Wire Wool Failure of a Compressor Rotor

38th Turbomachinery Symposium Case Study

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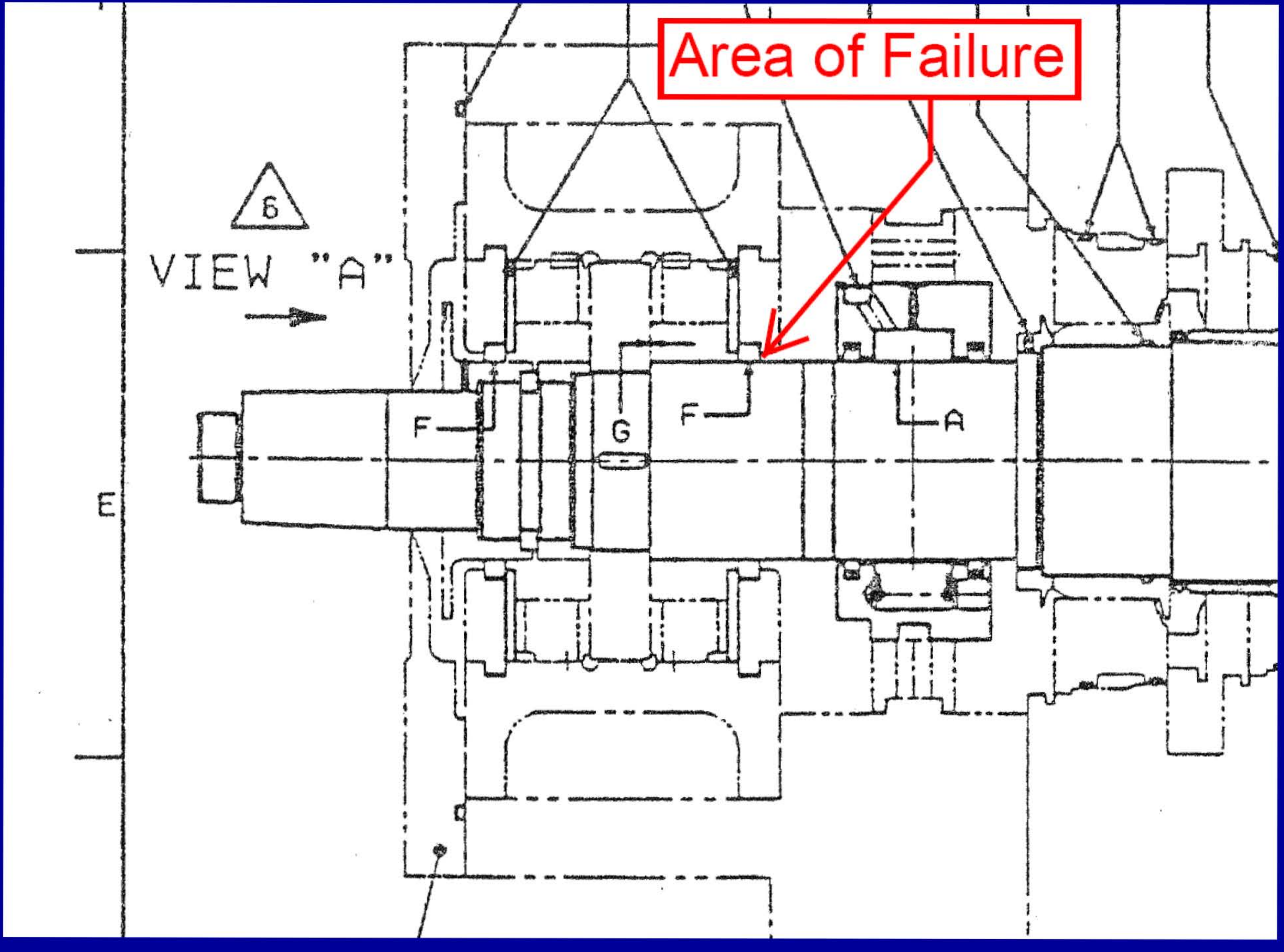
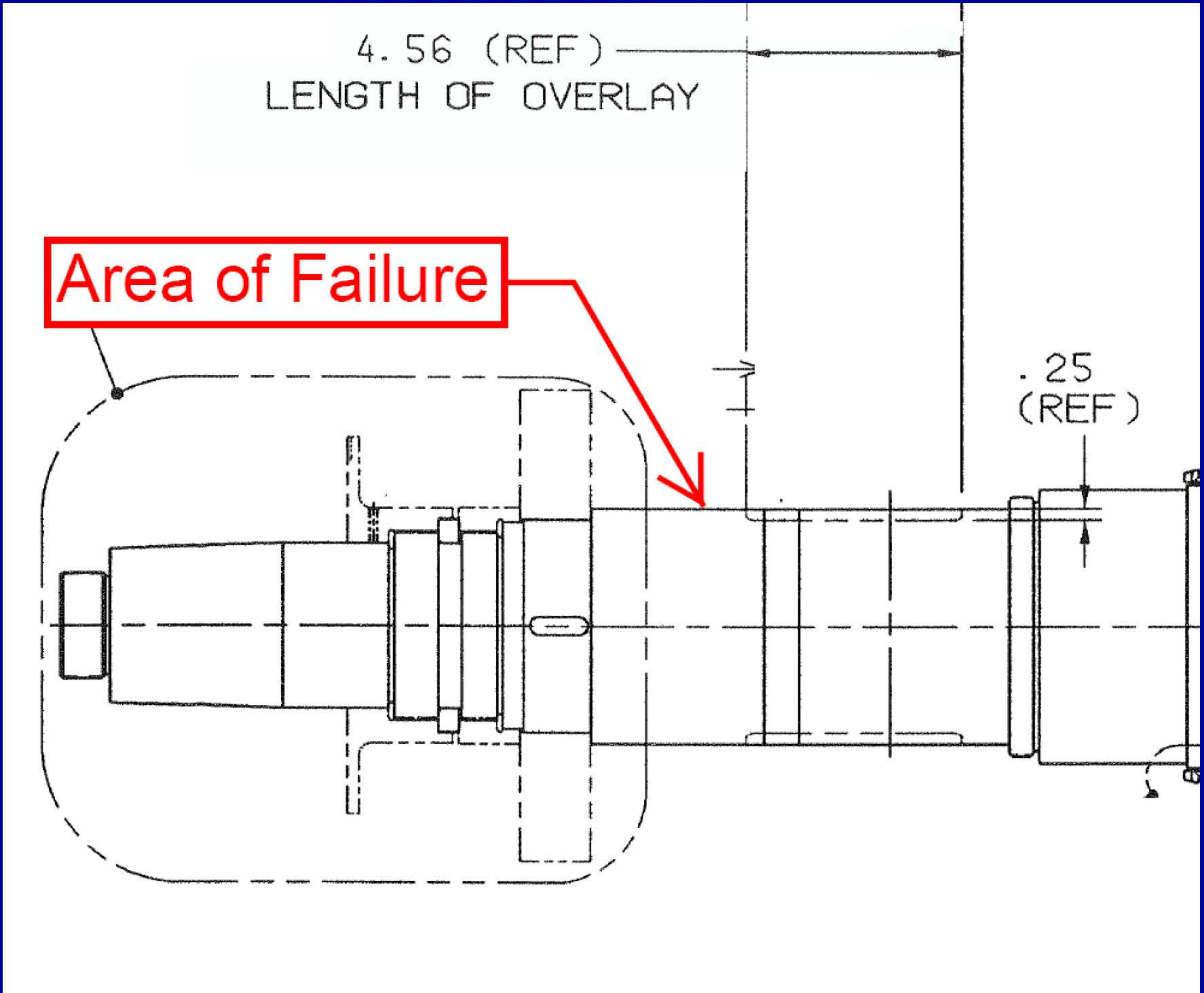
Machine Characteristics

- Double flow beam type centrifugal compressor driven by an electric motor on one end and a steam turbine on the other
- 13,390 HP
- 8676 rpm
- 15-5 PH shaft material with low carbon manganese steel overlay in bearing journal areas



Area of Failure
6
VIEW "A"
E
F
G
F
A

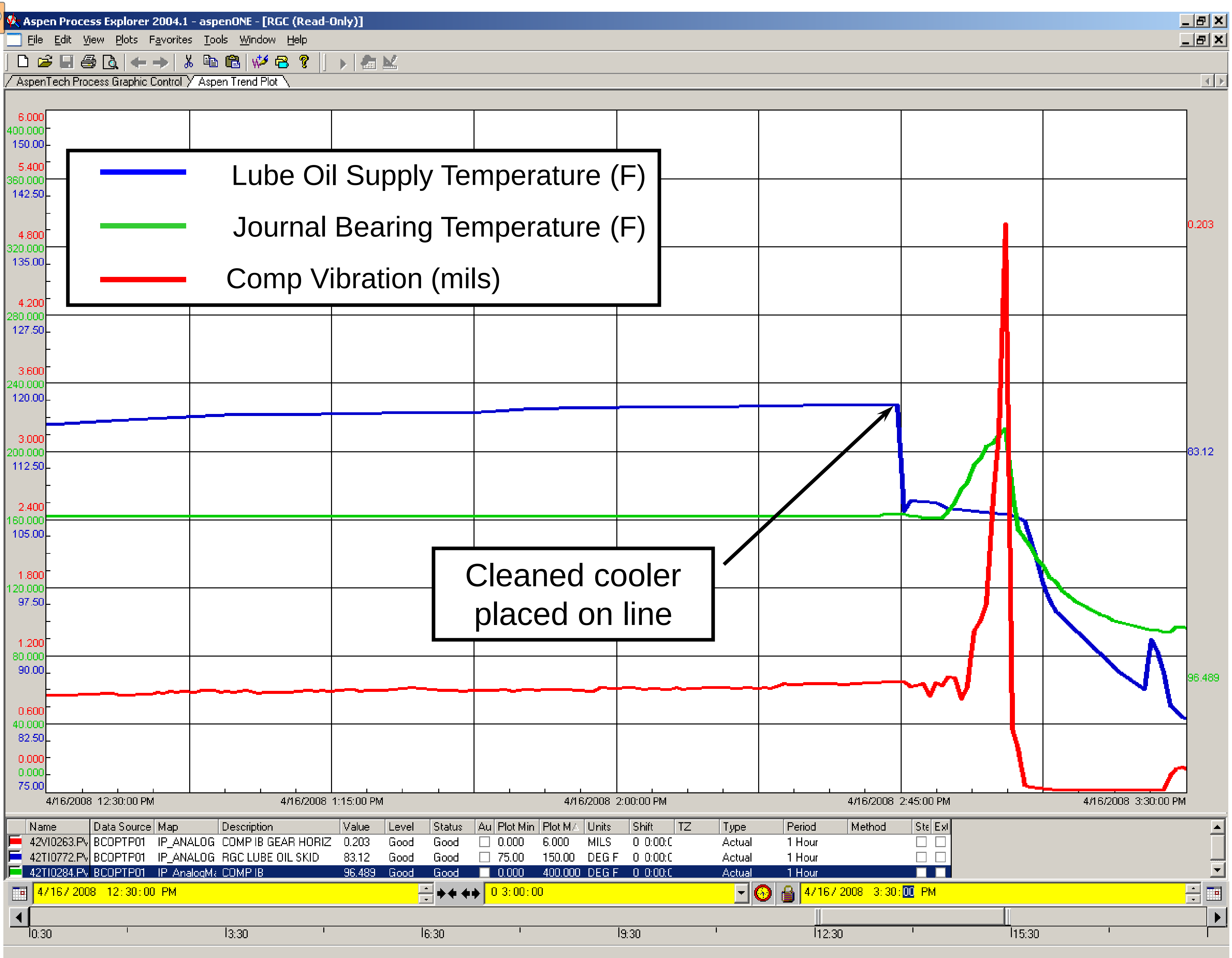

4.56 (REF)
LENGTH OF OVERLAY
Area of Failure
.25
(REF)

Timeline of Events

- Machine restarted after complete overhaul and oil system flush
- Cooling water to oil cooler not lined up – oil supply to deck approaches 170 F
- Cooling water reinstated but vibration tracks oil supply temperature swings – swings caused by fouled cooler
- One cooler taken off-line to clean water (tube) side – bundle pulled

Timeline of Events (cont'd)

- Bundle reinstalled and cooler placed back on line
- Approximately 6 minutes later the journal bearing temperature began to increase
- Three minutes later the vibration dipped and then began a rapid increase
- Machine tripped out by board operator – 9 mils vibration recorded on Bently system


Aspen Process Explorer 2004.1 - aspenONE - [RGC (Read-Only)]
File Edit View Plots Favorites Tools Window Help
AspenTech Process Graphic Control
Aspen Trend Plot
Lube Oil Supply Temperature (F)
Journal Bearing Temperature (F)
Comp Vibration (mils)
Cleaned cooler placed on line
6.000
400.000
150.00
5.400
360.000
142.50
4.800
320.000
135.00
4.200
280.000
127.50
3.600
240.000
120.00
3.000
200.000
112.50
2.400
160.000
105.00
1.800
120.000
97.50
1.200
80.000
90.00
0.600
40.000
82.50
0.000
0.000
75.00
0.203
83.12
96.489
4/16/2008 12:30:00 PM
4/16/2008 1:15:00 PM
4/16/2008 2:00:00 PM
4/16/2008 2:45:00 PM
4/16/2008 3:30:00 PM
Name Data Source Map Description Value Level Status Au Plot Min Plot Max Units Shift TZ Type Period Method Ste Ex
42VI0263.PV BCOPTP01 IP_ANALOG COMP IB GEAR HORIZ 0.203 Good Good 0.000 6.000 MILS 0 0:00:0 Actual 1 Hour
42TI0772.PV BCOPTP01 IP_ANALOG RGC LUBE OIL SKID 83.12 Good Good 75.00 150.00 DEG F 0 0:00:0 Actual 1 Hour
42TI0284.PV BCOPTP01 IP_AnalogM COMP IB 96.489 Good Good 0.000 400.000 DEG F 0 0:00:0 Actual 1 Hour
4/16/2008 12:30:00 PM
0 3:00:00
4/16/2008 3:30:00 PM
0:30
3:30
6:30
9:30
12:30
15:30

- With machine disassembled it was readily apparent that it had experienced a wire wool failure.
- Debris from machining appeared as wire wool.

  – Pre-disassembly
    - Shaft runout approaching 25 mils TIR
    - Spiral windings in oil drain line bull’s eye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Wire Wool Background

- Mechanism driven by:
  - Steels containing chromium in excess of 1-1.5%
    - 15-5 PH / 17-4 PH
    - 400 series stainless
  - Shaft speeds in excess of 67-80 feet/sec
  - Foreign particle (soft or hard)
  - References / Further Reading
    - API RP 687 Rotor Repair, First Edition p 1-157
    - *Metallurgical Considerations in Wire Wool Type Wear Bearing Phenomena,* F. Fidler, 1970

Wire Wool Background (cont'd)

- Typical Failure Sequence
  - Foreign particle introduced into tight clearance
  - Frictional heat generated due to particle rub at high speed
  - Chromium in the steel in the presence of a hydrocarbon oil is converted to hard chromium carbide
  - Chromium carbide particles embed in stationary component and act as a cutting tool
  - The mechanism self-propagates until something gives

Additional Findings

- Other bearing journals exhibited scoring
- Oil filter housing contained significant amount of large debris
- Oil pump suction screen mesh much tighter than large debris


Engineered Sealing Systems

Additional Findings

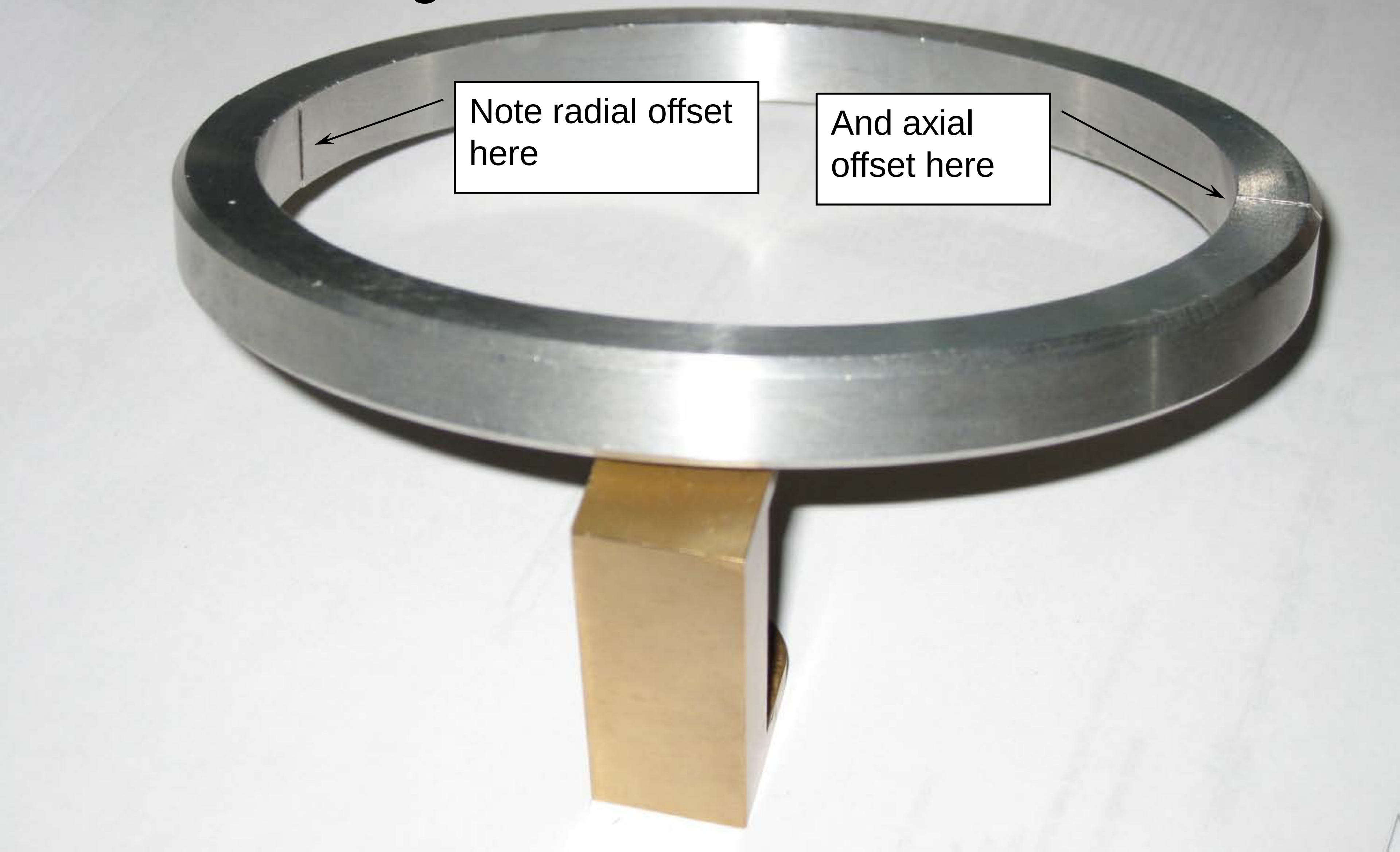
- Debris originated from:
  - Lube oil supply high temperature swings performed additional “cleaning”?
    - Oil temperature excursion to 170 F
    - Sudden oil temperature drop when cooler placed on line
  - Contaminated oil cooler bundle?
    - Would require passage through filter

      Reference *Dynamic Filter Efficiency*
  - Combination of above?

Additional Findings

- Oil seal
  - Split design incorporated due to coupling on thrust bearing end
  - Spare thrust bearing oil seal had offsets at splitline
  - Existing oil seal design could lock up thus further forcing any trash against shaft

Spare Oil Seal – Example of Design and Manufacturing Flaws



Modifications – Oil Seal

- Match marked halves
- Add dowels to splitline to improve alignment capability.
- Add anti-rotation slot to the lower half holder. This ensures that the anti-rotation pin does not accidentally get hung in the existing hole in the upper half. Plugged hole in upper half.
- Axial clearance changed to .005 to .010" (old design clearance was .002" to .005").
- Seal captured by bolted cover vs. relying on thrust bearing

Repairs – Previous Service Shaft

- Shaft of previous service rotor coated to eliminate high chrome at surface
  - Tungsten carbide coating, minimum thickness of .005” per side, but for this repair it was approximately .015” per side
  - Surface finish was made the same as the surrounding metal at a value of 18 Ra.
  - The coating is a JP-5000 coating.

Wire Wool Failures – Other Things to Watch For

- Oils with EP additives
- Oils with chlorinated paraffins (typically cutting oils)
- Issues in more traditional rotor metallurgy such as 4140 or 4340
- *Dry* failures in compressor interstage seal and balance piston areas.
  - Further reading - *"Wire Wool", "Black Scab" or "Machining" Failure Mechanism in Turbomachinery – 5 Case Histories*, Tim Christ Turbomachinery Symposium Case Study – August 2001

Lessons Learned

- Historical success does not mean that design improvements do not exist
- Hindsight truly is 20/20
- Cleanliness is paramount when exposing the oil side of coolers to atmosphere
- Swapping from dirty to clean coolers should be performed smoothly to minimize temperature and viscosity swings