Vibration Testing and Troubleshooting of Coke Drums

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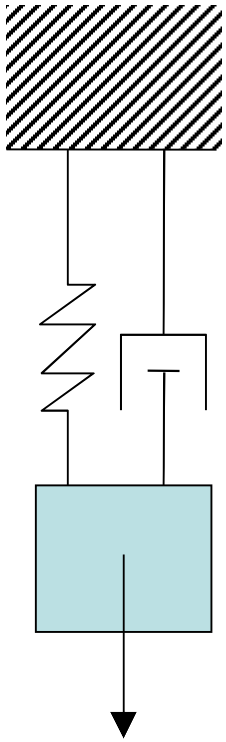
OVERVIEW

- 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



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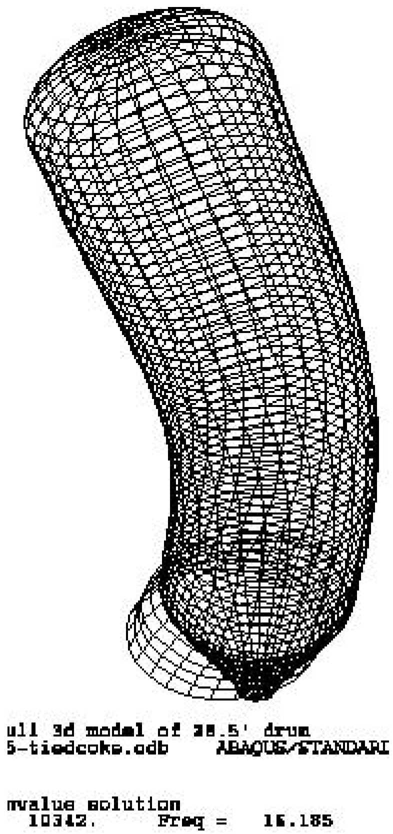
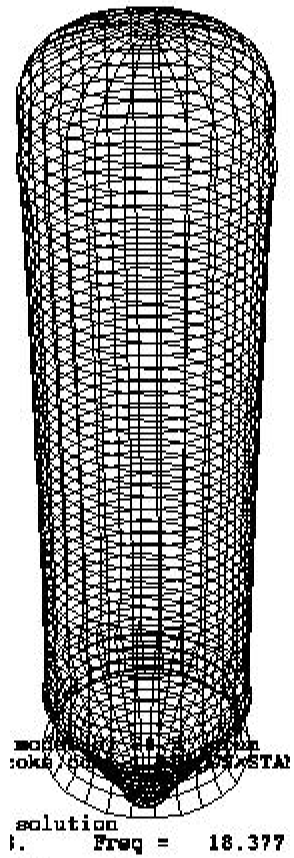
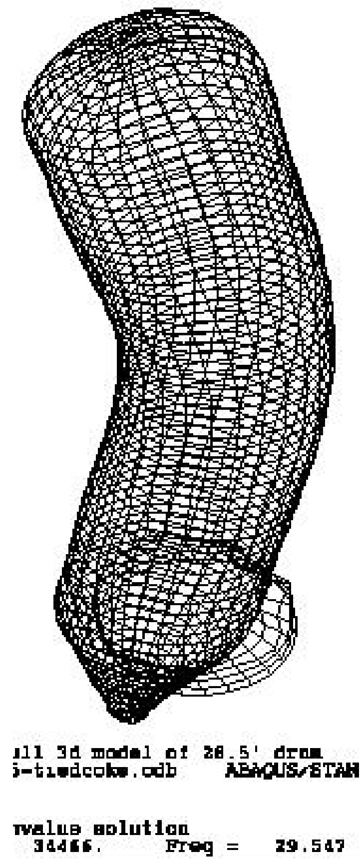
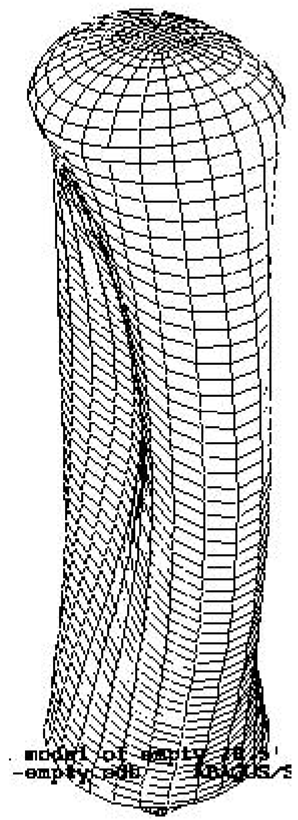
DRUM DYNAMICS









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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?

DRUM DESIGN AND OPERATION

1996 API Coke Drum Survey, 2003

- 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.

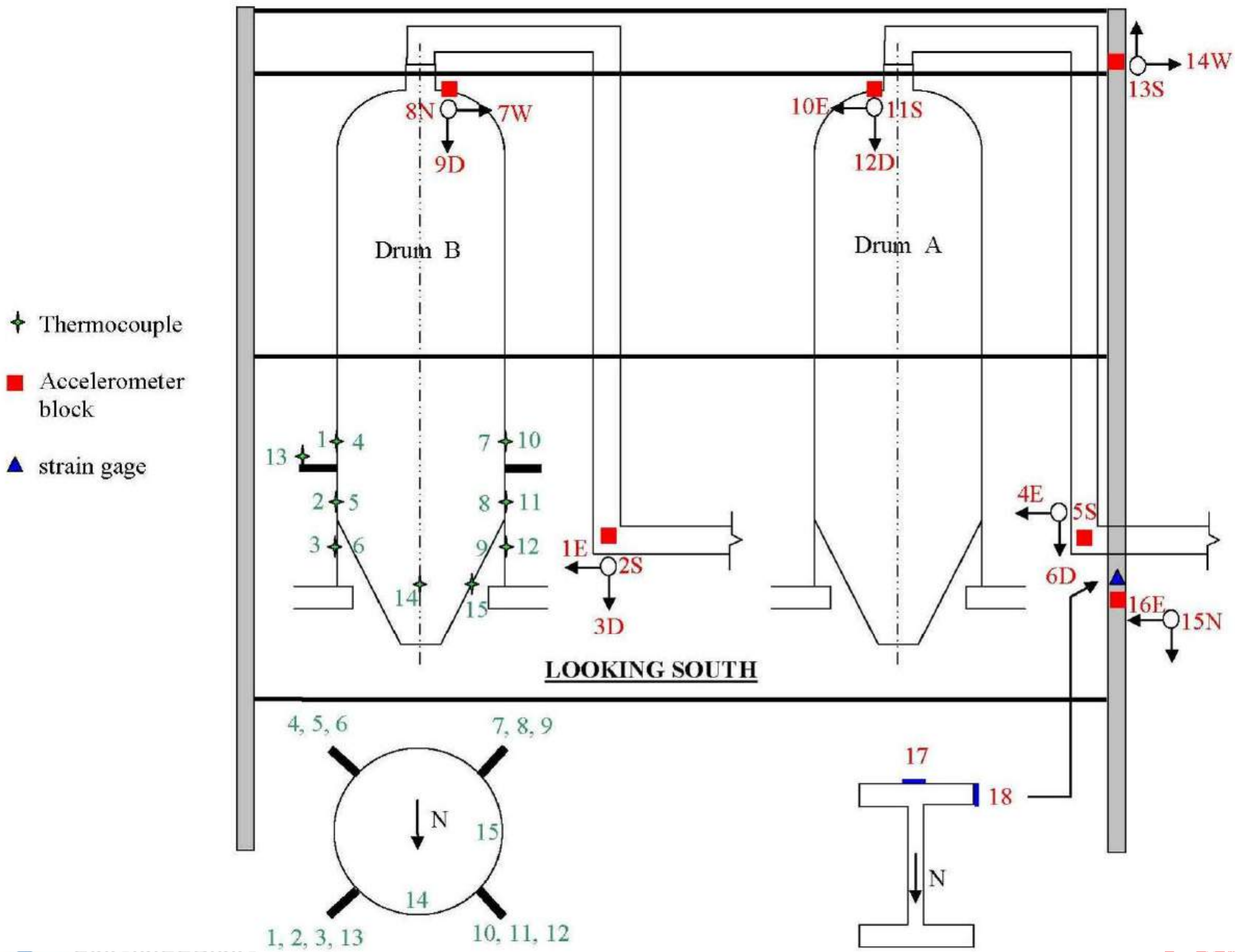
PROCEDURE

- 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

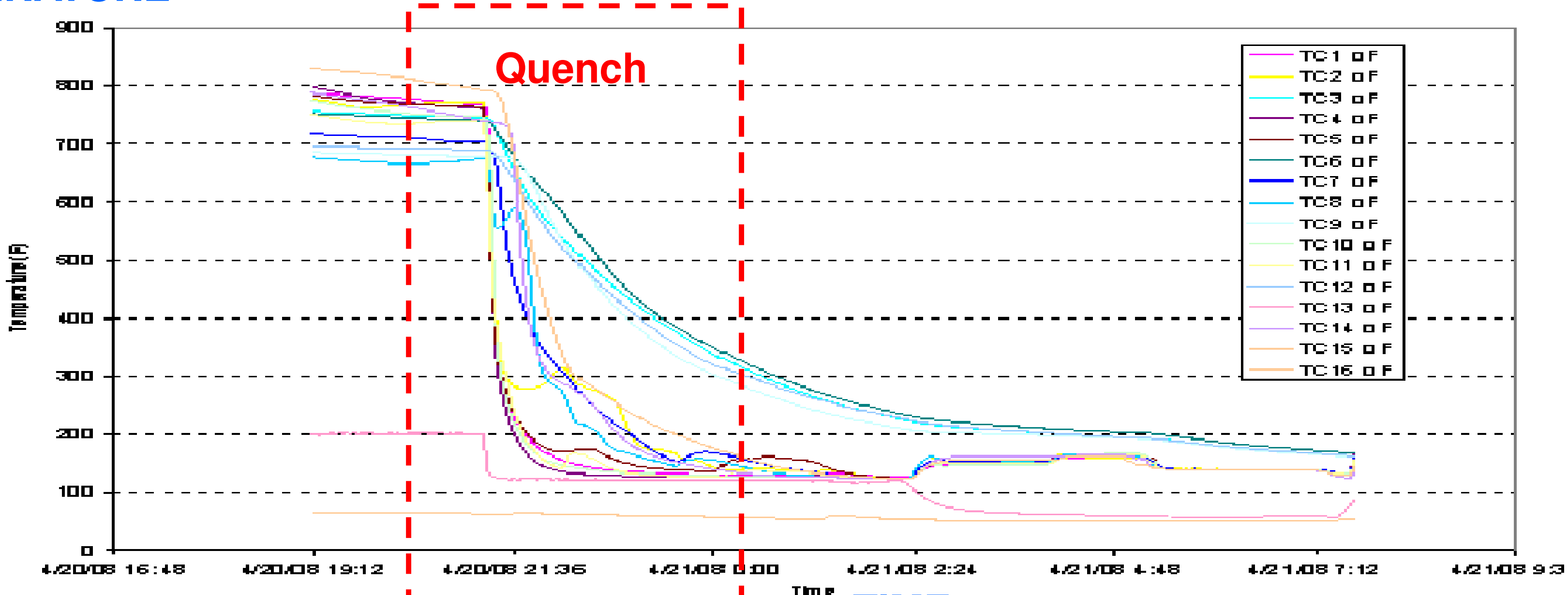
- Vibration data acquisition system
  - 16 channel unit
  - 16 seismic accelerometers @ 102 samples per second
  - 2 strain gages (low-speed DC channels)
- Temperature data acquisition system
  - StrainDAQ unit
  - 16 thermocouples
  - 1 sample per two seconds
- Data collection was continuous without interruption during the entire monitoring period.

Sensor Layout



Example Quench Transient

TEMPERATURE



TIME

ACCELERATION

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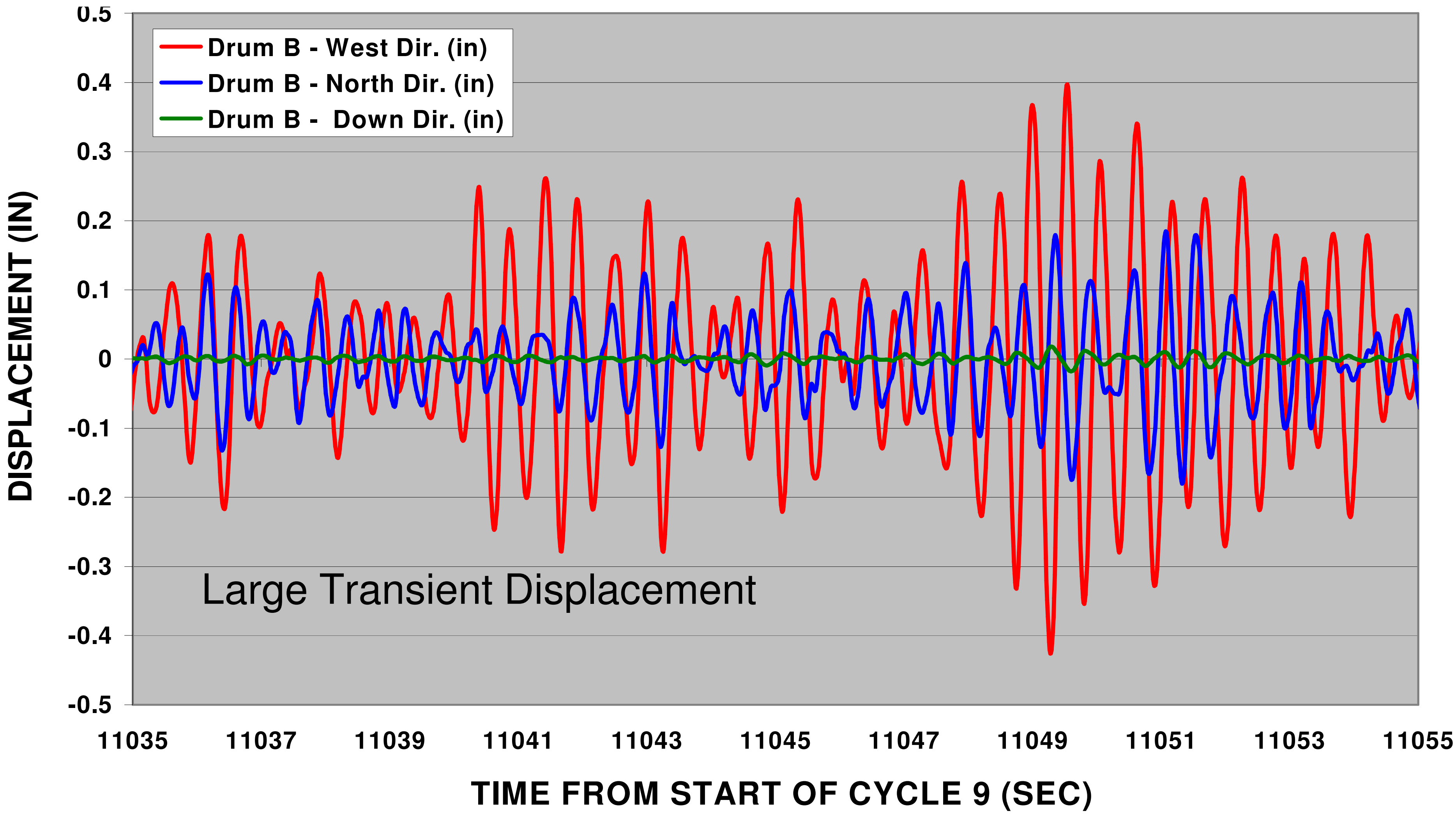
Integrated Displacement Data



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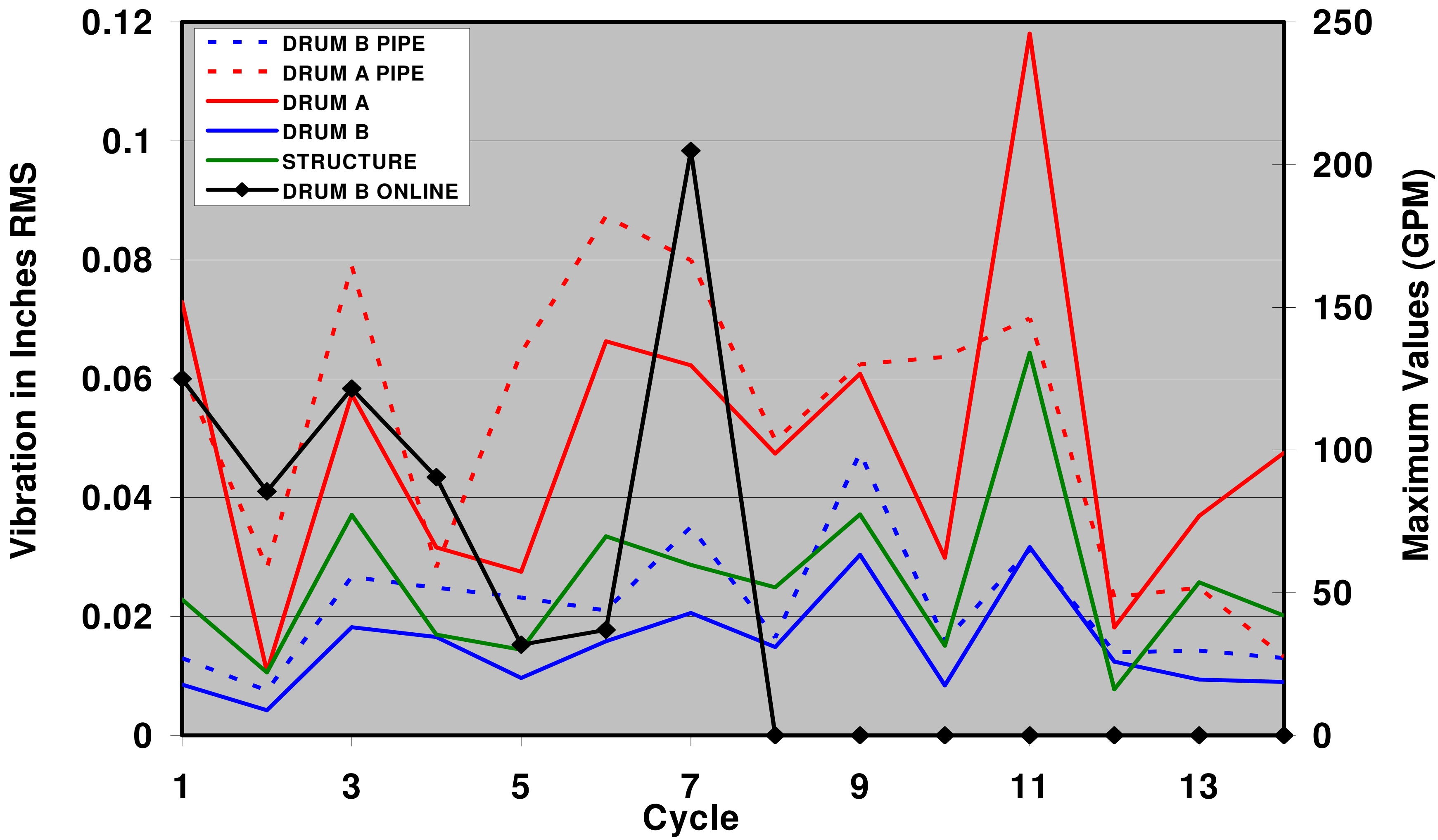
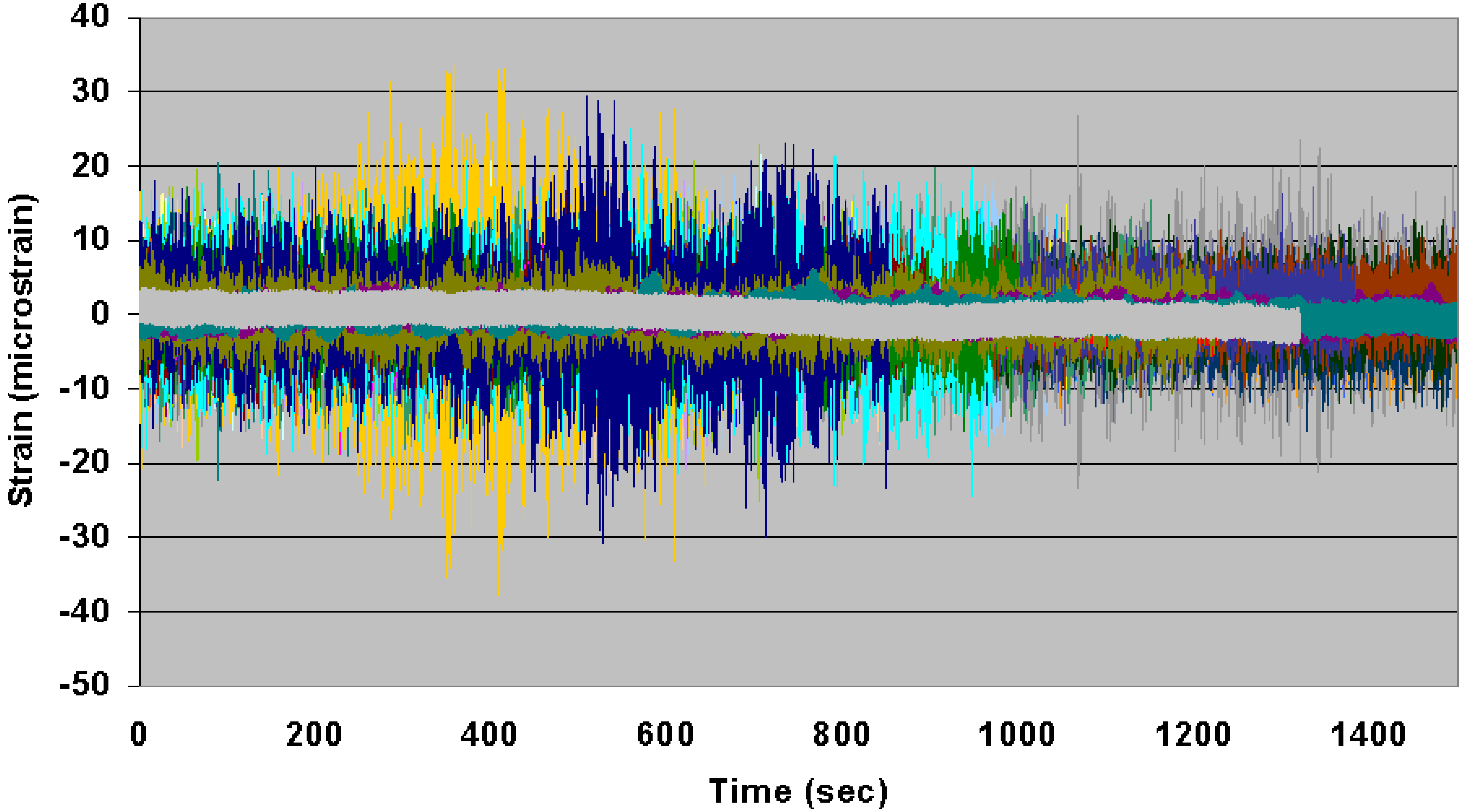
Vibration Versus Flow Rate



Strain Gauge Data

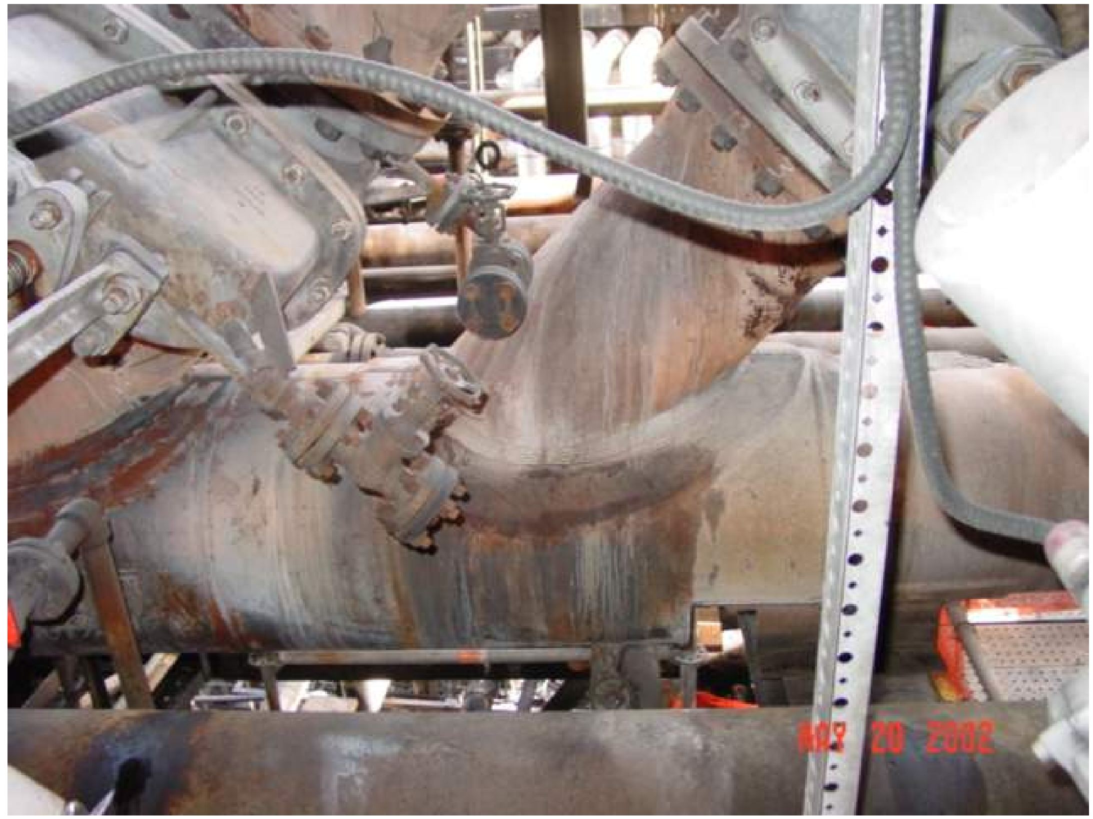


CASE-1 SUMMARY

- 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

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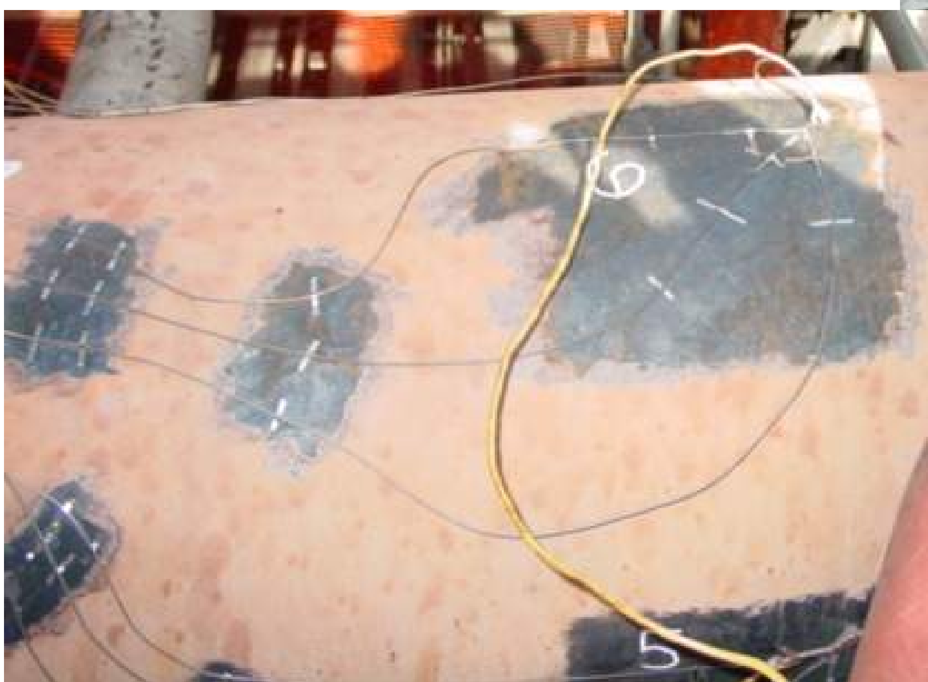
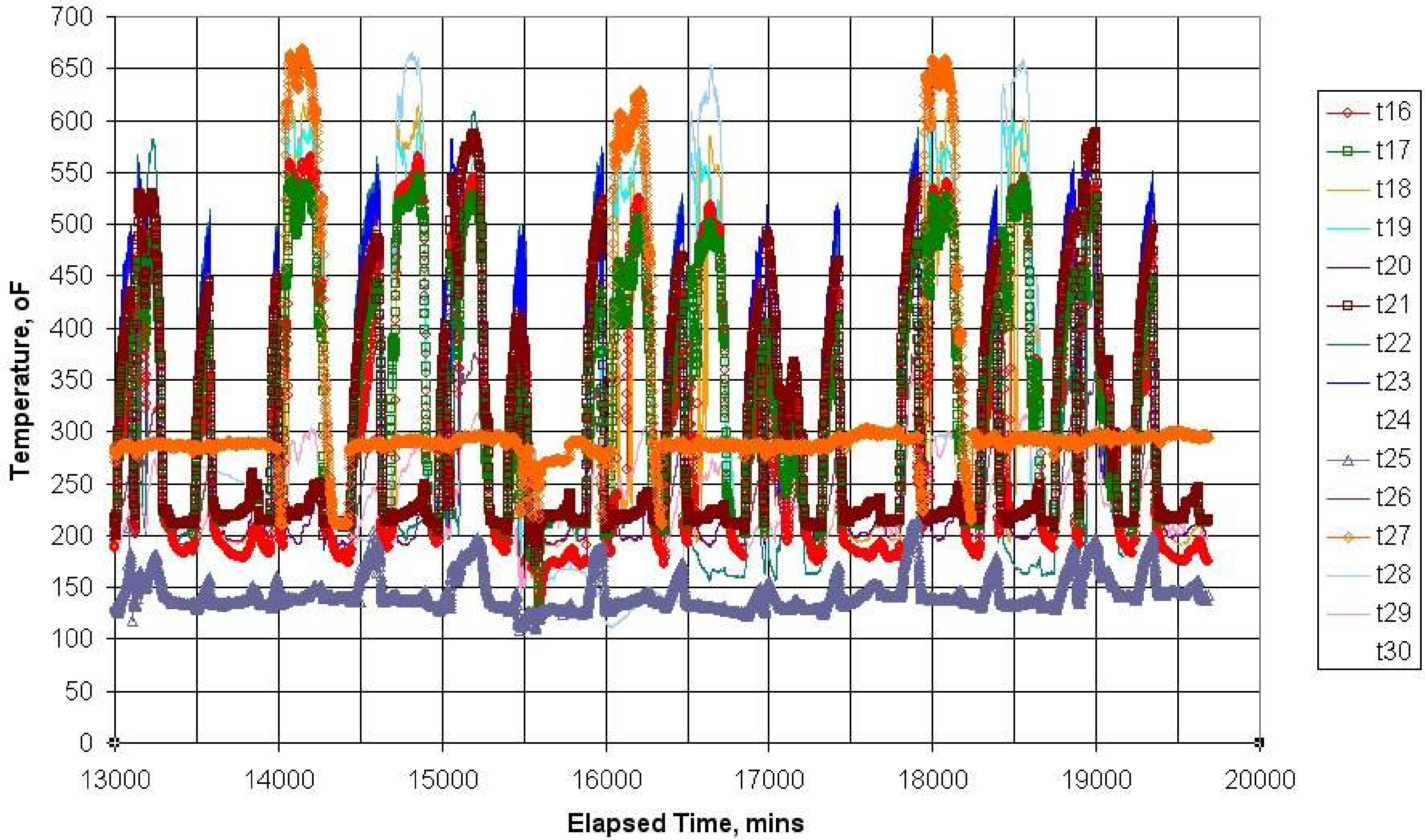
INSTRUMENTATION

Intrinsically Safe Instrumentation System

FIELD MONITORING



TEMPERATURE MEASUREMENTS



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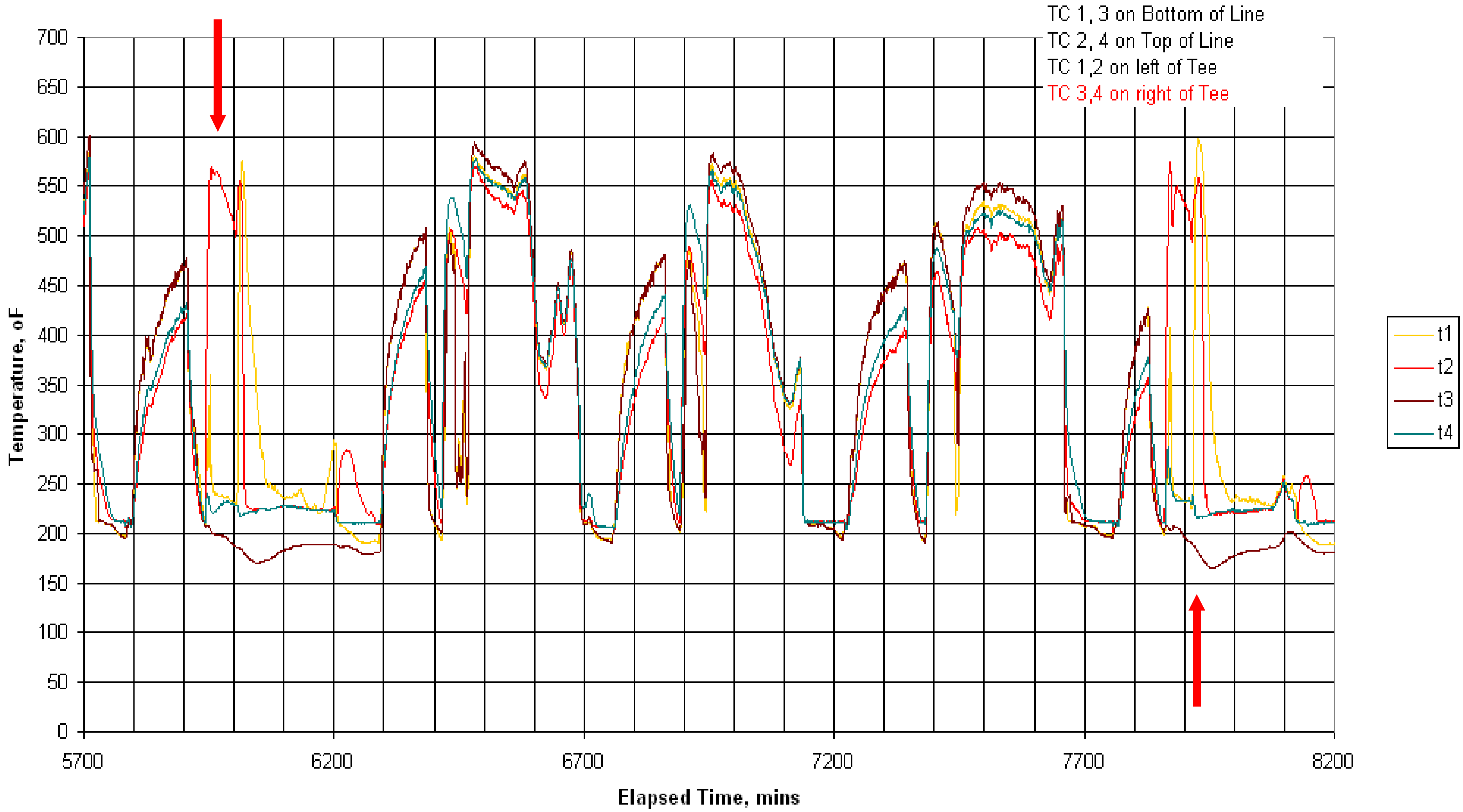
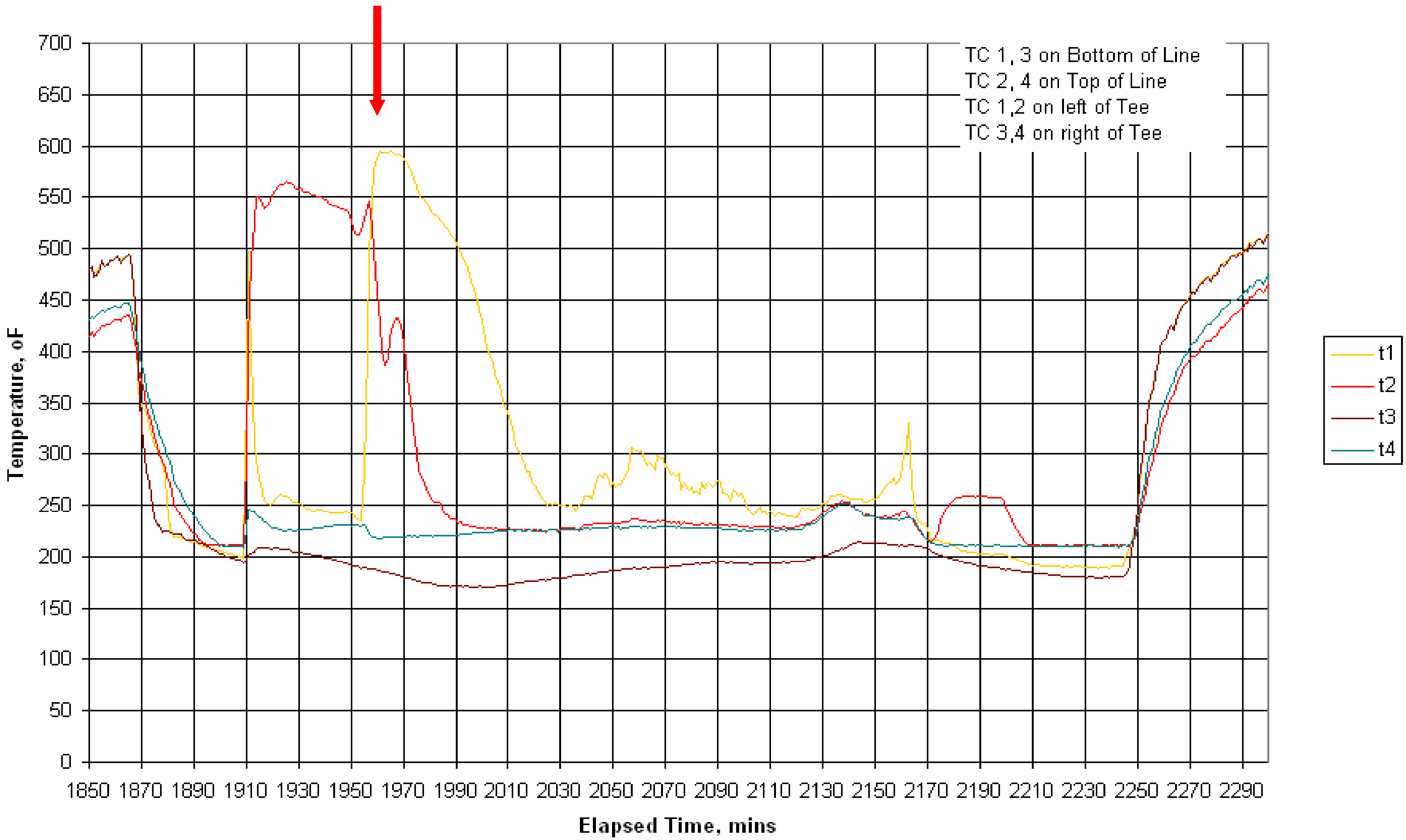
THERMAL GRADIENTS

Every forth cycle



CLOSEUP



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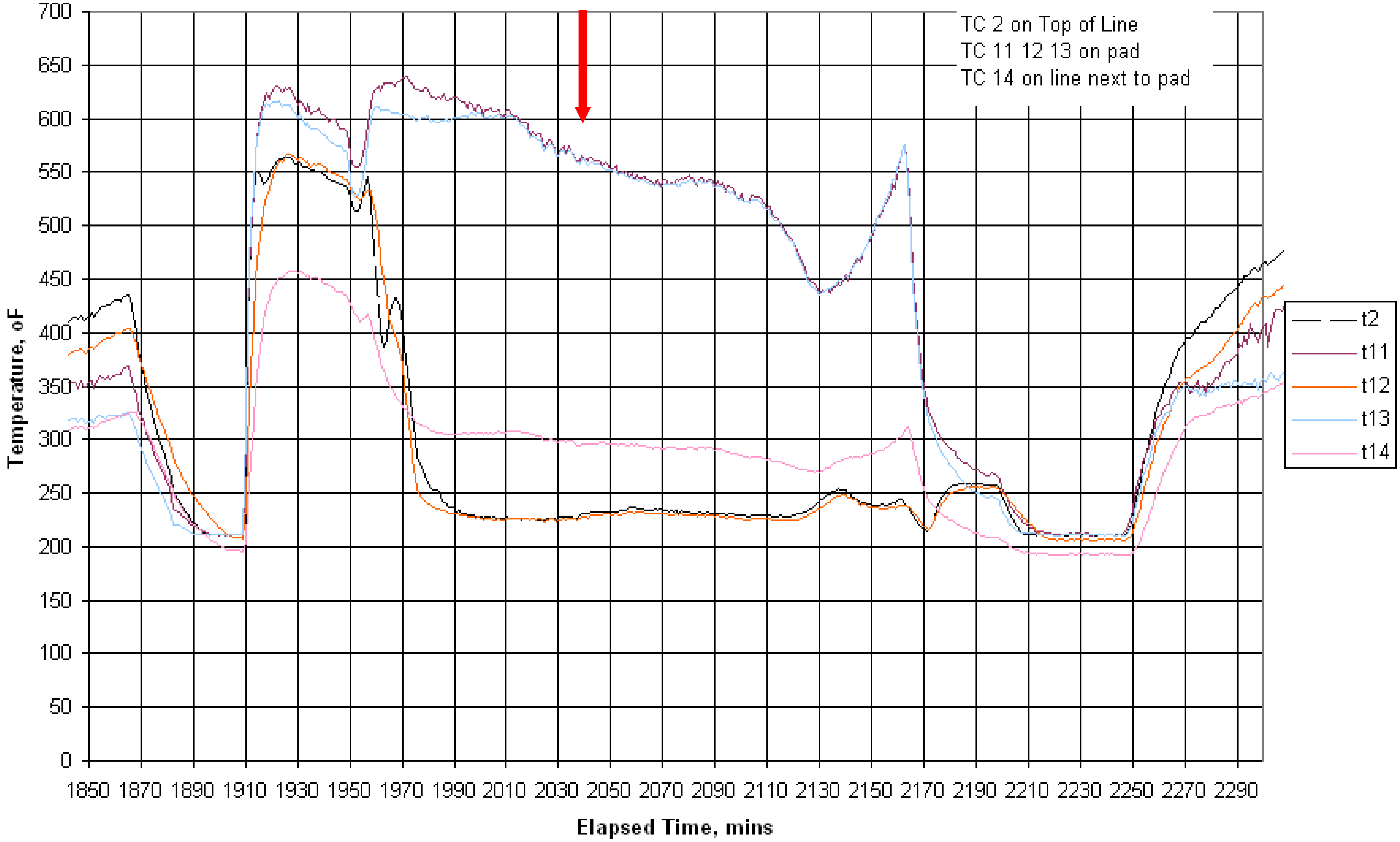
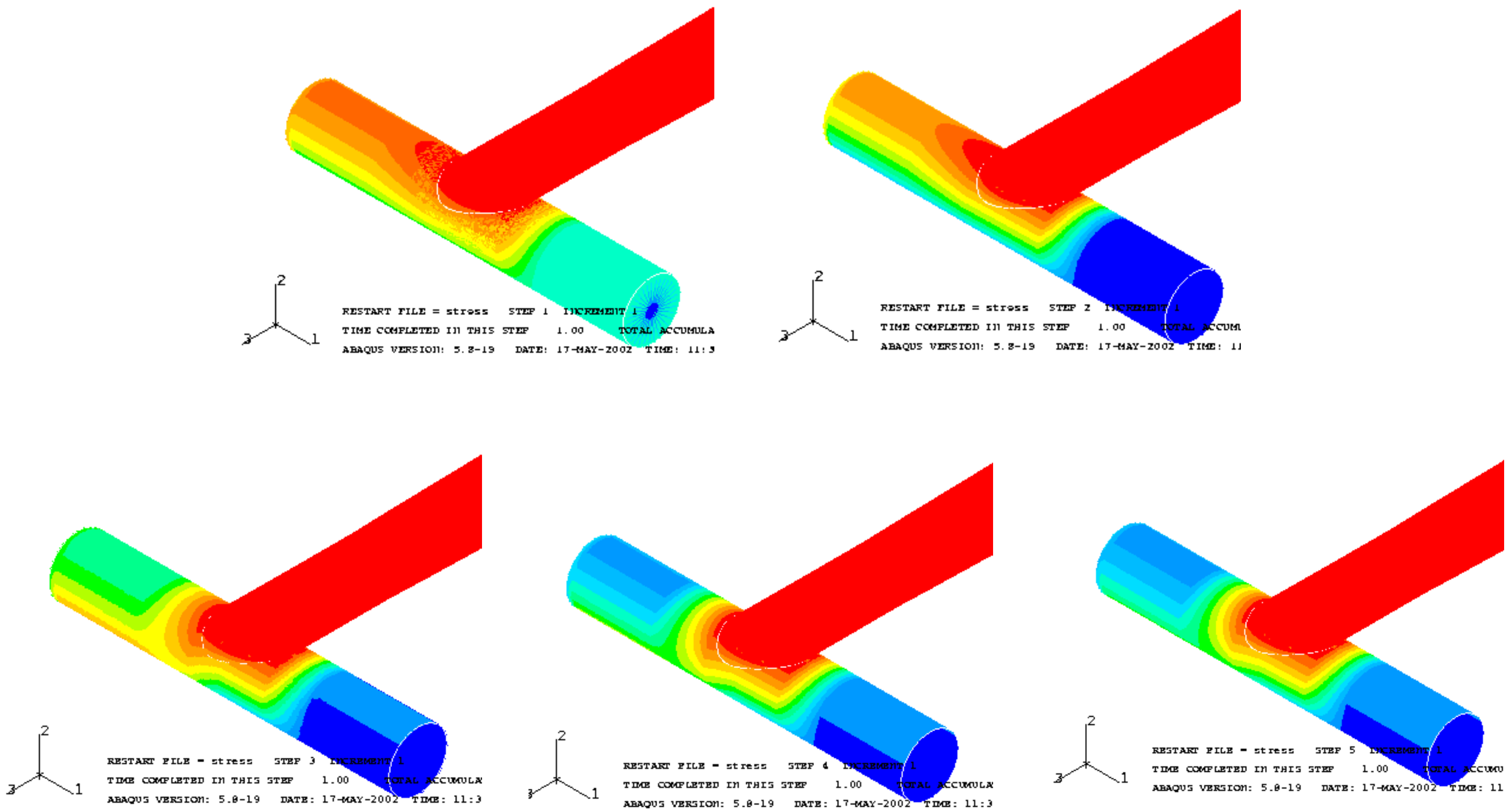
PAD THERMAL GRADIENTS

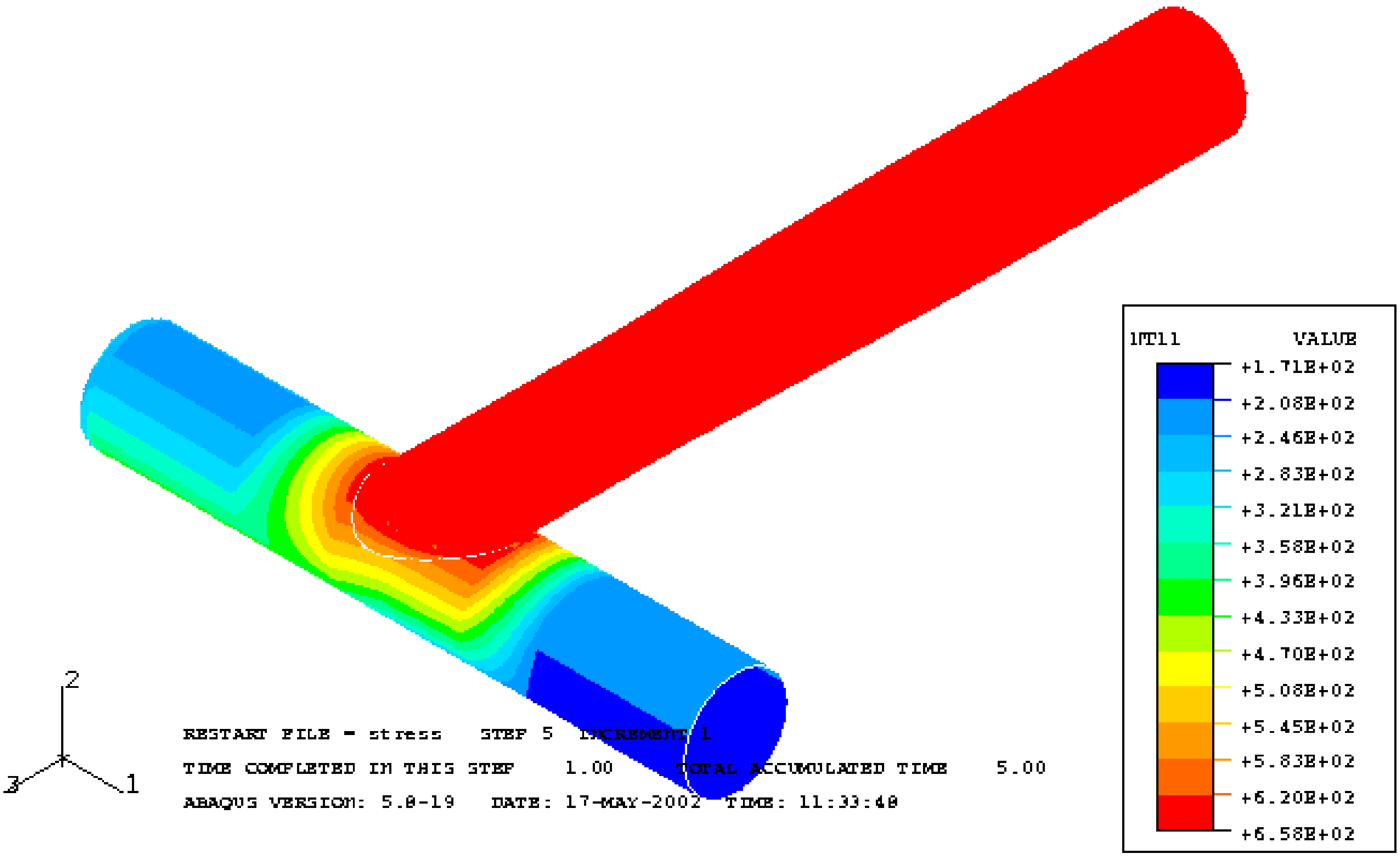


Extracted load cases

Five thermal profiles during the coking cycle



Thermal Load Case



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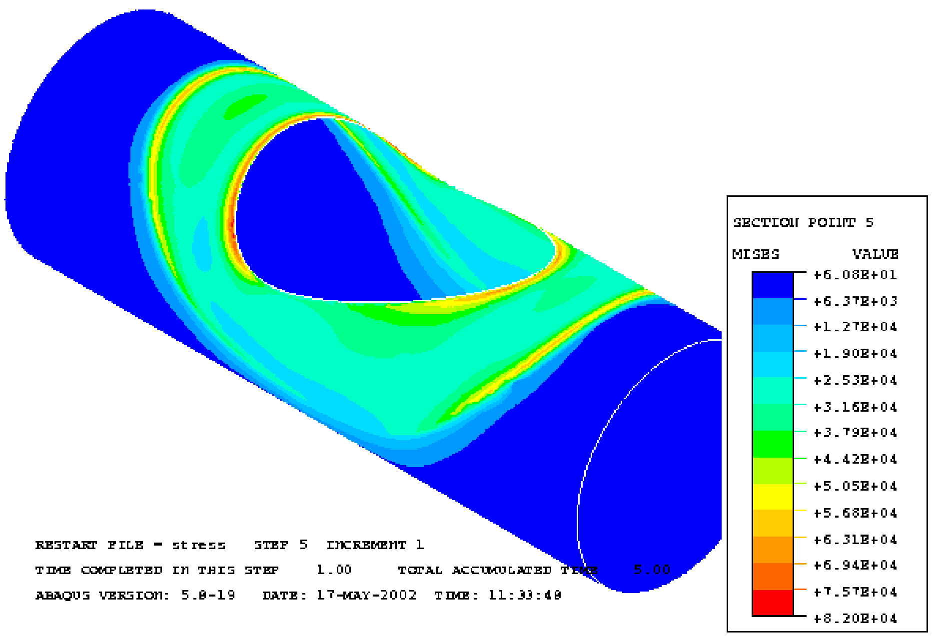
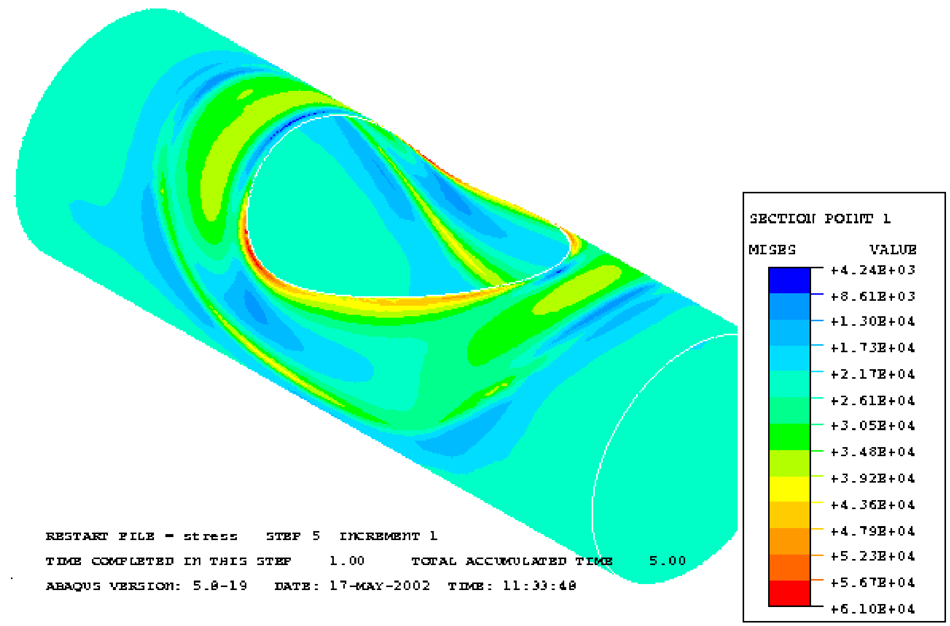
Von Mises Stress in the pipe

outside

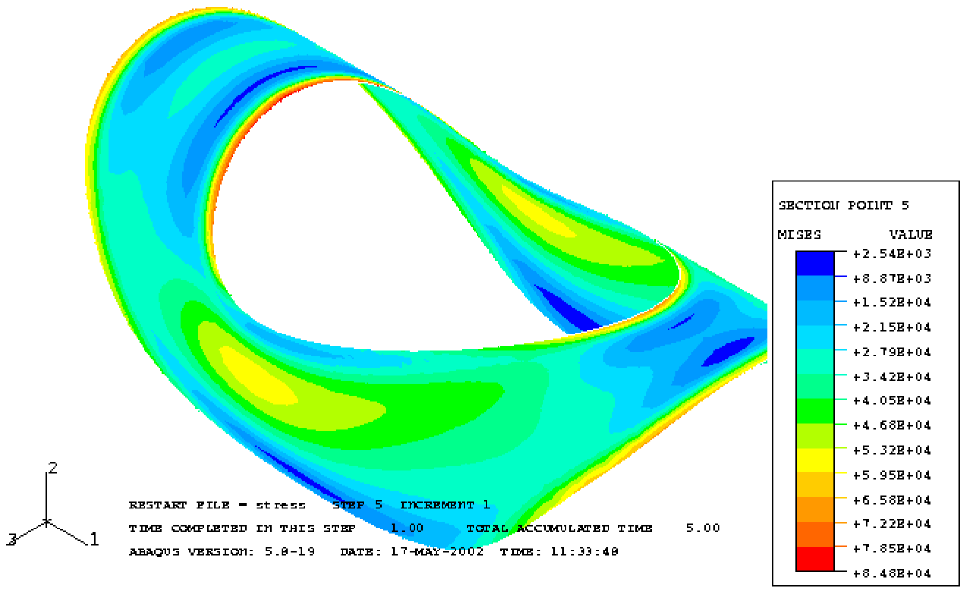


inside

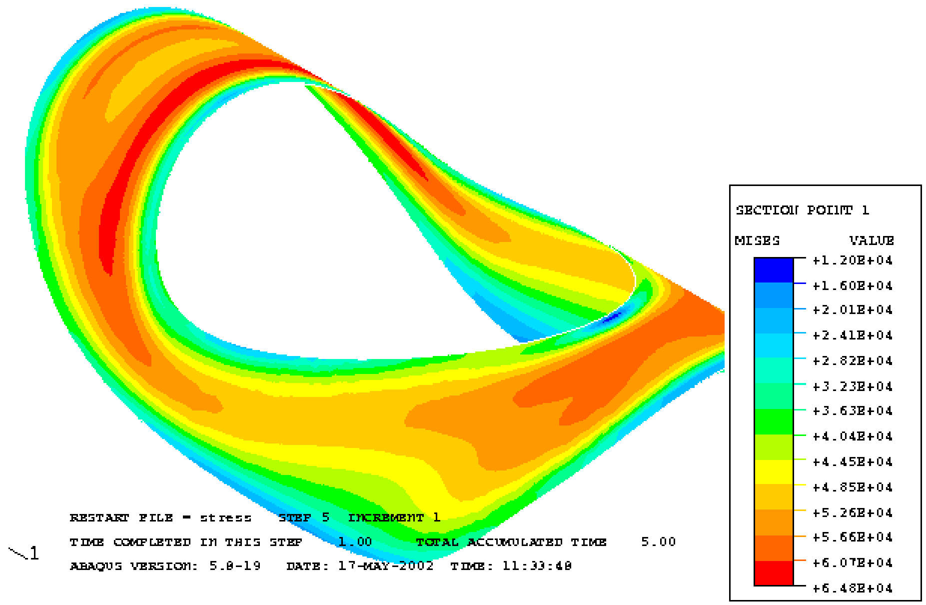


Von Mises Stress inside the pad

outside



inside



Fatigue Assessment

- Maximum thermal stress range is 92 ksi.
- Alternate stress is 49.8 ksi.
- Correction for E at 400^0F
- 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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