# Root Cause Analysis:
# Improving Performance for Bottom-Line Results

## Case History #6

Weyerhaeuser Company
Valliant, OK

## Undesirable Event

Catastrophic Failure of the Thermo Compressor Cone
for the # 3 Paper Machine

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# Case History #6: Weyerhaeuser Company

Valliant, Ok.

**UNDERSIRABLE EVENT:** Catastrophic Failure of the Thermo Compressor Cone for the Number 3 paper Machine.

**UNDESIRABLE EVENT SUMMARY:** New equipment for Paper Machine Number 3 was started up on March 1, 2000. After about two months service a crack developed around the gauge port of the Thermo Compressor propagating longitudinally from the toe of the fillet weld, around the gauge port, into the base material of the Thermo Compressor (Figure 12.12).


**Figure 12.12:** Crack Origin

The Thermo Compressor was replaced with a like component. After two days service, a leak developed at the longitudinal weld seam similar to the initial failure of the original Thermo Compressor (Figure 12.13).

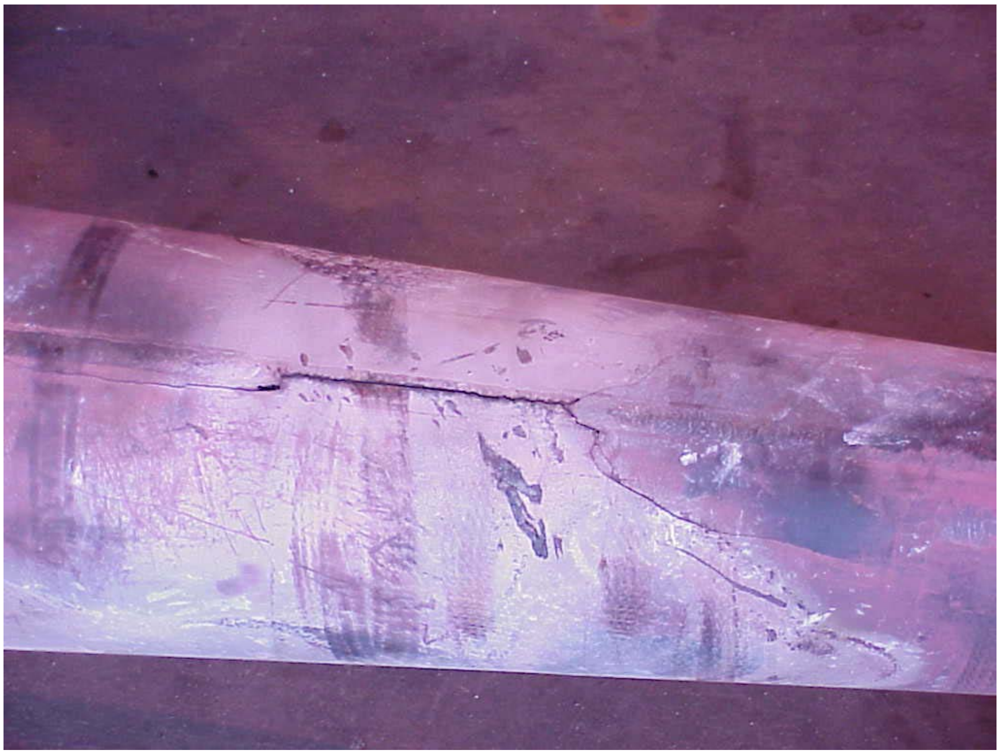


**Figure 12.13:** Crack Along Longitudinal Seam of Thermo Compressor Cone

Thermo Compressor piping was visually inspected and subsequently analyzed because of the repeated failures of the cone attachments and the component body. In doing so, a conventional piping analysis of the design considering gravity, pressure and thermal growth forces showed that they were well within the appropriate standards during normal operation, both with and without the Thermo Compressor in service. Flaws in the pipe elbow of the Thermo Compressor were shown to progress into the piping wall and were, therefore, quite serious. In addition, visual inspection of the weld area revealed defects that contributed to the failure, including cracking and undercut (Figure 12.14).

**Figure 12.14:** Weld Defects in Thermo Compressor

Micro and Marco metallurgical examination of the weld area and heat affected zone uncovered addition weld application and heat-treating defects that accounted for the stepping appearance of the cracks. These examinations showed that the cracking followed a pattern that stepped from filler and base metal inclusions (Figure 12.15) on a background tempered martensite base metal microstructure. In essence, the crack approximated a pattern that represented flaws in the cone's metallurgical microstructure, or the path of least resistance throughout the filler and base metals of the Thermo Compressor's cone shaped body.

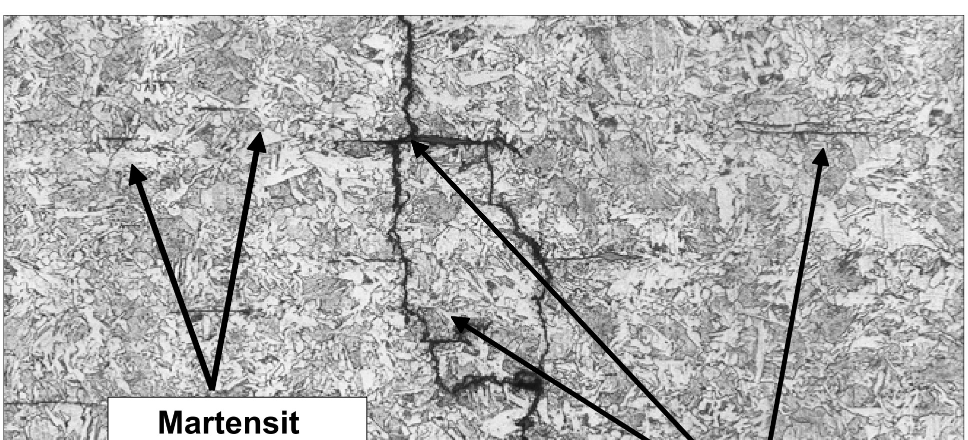


**Figure 12.15:** Microstructure Defects

Visual examination of the weld's crack cross sectional area showed evidence of fatigue contributing to the failure of the Thermo Compressor Cone. As illustrated in (Figure 12.16), the arrow shows the direction of the crack in the base metal. In addition, upon further close examination you can see circular beach marks that fan out from the outside diameter of the cone. This combined with the ratchet marks and a generally flat surface, are clear indications of a fatigue related failure demanding further examination of the process.

To confirm fatigue as a contributor to the failure being analyzed, pipe wall flexure natural frequencies in the piping that constitute the Thermo Compressor were identified with numerical methods and confirmed through testing by plant personnel in the field under operating conditions. Here it was determined that the natural frequency mode shapes were consistent with the location and orientation of the cracks. Furthermore, all failure modes – attached cracking, loosening nuts, and cracked cone – are consistent with the vibration induced from Thermo Compressor operation. The analytical conclusion of the source of the fluctuating stress that was producing the fatigue failures was determined to be pipe wall resonance, and that any coincidental acoustical resonance would synergistically magnify this vibratory stress.

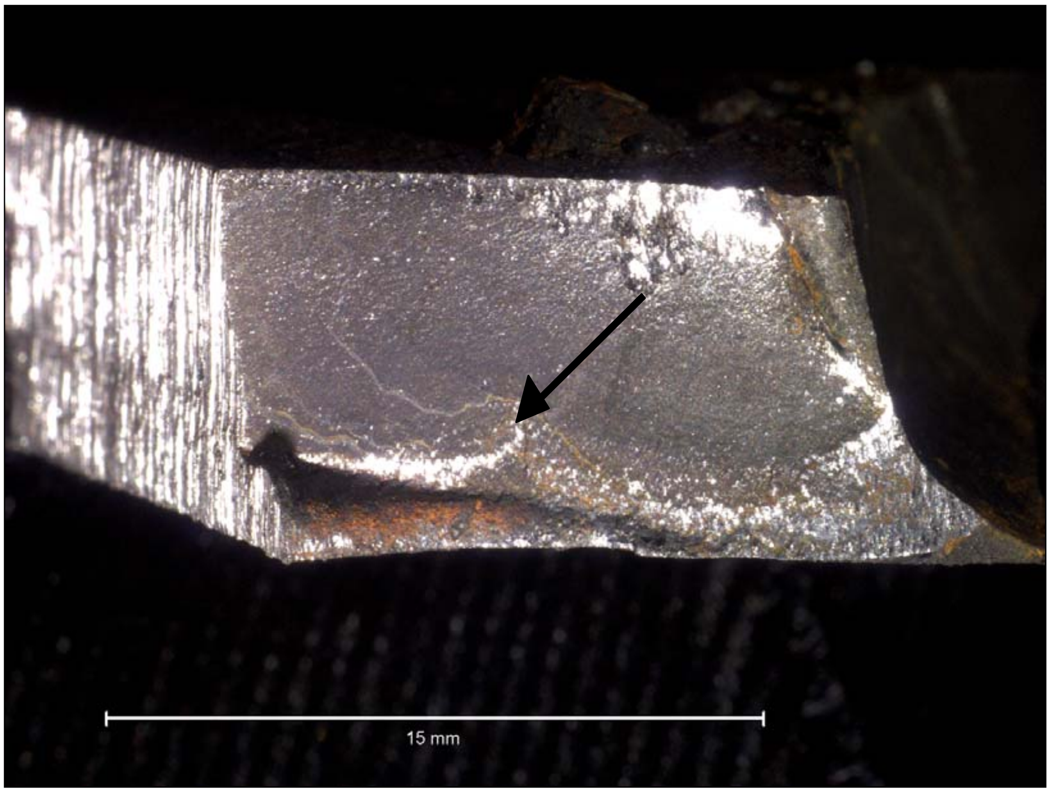



**Figure 12.16:** Fatigue Indications

The system analyzed for gravity, pressure and thermal stress is illustrated in (Figure 12.17). The existing 65 psig steam header was limited in the model because it appeared to be unnecessary.

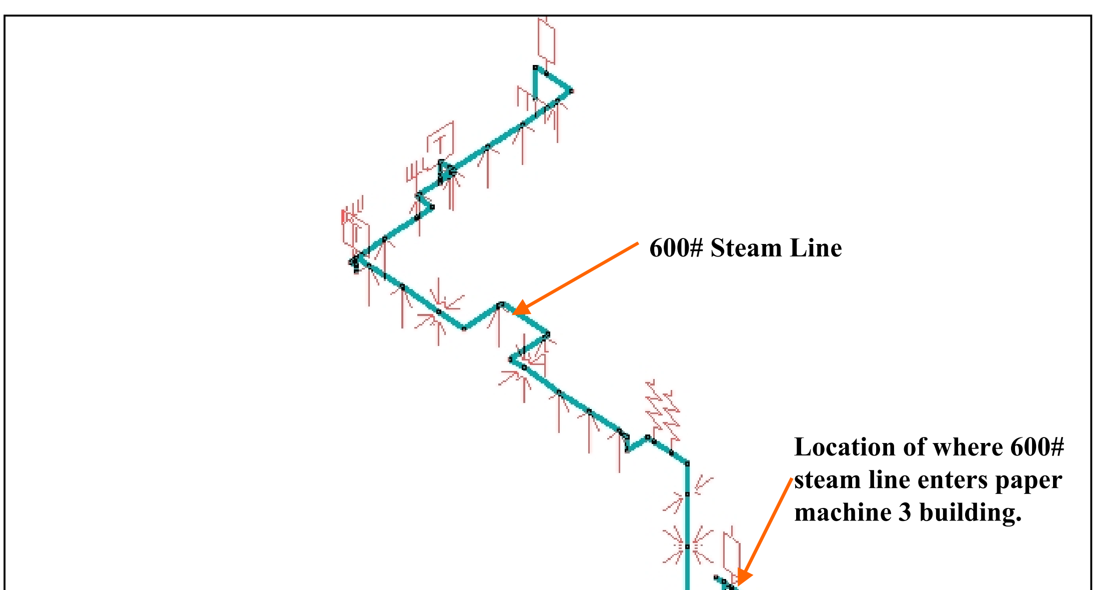


**Figure 12.17:** Piping System with 65 psig Steam Header Excluding Expansion Loop

Piping stress in and around the Thermo Compressor was determined to be low and there was seemingly no correlation between the failures and piping stress from gravity, pressure and thermal loadings.

Vibration of the piping from which the Thermo Compressor cone is constructed was analyzed by constructing a finite element computer model. Several natural frequencies were identified by dynamic analysis. The natural frequency mode shape that occurs at 540 Hz (seen in Figure 12.18) shows a pipe wall flexure that will produce the highest stress at precisely the location of an experienced crack. In addition, the stress will also fluctuate, which is a necessary prerequisite for fatigue cracking.

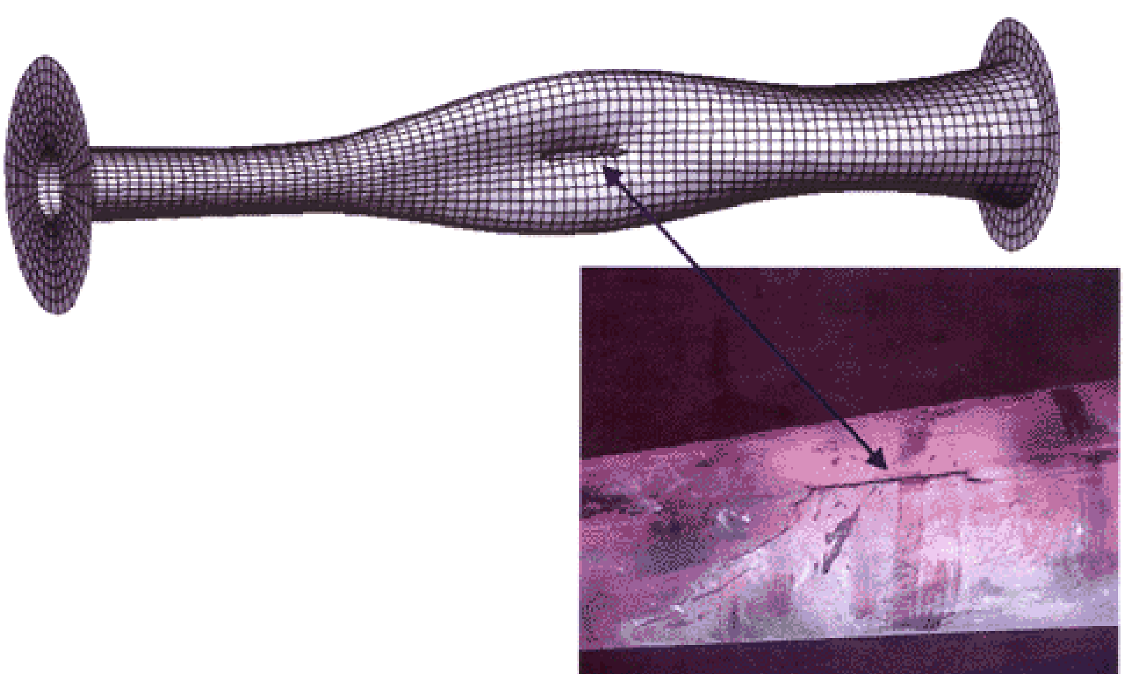


**Figure 12.18:** Dynamic Finite Element Model of the Thermo Compressor Cone Showing a Fundamental 540 Hz Natural Frequency Pipe Wall Flexure Mode

The mode shape of (Figure 12.18**)** does not explain the initial crack branching into two cracks at the left end. The mode shape of (Figure 12.19) shows the initial crack running into high fluctuating stress fields that are at nominally 45 degrees on either side. The concave and convex areas alternate and provide the fluctuating high stress fields necessary for the fatigue crack to advance in their directions.

Field measurement of the thicker cone showed a strong, undamped resonance at 780 Hz (46,000 cpm). This coincides with the 777 Hz natural frequency of the pipe wall and explains the axial crack branching to higher stress fields.

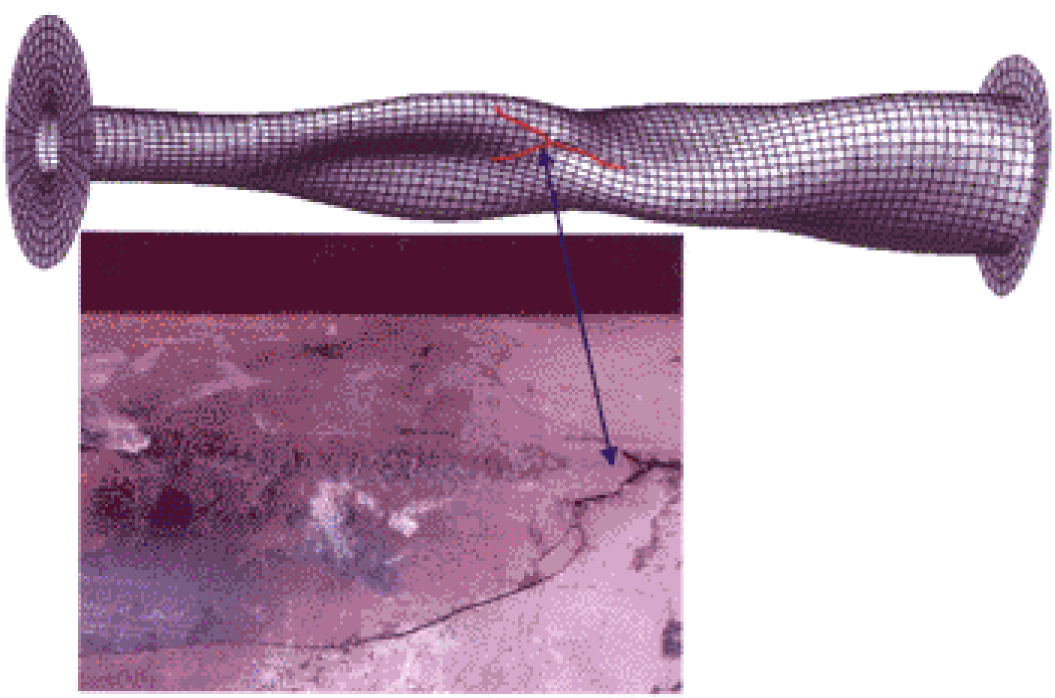
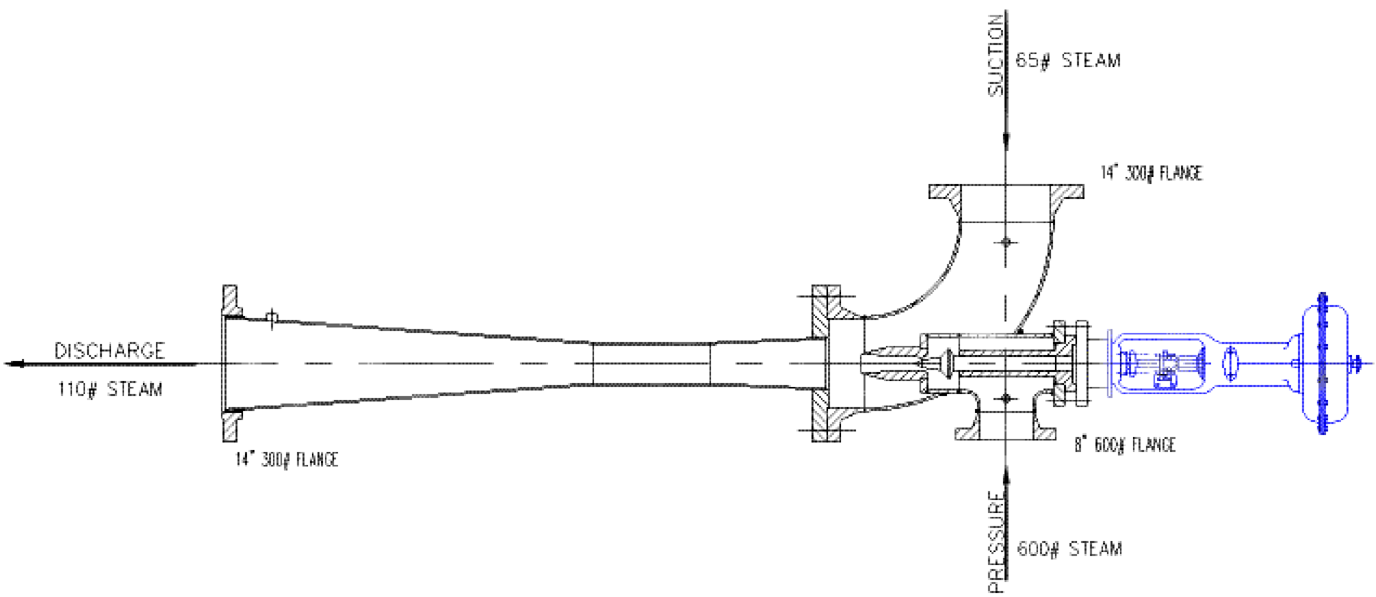


**Figure 12.19:** Natural Frequency Mode at 777 Hz

The piping elbow that forms the Thermo Compressor had weld flaws that extended into the wall of the elbow (Figure 12.20).




**Insert Figure 12.20:** Thermo Compressor

Spring hangers were not properly adjusted because the basis for adjusting the support system is unclear. The design calls for a cold setting, which is defined as total shutdown of the system, and a hot setting that is obviously with the Thermo Compressor in operation.

It was observed that the mechanical fasteners for the Thermo Compressor flange near the spectacle blind tie-in at the 65 psig header were loosening during operation due to high frequency piping vibrations. The piping vibration and high Db noise levels from the Thermo Compressor are proportionately amplified by excitation of the Thermo Compressor's structural natural frequencies, especially in concert with acoustical natural frequencies. This contributed to the creation of a steam leak due to gasket or flange facing damage from previous operation with loose mechanical fasteners.

In general, static loads are acceptable by engineering code. Failure cannot be contributed to the static loads induced by the system but by a fatigue mechanism. In addition, cracking failures on the Thermo Compressor cone are related to pipe wall flexure resonance that is excited by normal Thermo Compressor noise and vibration. Any coincidental acoustical natural frequencies, or their harmonics, will accentuate vibratory stress.

The quality issues addressed earlier are significant to improving the life of the Thermo Compressor. The margin of safety on the Thermo Compressor cone is unknown at this moment but can be determined with an engineering assessment involving quantitative dynamic finite element analysis for stress with fatigue considerations.

**LINE-ITEM FROM MODIFIED FMEA**

**IDENTIFIED ROOT CAUSES**

Physical Roots –

- Inadequate Supports for Thermo Compressor and Associated Piping
- Defective Thermo Compressor Base Metal
- Shop Welds Defective
- Condensate in The System Because of Control Valve Positioning on the 3rd and 4th Sections
- Incomplete Fusion
- Condensate Drains Impeded by Back Pressure in the System

Human Roots –

- Support System Design Error
- Thermo Compressor Not Specified Correctly
- Weld Application Error
- Design Deficiency of Condensate System
- Weld Technique Defective
- Running at Low/High Turn Down Ratios

Latent Roots –

- Inadequate Component Specifications for Support System
- Vendor Did Not Understand System Operating Environment
- Inadequate Specifications Supplied to Vendor for Thermo Compressor
- Original Design of Condensate Traps Inadequate for Service
- No Weld Procedure Specification

- Varying Operating Speeds to Meet Customer/Plant Requirements
- Did Not Follow Weld Procedure
- No Heat Treatment Requirements for Thermo Compressor

**IMPLEMENTED CORRECTIVE ACTIONS**

- New Specifications for Permanent Replacement Thermo Compressor Cone to Include:
  - Base Metal to be ½ inch Chrome Moly Material Instead of 5/16 inch Grade 516 Carbon Steel
  - 100% Radiographic Examination (x-ray) for all Welds
  - Delete Installation of Gauge Port From the Thermo Compressor
  - Stress Relieve the Assembly After Fabrication

- Require Thermo Compressor Manufacturer to Supply:
  - Welding Procedure Specification Used in Manufacturing
  - Radiographic Film Showing all Weld Passes per ASME B31.1 & ASME Section IX.
  - Stress Relieving Procedure per ASME Section IX

- Conduct an Engineering Assessment to Determine the Margin of Safety Against Thermo Compressor Cone Failure – Methodology and Calculations Should Be Well Documented and Open to Critical Review.
- Take Vibration Measurements for Amplitude and Frequency to Analyze Piping Both Before and After Thermo Compressor Startup.
- Inspect for Steam Leaks at the Thermo Compressor Flanges During Startup and Periodically During Operation.
- Modify Piping and Associated Supports for the Thermo Compressor in a Suspended Manner with the Required Clearance Between the Piping and the Support Structure as Indicated by the Outcome of the Stress Analysis.
- Adjust Spring Hangers and Note and Mark the Hangers to Reflect both Cold and Hot Positions.
- Install a Thermal Well in the 600# Steam to the Thermo Compressor to Monitor the Stability of the Steam Temperature at the Point of Use.
- Reroute the Drainage of the Condensate Traps from the 65#, 600# and 120# Steam Piping to Minimize the Effects of Backpressure and Steam/Water Hammer in the Condensate Drainage System.
- Revise Operating Procedures to Limit the Thermo Compressor Turndown Ratio Between the 65# inlet and outlet to be less than 1.80 to Mitigate Continuous Surging When Reaching the Theoretical Limit of the Thermo Compressor.

**EFFECT ON BOTTOM-LINE**

TRACKING METRICS: Production Capacity Increase

BOTTOM-LINE RESULTS: 25% Increase in Production Capacity

CORRECTIVE ACTION TIME FRAMES: Approximately 4 Months

RCA TEAM STATISTICS:

**Start Date: May 1, 2000** **End Date: May 8, 2000**

**Estimated Cost to Conduct RCA: $41,476** **Return on Investment: 1040%**

**RCA TEAM ACKNOWLEDGEMENTS:**

**Principal Analyst:** Ronald L. Hughes

**Title:** Senior Reliability Consultant

**Company:** Reliability Center, Inc.

**Core RCA Team Members:**

| | |
|---|---|
| Douglas Dretzke - | Weyerhaeuser |
| Matt Connolly - | Weyerhaeuser |
| Steven Breaux - | Weyerhaeuser |
| Theron Henry - | Weyerhaeuser |
| Joel White - | Weyerhaeuser |
| Freddy Rodriguez - | Kellogg Brown and Root |

Additional RCA Team Comments: ***"Ron Hughes has done a tremendous job for Weyerhaeuser at Valliant and represented RCI in a highly professional manner. I believe that his contributions have advanced our skills and will enhance our future profitability***.