Vibration Testing and Troubleshooting of Coke Drums

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OVERVIEW

• Vibrations Basics
• Drum Dynamics
• What is Affected
• Potential Consequences
• Case study
VIBRATIONS BASICS

- Response of a flexible structure to excitation (fluid flow, pressure pulsations, sloshing, etc.)

- Components
  - Mass (inertia)
  - Spring stiffness (Force–Displacement)
  - Dashpot viscous damping (Force–Velocity)

- Basic characteristics:
  - Natural frequency (or frequencies)
  - Mode shapes

- Input – output
  - Force
  - Displacement
WHAT IS AFFECTED

- Pipes and pipe supports
- Base-plate bolts and grout
- Non-structural (stairs, lights, guardrails, ..)
- Machinery (elevator, pumps, ..)
- Superstructure (concrete and steel)
- Foundation system (substructure and soil)

- Humans!
POTENTIAL CONSEQUENCES

- Operator discomfort or fatigue
- Poor performance
- Acceleration of corrosion damage
- Interruption of operations during repairs
- Fatigue cracks (leaks/ fires)
- Bodily injuries
WHAT TO DO?

• **Measure**
  • Vibrations
  • Strain
  • Process variables

• **Analyze**
  • Stress / fatigue
  • Human tolerance

• **Mitigate**
  • Process
  • Structure
CASE STUDY - 1

- Two-drum unit
- “Significant” vibrations in structure
- Conflicting views on
  - When they vibrate the most
  - Which one vibrates more
- Failures
  - Piping supports
  - Anchor bolts
  - Base plate grout
- Is the unit safe?
- Can the process be optimized to minimize vibrations?

- 16 feet in diameter - relatively small for the mid 80’s
- 76 feet in height - average to tall
- Slender drums
- Very common 1 ¼ Cr - 1/2Mo material
- 17 hour fill cycle - average to relatively slow operation
OBJECTIVES

• Monitor vibrations in the drums, piping, and structure.
• Obtain synchronized temperature and strain measurements.
• Determine the timing and characteristics of maximum vibrations.
• Determine severity of dynamic stresses and potential for fatigue damage in the structure.
• Conduct sensitivity analysis of vibrations versus process variables.
PROCEDURE

• Installed 33 sensors and two data acquisition systems on the drums, piping, and structure.
• Monitored the unit for a period of 20 days (14 cycles)
• Processed and analyzed the data in time and frequency domain.
• Analyzed the correlation between key process variables with vibration, strain, and temperature measurements.
INSTRUMENTATION

Vibration data acquisition system
  16 channel unit
  16 seismic accelerometers @ 102 samples per second
  2 strain gages (low-speed DC channels)

Temperature data acquisition system
  StrainDAQ unit
  16 thermocouples
  1 sample per two seconds

Data collection was continuous without interruption during the entire monitoring period.
Sensor Layout

[Diagram showing a sensor layout with labels for Thermocouple, Accelerometer block, and strain gage.]
Example Quench Transient
Integrated Displacement Data

TIME FROM START OF CYCLE 9 (SEC)

DISPLACEMENT (IN)

Drum B - West Dir. (in)
Drum B - North Dir. (in)
Drum B - Down Dir. (in)

Large Transient Displacement
Vibration Versus Flow Rate

- DRUM B PIPE
- DRUM A PIPE
- DRUM A
- DRUM B
- STRUCTURE
- DRUM B ONLINE

Vibration in Inches RMS

Maximum Values (GPM)
Strain Gauge Data
CASE-1 SUMMARY

• Drum vibration magnitude was maximum during the quench part of the cycle in the East-West direction.
• The two drums vibrated in a comparable manner both from magnitude and frequency standpoints.
• The maximum recorded peak displacements were 0.58, 0.35, and 0.23 inches for the drums, the piping, and the structure, respectively.
• Measured dynamic strains in the structure were below the fatigue-inducing levels.
• The correlation between vibration levels and recorded process parameters was established.
CASE STUDY -2

• Four-drum unit.
• Blow-down line.
• Cracks and leaks.
• Angled-tee joint.
• Thermal cycles.
• 3D loads.
• Vibrations.
• Why?
• How to fix it?
ACTION PLAN

1. Instrumentation
   - Strain gages
   - Thermocouples
2. Extraction of loading conditions
3. Finite element analysis
4. Fatigue Assessment
INSTRUMENTATION

Intrinsically Safe Instrumentation System
FIELD MONITORING
TEMPERATURE MEASUREMENTS
THERMAL GRADIENTS

Every forth cycle

TC 1, 3 on Bottom of Line
TC 2, 4 on Top of Line
TC 1, 2 on left of Tee
TC 3, 4 on right of Tee
CLOSEUP

TC 1, 3 on Bottom of Line
TC 2, 4 on Top of Line
TC 1, 2 on left of Tee
TC 3, 4 on right of Tee

Temperature, °F

Elapsed Time, mins
PAD THERMAL GRADIENTS

TC 2 on Top of Line
TC 11 12 13 on pad
TC 14 on line next to pad

Temperature, °F

Elapsed Time, mins

26
Extracted load cases

Five thermal profiles during the coking cycle
Thermal Load Case
Von Mises Stress in the pipe

outside

inside
Von Mises Stress inside the pad

outside

inside
Fatigue Assessment

• Maximum thermal stress range is 92 ksi.
• Alternate stress is 49.8 ksi.
• Correction for E at 400°F
• Fatigue life is 4,441 cycles.
CASE-2 SUMMARY

• Vibrations and pressure are not the main problem.

• The failure is caused by severe thermal transients that generate 92 ksi stress range in the pipe at the location of cracks.

• Recommendations to minimize stresses and increase fatigue life:
  • Redesigned integral fitting.
  • Fatigue-resistant welds.
Questions?

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