assessment
  - Acoustic Emission Testing
  - Inspection Planning
- Crack Growth Prediction
  - Fracture Mechanics and Crack Growth evaluations using actual operating data
  - Low Cycle Fatigue Damage Accumulation
- Bulge Analysis

- Drum Design and Modeling
  - Using Actual Operating Transients
    - Skirt
    - Shell
    - Piping and Nozzles
  - Life Assessment and Extension Recommendations
  - Metallurgical Consulting and Testing
    - Weld Repair Procedures
    - Creep Analysis and Omega Testing
  - Heater Condition and Life Assessment
  - Root Cause Failure Analysis
  - Forensic and Litigation Support
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Remaining Life Evaluation of Coke Drums

Using Strain Gages For Fact-Based Structural Characterization

Keeping aged coker vessels in reliable, continuous service can be costly and difficult, particularly when there is little remaining life to consider. In light of the increased risks associated with continued operation, it is essential that decisions about repair, replacement or continued use as-is be based on solid facts about the vessel's condition. There is a demonstrated relationship between drum failure and low cycle fatigue. Strain gage measurements have been found to be an important tool to define actual loading stress ranges experienced by an operating delayed coke drum.

The Problem With Aged Coke Drums

The problems with aged coke drums are usually associated with 1) frequent repairs to shell circumference seams near large distortions, 2) skirt junction cracking to the shell and cone, and 3) nozzle failure. These problems are further complicated by shortened cycles and non-uniform cooling. The good news, however, is that except for the worst case situations, an understanding of drums condition allows time for reasonable planning to prolong its useful life. A thorough coke drum evaluation program usually involves several steps. These include:

- Determine shape profile
- Detailed thickness survey of longitude and circumference
- Strain gage recording of 100 cycles
- Metallurgical assessment
- Operating and repair history
- Critical crack length study
- Re-rate as corrugated cylinder vessel

Figure 1. This coke drum was extensively repaired during its last year of life. Drum was removed when its replacement arrived.
How Strain Gages Are Used
Strain gages are installed at strategic locations on a representative or worst case drum. Typically a hoop/axial pair are placed at a maximum diameter “peak” and a minimum diameter “valley” near the center of the coke bed. Thermocouples are also placed nearby the gages. This combination allows for better description of the membrane stress. Strain gages on the surface measure Membrane + Bending. A conservative approach is to assume all measured stress is the average membrane stress when the minimum diameter alone is measured. Measurements on the maximum diameter may include the negative component of bending and decrease the net result.

Data should be recorded for enough cycles to establish a valid statistical mean stress during quench. The data acquisition system can be unmanned, recording data to disk for subsequent replay and study. The typical stress range will be used to perform low cycle fatigue calculations for the shell and welds. If additional structural analysis of the drum is anticipated, then thermocouples can be placed from top to bottom at each horizontal seam and recorded at the same time. Experience has shown that the gages, when properly installed, can last for years and record hundreds of operating cycles.

What Strain Gage Testing Reveals
Low cycle fatigue is considered the failure mode for cyclic service coke drums. Life is based on the number of cycles of operation at specific stress ranges, not as a function of time to failure. The example in Figure 3 illustrates the three stages of fatigue failure. Continued operation beyond 95% of the cyclic life is dependent upon the inspector’s ability to find and measure the crack, and upon the successful repair of those cracks which have reached half of their critical, or final size.

For more information on the use of strain gages for structural characterization in fact-based coke drum FFS evaluations, call the SES office nearest you today.

...Or visit our web site at http://stresseng.com

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