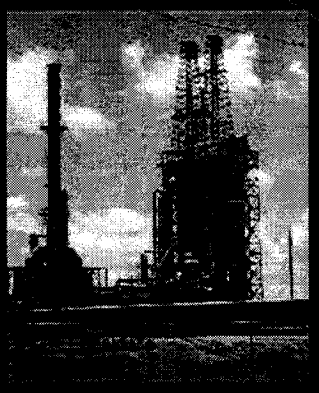
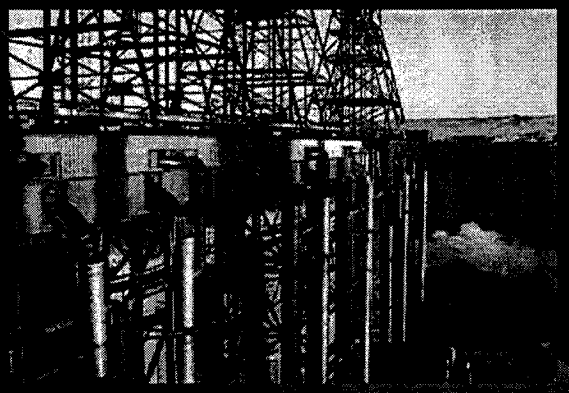
Coke Drum Health Monitoring And Reliability Improvement

Stress Engineering Services, Inc.





Stress Engineering Services

- 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 - 2nd 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

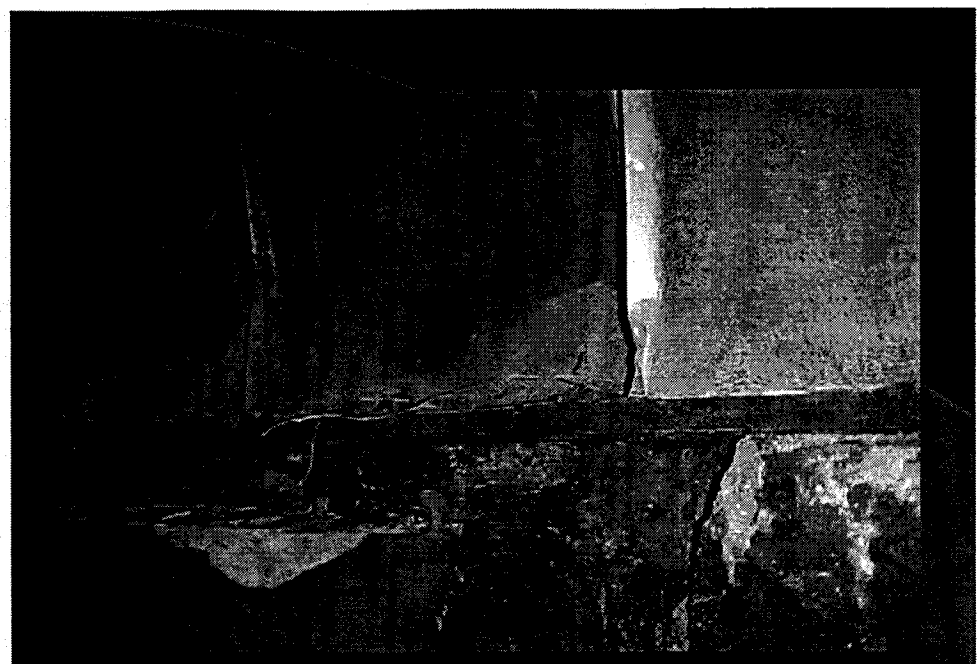
- Designed for LCF Shell & Skirt
- Designed using "actual" measured thermal transients, rates and strain ranges
- Designed for "Coke Crush" – Citgo Patent
- Conoco/Bechtel drums (3ea.) have SES Health Monitoring Systems installed
- Designed for 20-40 year life

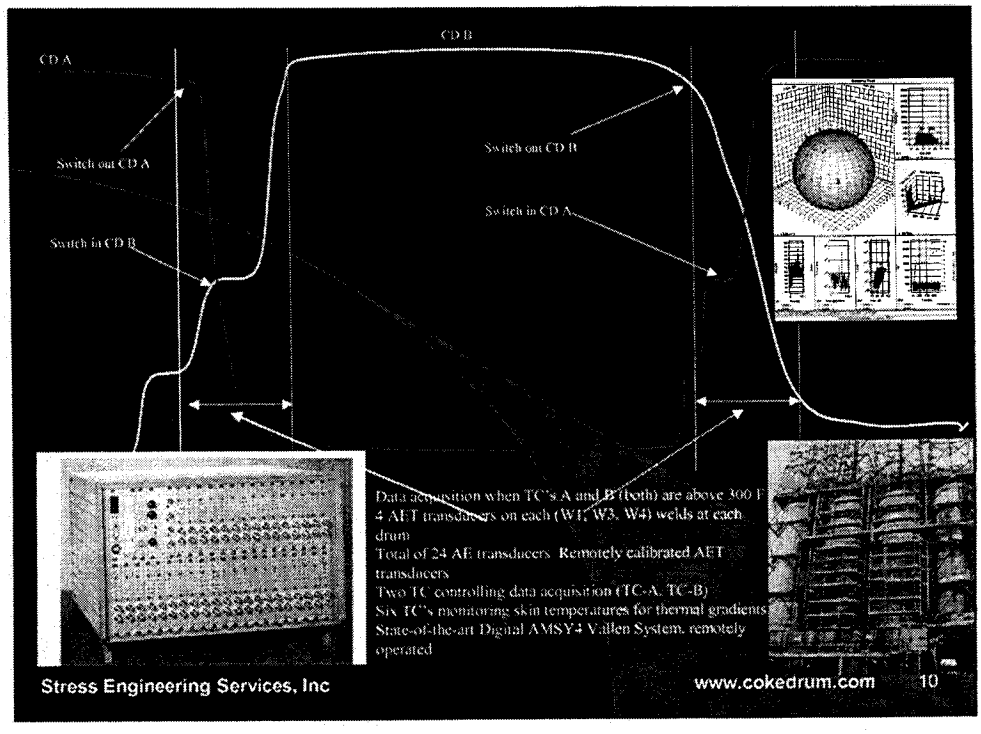
Recent SES Coke Drum Projects
Monitoring and Assessment of 1500 Cycles and 46 + Coke Drums

- 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:

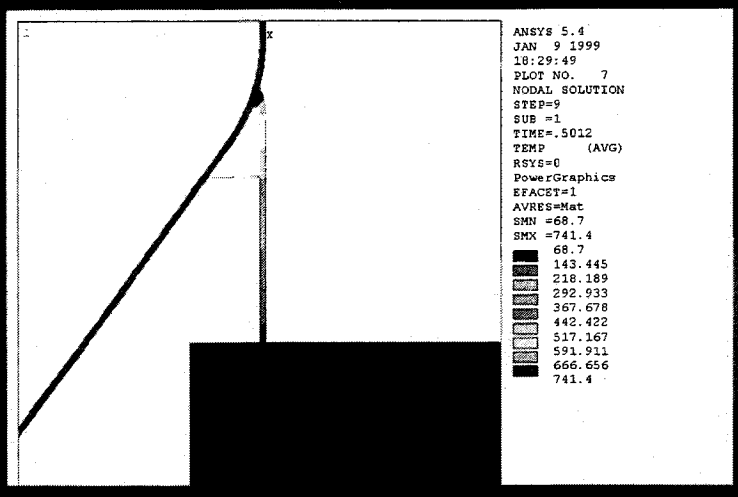
- Permanent AE monitoring to detect drum cracking
- Foundation and concrete repairs
- Operational optimization and yield increases with existing equipment through "BEST PRACTICES"
- Impact of Shorter Cycles and different feeds
- Detection of "hot drums" and drums with "water" prior to opening



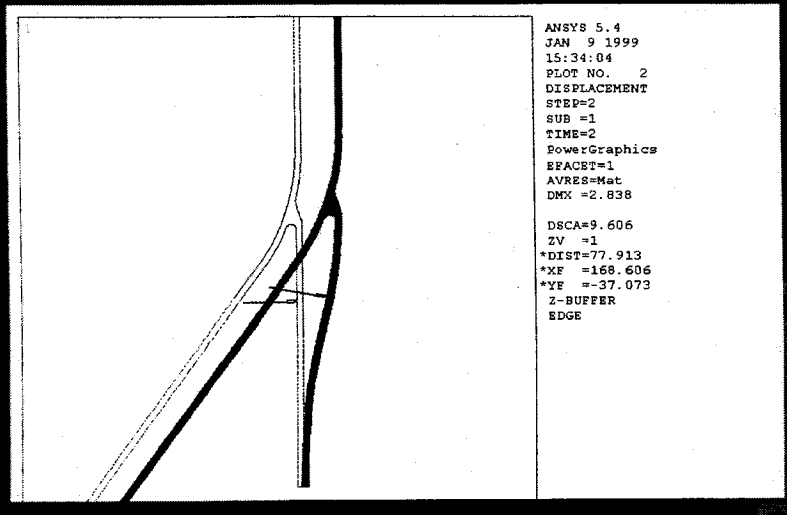


Data acquisition when TC's A and B (both) are above 300 F
4 AET transducers on each (W1, W3, W4) welds at each drum
Total of 24 AE transducers. Remotely calibrated AET transducers
Two TC controlling data acquisition (TC-A, TC-B)
Six TC's monitoring skin temperatures for thermal gradients
State-of-the-art Digital AMSY4 Vallen System, remotely operated

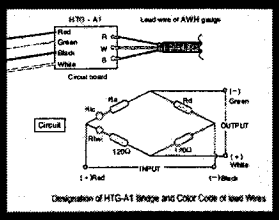
Temperature distribution soon after Switching

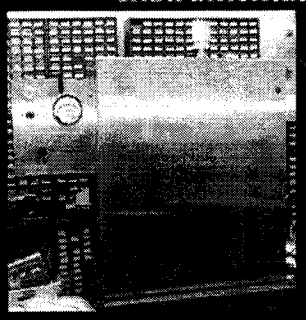


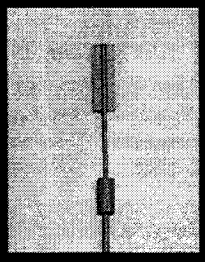
Skirt is forced outward during Fill transient

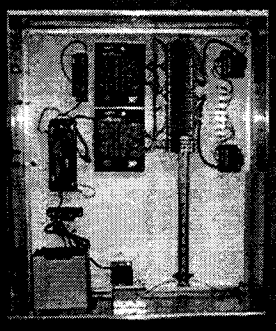


High Temperature Strain Gage with Intrinsically Safe Instrumentation







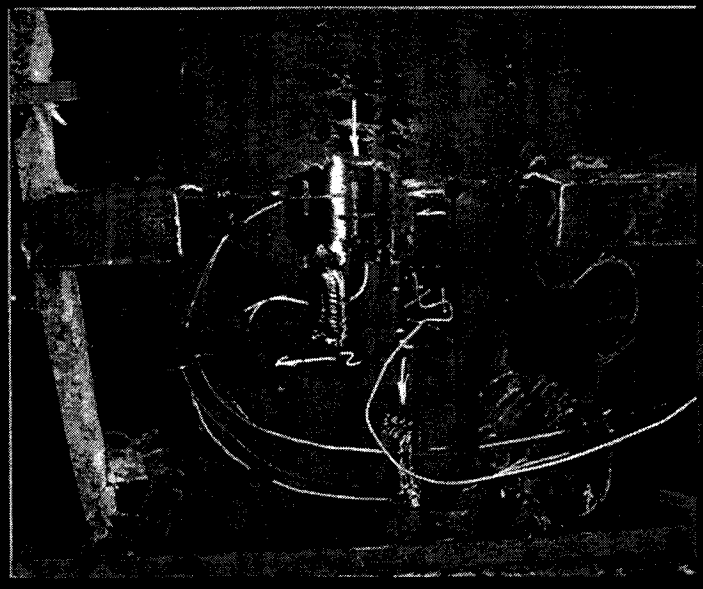


Strain Gage Locations on Shell

Loc 1 and 2

Loc 3 (and 4)

Strain Gage Locations at Skirt Attachment



Structural Health Monitoring Data Processing Tasks

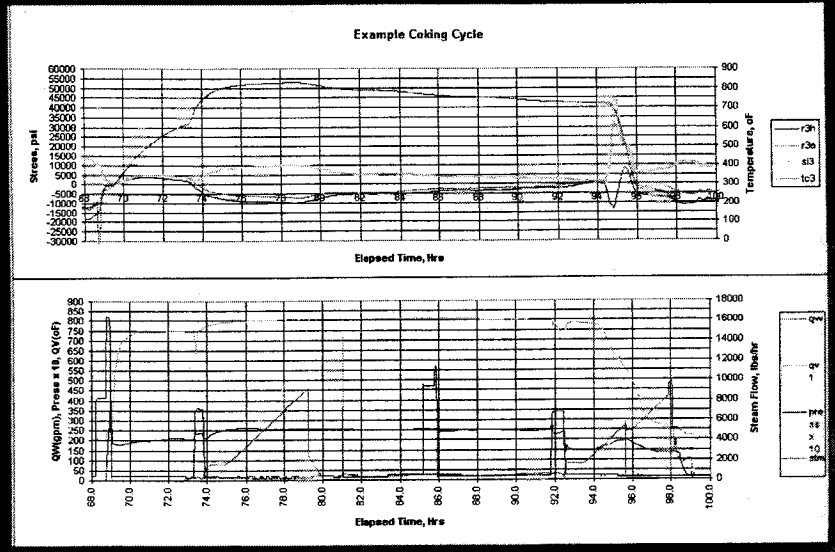
- Review Recorded Data for
  - High Temperature Strain Gages
  - Thermocouples
- Correct Readings for Temperature Error
- Calculate each pair for Bi-Axial Principal Stress and Stress Intensity
- Determine Stress Range each Cycle
- Compile Histograms and Damage Accumulation
- Evaluate Process Cause and Structural Effect
- Compare Different Operating Procedures for resulting Structural Damage

cokedrum.com

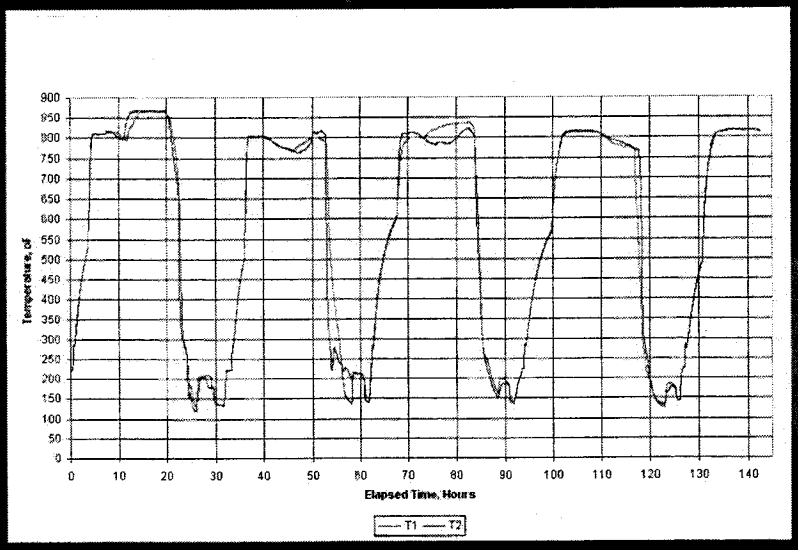
SES combines their measurement experience with the latest engineering software tools and materials engineering knowledge to provide **"Health Monitoring Technology"** for fixed equipment, this enables plant personnel to solve daily engineering problems and improve plant integrity, safety and profitability.

- I Structural Monitoring Systems Using Strain Gages
- II Defect Identification and Assessment
- III Crack Growth Prediction
- IV Bulge Analysis
- V Drum Design and Modeling Using Actual Operating Transients
- VI Life Assessment and Extension Recommendations
- VII Metallurgical Consulting and Testing
- VIII Heater Condition and Life Assessment
- IX Root Cause Failure Analysis
- X Forensic and Litigation Support

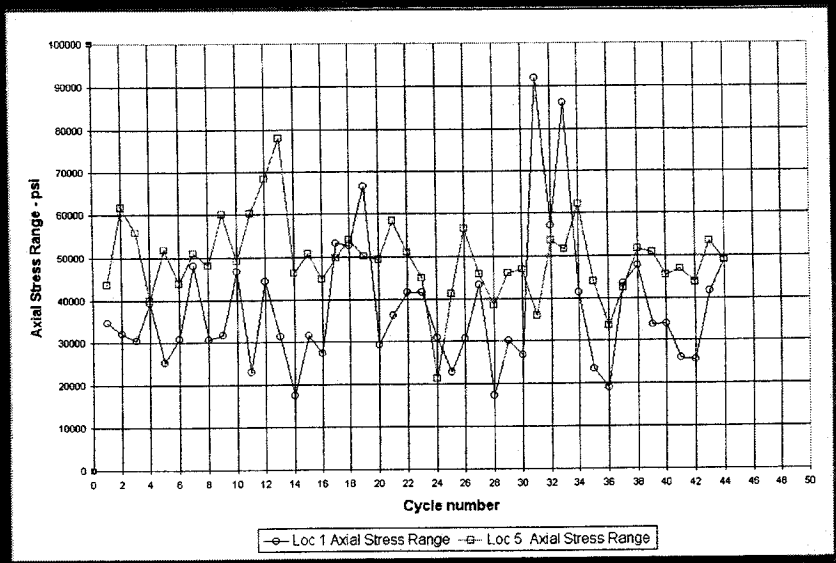
Typical Coking Cycle for Process and Stress



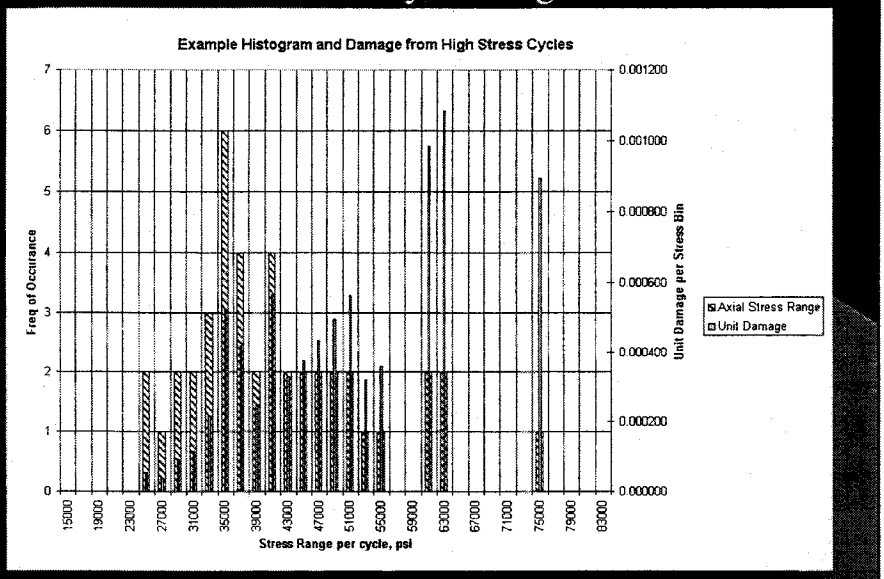
Typical Cycle Differences



Stress Range Plot for each Cycle



Histogram of Stress Ranges and Damage for Low Cycle Fatigue



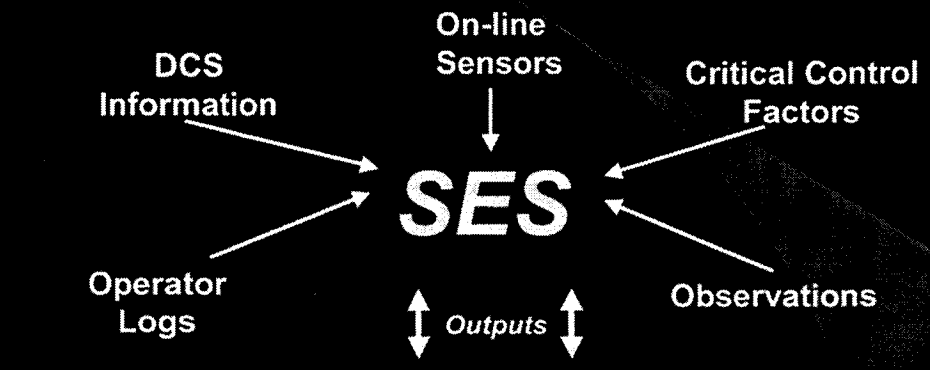
Calculation of Fatigue Damage for each Stress Component and Determine Cycle Life

Summary of Stress Range, Allowed Cycles, and Fatigue Damage

Stress Engineering Services

					Unit Damage 0.000217
Temp oF =	425				Cycles
E=	28.625				4,609
Location 3		Axial Stress Range			
		n	N		n/N
Stress	*Strain*	*Frequency*	*Cycles*		*Damage*
15000	524	1	*244249*		0.000004
17000	594	0	*150469*		0.000000
19000	664	1	*99360*		0.000010
21000	734	0	*68529*		0.000000
23000	803	4	*49481*		0.000081
25000	873	1	*36680*		0.000027
27000	943	7	*27909*		0.000251
29000	1013	0	*21721*		0.000000
31000	1083	3	*17242*		0.000174
33000	1153	3	*13927*		0.000215
35000	1223	1	*11425*		0.000088
37000	1293	2	*9503*		0.000210
39000	1362	2	***8228***		0.000243
41000	1432	3	***7090***		0.000423
43000	1502	1	***6112***		0.000164

Integration With SES "DrumBeat" Analysis



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

Stress Engineering Services, Inc
13800 Westfair East
Houston, Texas 77041
281-955-2900
www.stress.com
www.cokedrum.com

STRESS ENGINEERING SERVICES, INC.

Houston 281-955-2900 • **Cincinnati** 513-336-6701 • **New Orleans** 504-828-4066

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.

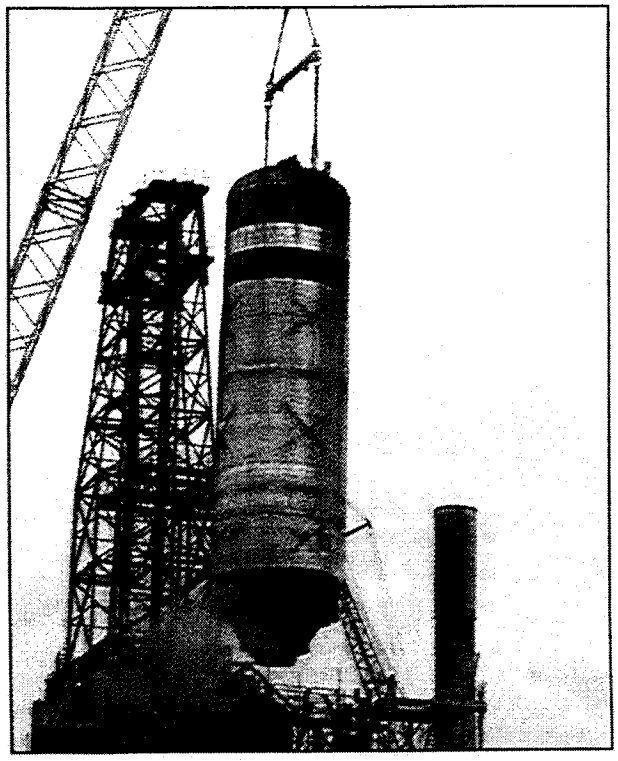


Figure 1. This coke drum was extensively repaired during its last year of life. Drum was removed when its replacement arrived.

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

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.

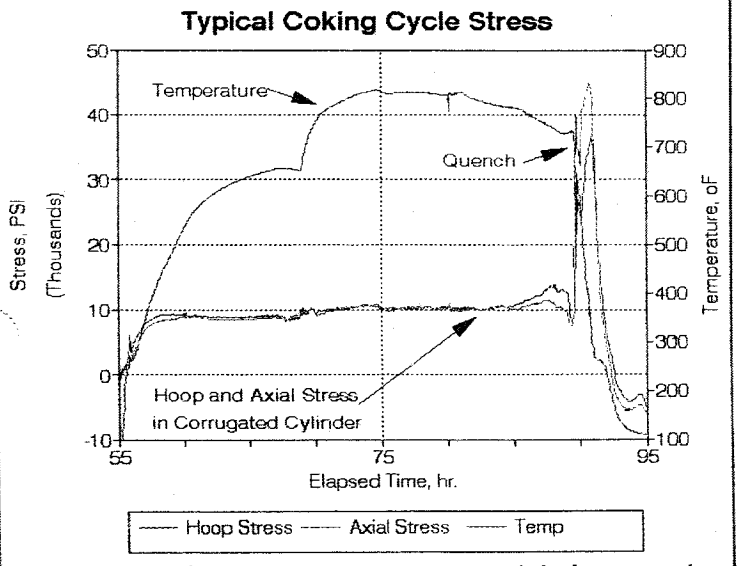


Figure 2. Large stresses are generated during quench. A typical coking cycle is shown.

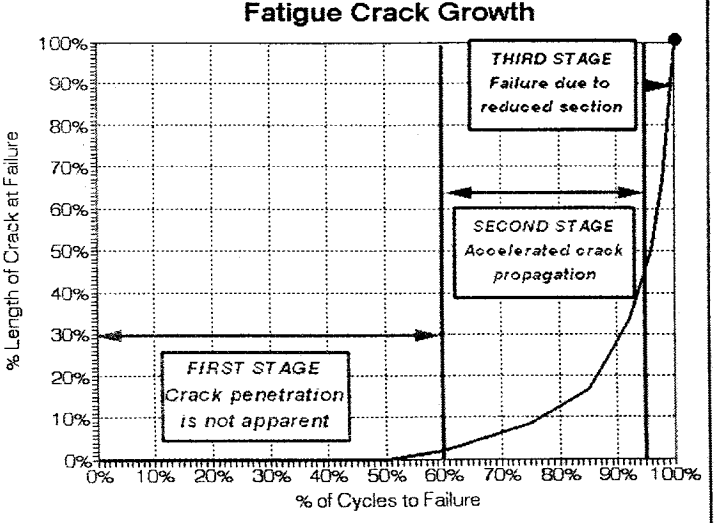


Figure 3. Three stages of Fatigue Crack Growth. Operation beyond 85% cyclic life or 50% of critical length requires diligent inspection and repair.

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 inspectors 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

Houston 281-955-2900 • **Cincinnati** 513-336-6701 • **New Orleans** 504-828-4066