

What Makes an Award Winning PdM Program ?

Ted Royal

Senior Engineer, Predictive Maintenance

Duke Energy-Catawba Nuclear Site

September 11, 2009

7 Keys to PdM Success

- 1) *“Never mistake activity for achievement” John Wooden, Basketball Coach*
- 2) *Time must be cherished – “to make good use of your time, you’ve got to know what’s most important and then give it all you’ve got” Lee Iacocca*
- 3) *“Learn from mistakes and failures” My Dad and many others*
- 4) *Others are smarter than you – “Who is wise? He that learns from everyone” Ben Franklin*
- 5) *“Good is never good enough” - Many*
- 6) *“Success Breeds Success” - Many*
- 7) *“Never mistake vibration for forward movement” - Unknown*

Catawba

One of three Duke Nuclear Plants

Catawba 1,2- 1129 MWe each, Westinghouse NSSS, GE turbine-generator

McGuire 1,2- 1100 MWe each, Westinghouse NSSS, Westinghouse turbine-generator

Oconee 1,2,3- 846 MWe each, B&W, GE turbine-generator



1 FLIR

□ 1 ▲ 92.2

81

Infrared Scan of Catawba at 3 am

60

Trefl=68 Tatm=68 Dst=6.6 FOV 24

8/21/06 3:18:22 AM -40 - +250 e=0.96 °F

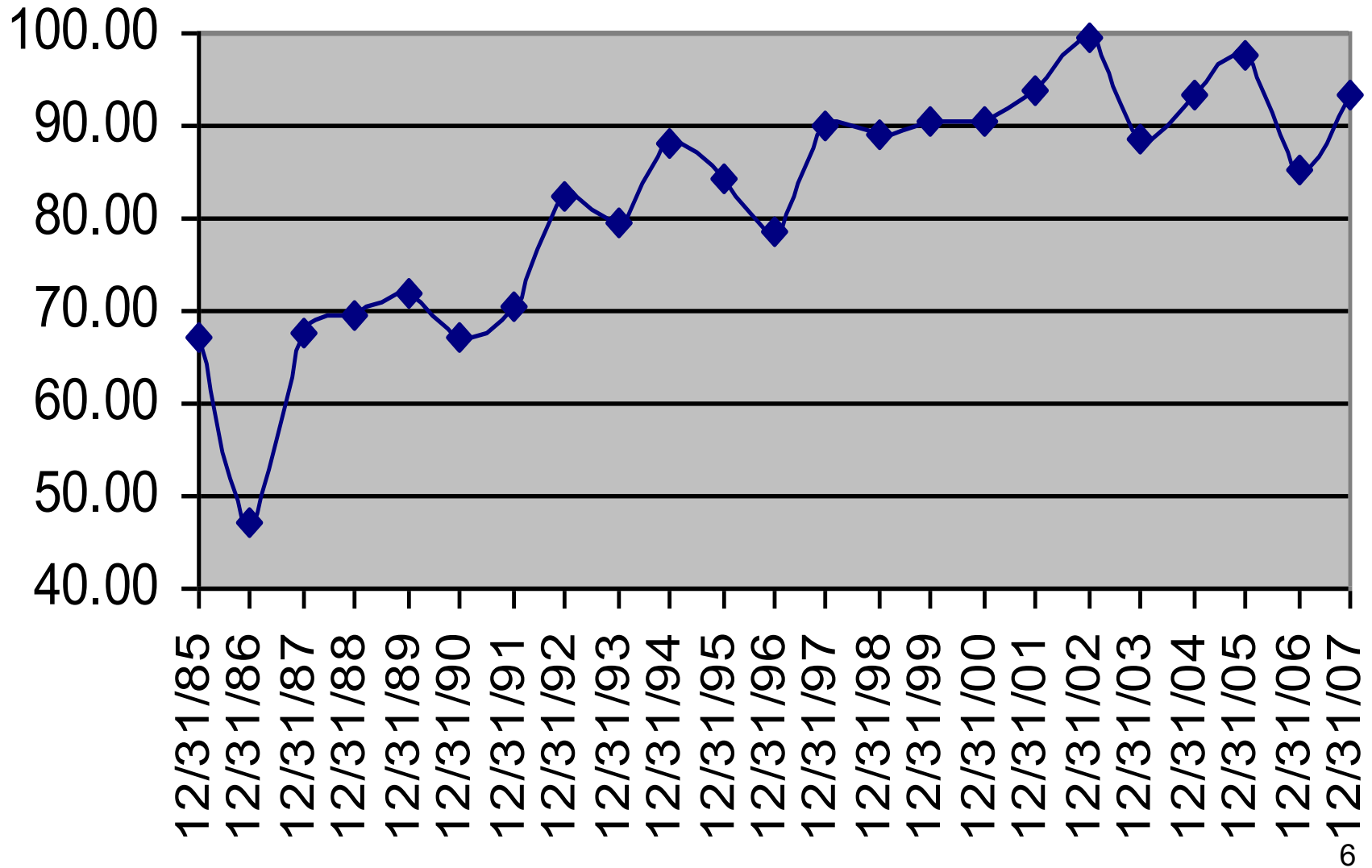
Catawba PdM History

- Prior to 1985, Reactive could be used to best describe Catawba's maintenance approach.
- Technology and process improvements accelerated implementation:
 - Small data collectors
 - Portable IR cameras
 - Faster computers
 - AP-913 Process improvements



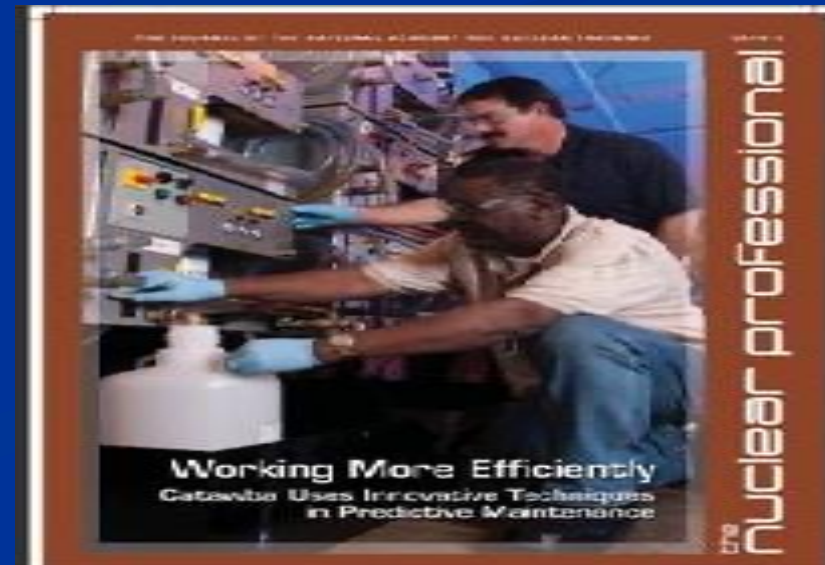
Reactive – Not Good

Catawba Site Capacity Factor



Catawba PdM Awards and Publications

- 2007: Uptime Magazine PdM Program of the Year
- 2008: INPO strength for innovative monitoring
- 2009: Nuclear Professional cover story



1st Key

Never Mistake Activity for Achievement

Develop A PdM Process

Never Mistake Activity for Achievement (Develop A Process)

Without a process, a PdM program will be busy with activity, but little will be accomplished

Catawba Strategy – INPO AP-913; Equipment Reliability process

Six Key Areas of Focus derived from INPO AP-913

- *Scoping and identification of critical components*
- *Performance Monitoring*
- *Corrective Action*
- *PM Implementation*
- *Continuing Equipment Reliability Improvement*
- *Long Term Planning and Life Cycle Management*

2nd Key

Time Must Be Cherished

*Optimize PdM time by
focusing on the most
important components*

Monitor the Most Important Machines

Risk Informed Approach to Categorization

- “A” Critical to Plant Operation/Safety
- “B” Protection of Significant Assets
- “C” Support to “A” or “B” Systems
- “D” Run to Failure

3rd Key

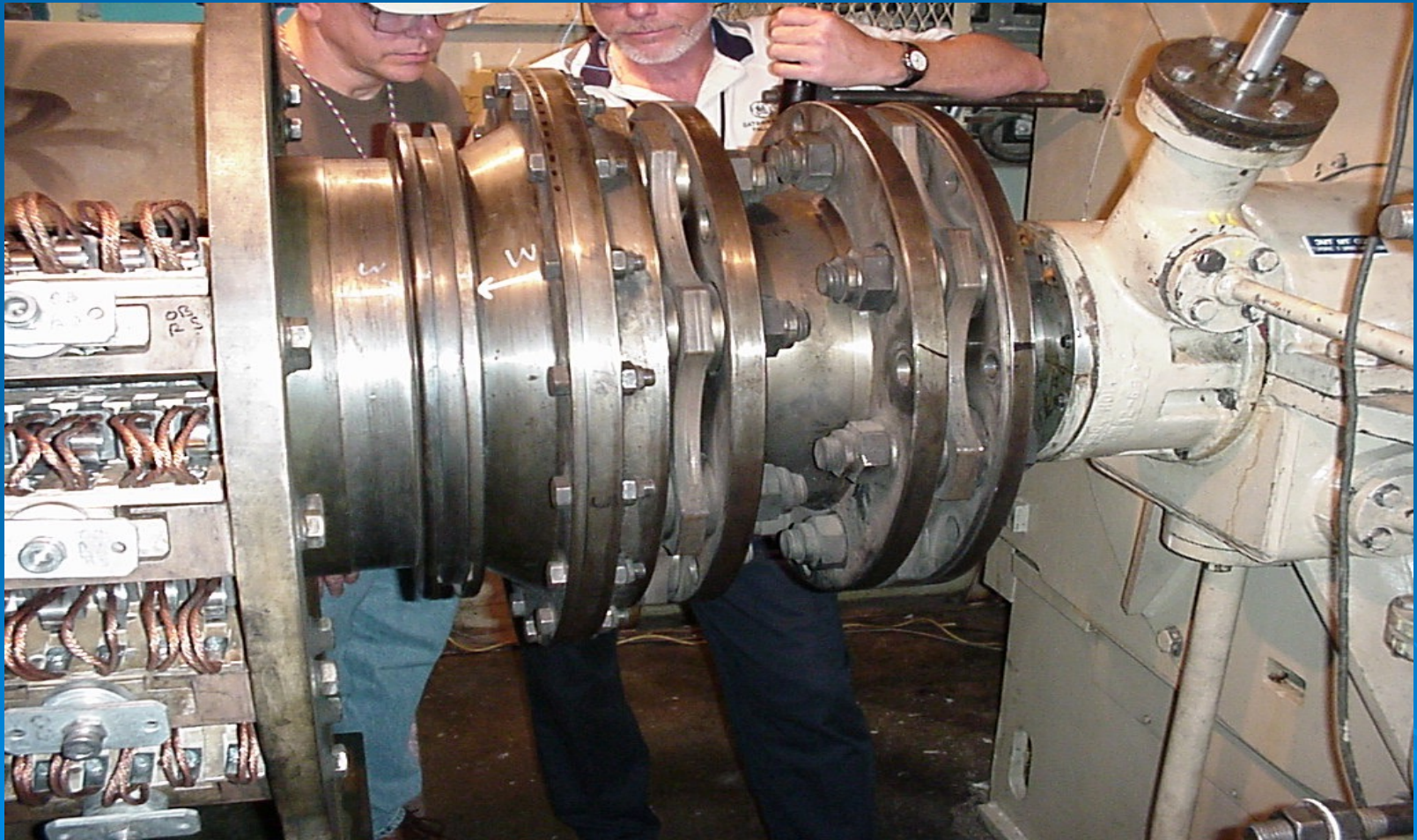
Learn From Mistakes and Failures

*Perform Root Cause
Analysis and Learn From
Mistakes*

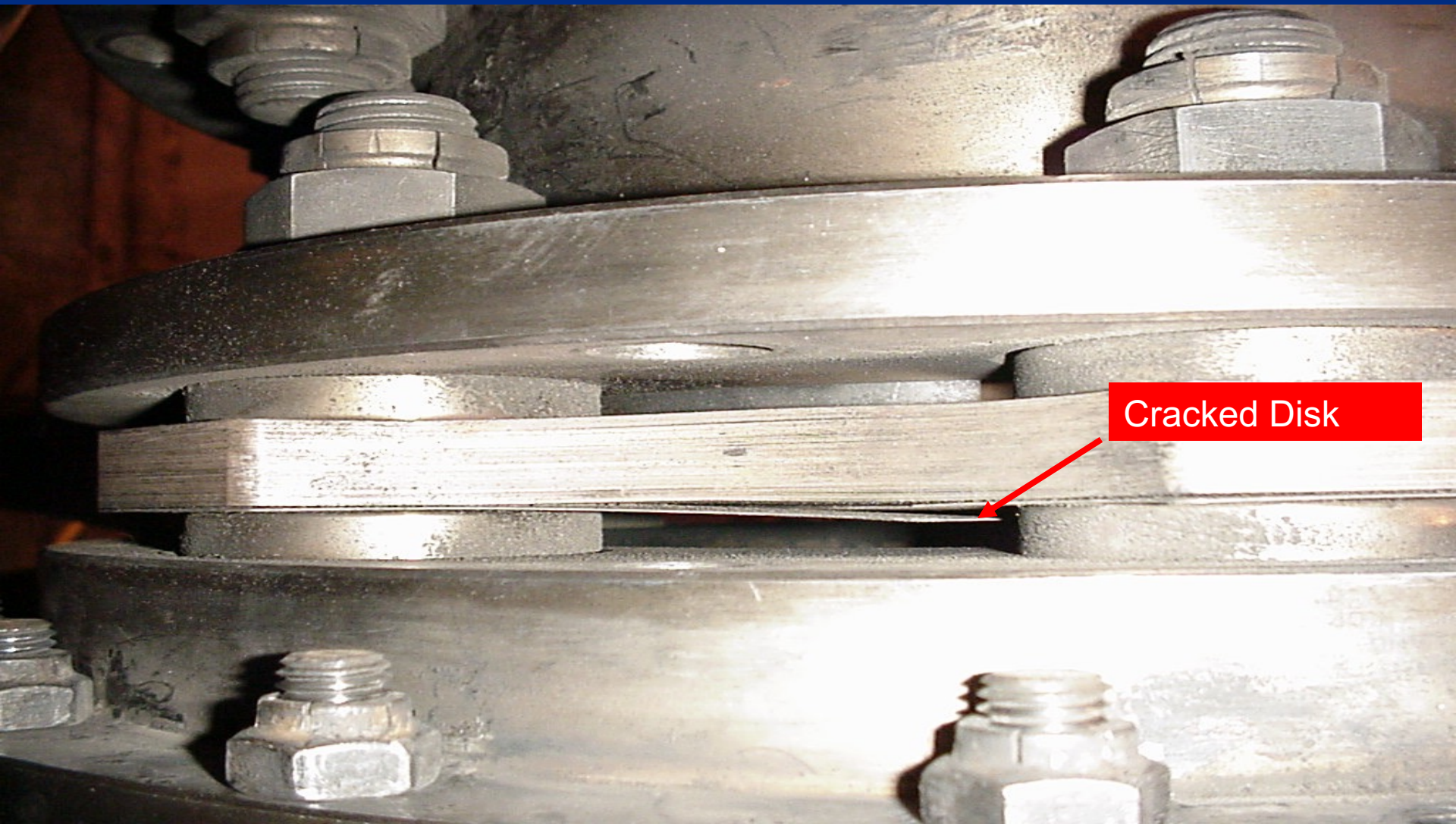
Learn From Mistakes: Corrective Actions

- Learn From Mistakes
- Root Cause analysis plays a big role here
- If the root cause determines that inadequate PM or PdM monitoring was a major factor in the failure, a change is needed (scope or frequency)

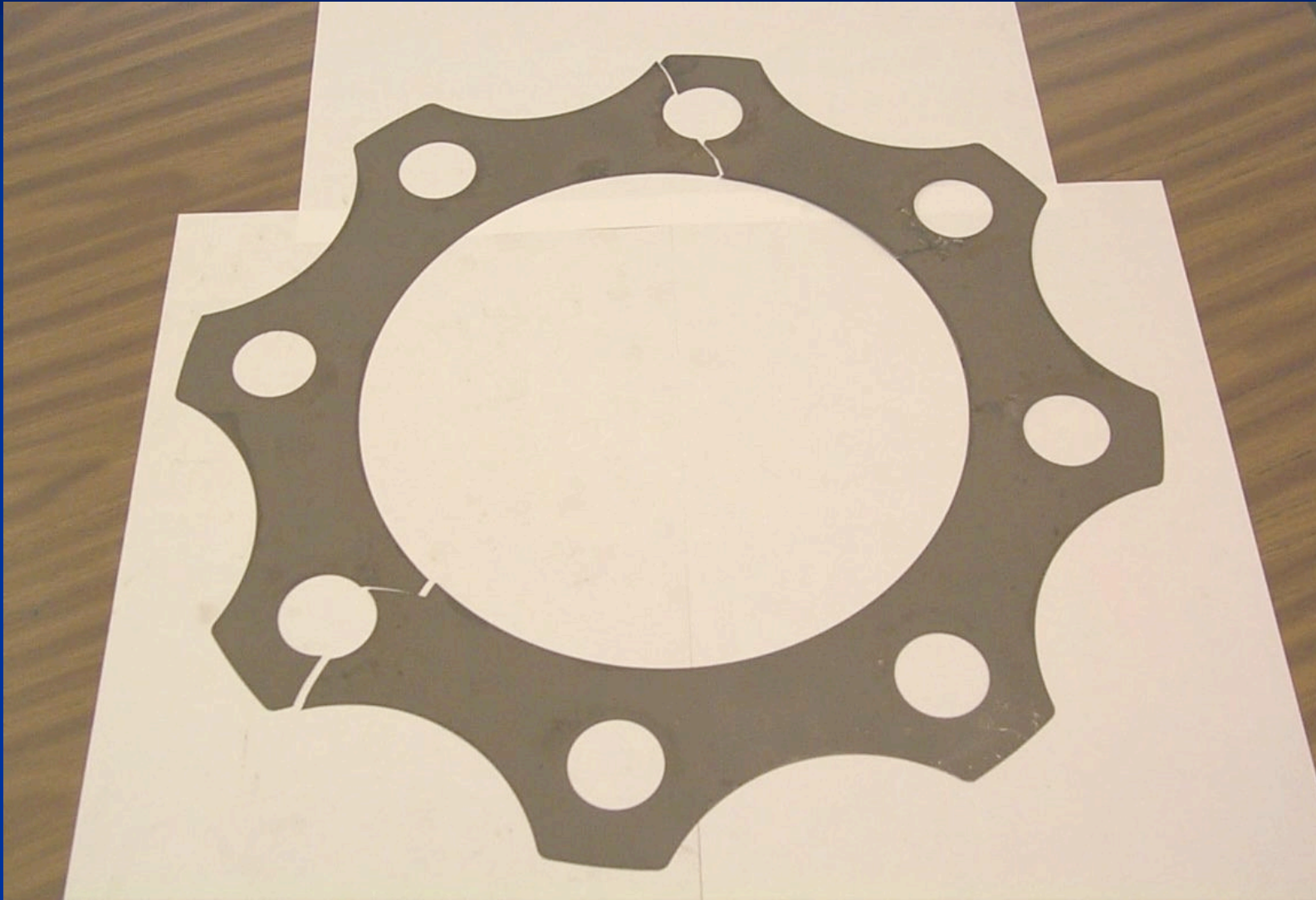
Case History: Flexible Coupling Failure at Oconee: Example of Inadequate PM and PdM



Coupling Failure Symptoms



Failure Analysis



Coupling Failure Symptoms

- Vibration amplitude on Brg # 11 rapidly rose from about 2 mils to ~ 8 mils shortly after startup from a RFO
- Vibration frequency was predominantly 1X
- Visual examination of the running coupling using a strobe showed disk flexing and broken disks. 64% of Generator side Discs and 46% of Exciter Side were Cracked
- Unit # 3 was shut down (Two day duration) for coupling replacement

Learning From Mistakes

- Cause of Failure was Long Term Cyclic Tensile Fatigue. Cracked Discs caused coupling instability and higher vibration levels
- Inadequate PdM alarm limits: The new coupling lowered overall vibration levels when first installed. *However, we failed to understand that vibration limits should also have been lower.* If we had initially lowered our vibration alarm limits, we would have caught the problem earlier.
- Inadequate PM: The new disc coupling was “Maintenance Free”...discs were Teflon coated and required no lubrication

4th Key

Others Are Smarter Than You

*Benchmarking and
Assessments*

Learning From Others: Assessments and Benchmarking

Assessments and benchmarking provide a critical review of the PdM program

■ Assessments:

- Every two years, one of the Duke nuclear plants has a 3rd party independent review of the PdM programs
- Annual self assessment as a part of the PdM Health Report .
- Use format similar to the EPRI 14 Point Self Assessment Guidelines

■ Benchmarking:

- With AREVA at Homaoka and Ikata Nuclear Sites (Japan)
- With INPO at KHNP (Korean Hydro and Nuclear Power)
- With EPRI/San Onofre at the RCM/CBM User's Group Meeting
- Duke's Fossil plants (Belews Creek-Oil Filtration)
- DOE Savannah River Site
- Waterford Nuclear Plant

Benchmarking

Duke Belews Creek
Plant: Oil Storage and
Filtration



Bondagi



5th Key

Good is Never Good Enough

*Develop Meaningful
Metrics and Proactive
Maintenance Measures*

PdM Health Reporting and Long Term Planning

- Periodic reviews of PdM health can reveal areas where weaknesses and improvements can be made
- Quarterly CSORE “hit list” reports are presented to the Plant Health Committee. Committee members comprised of Senior Management from all plant groups. This forum ensures proper support for identified machinery problems.
- PdM Overall Health reports are prepared annually and include metrics and program long range plans

PdM Health Reporting

<p>EPRI Gap Analysis 14 Point PdM Rating Gap Analysis using EPRI Self Assessment Guidelines Document # 1001032: 14 Key PdM Points</p> <p>Ratings (1-10) are applied for each of the following areas. This is performed annually</p> <ol style="list-style-type: none"> 1) PM Task Basis 2) Technology Application 3) Process Flow Definition 4) Program Leadership and Coordination 5) Organization, Roles, and Responsibilities 6) Information Management and Communication 7) Equipment Condition Assessment and Decision Making 8) Training and Qualifications 9) PdM Work Prioritization and Scheduling 10) Work Closeout and Maintenance Feedback 11) Goals and Performance Metrics 12) Calculation of Cost-Benefits and Return on Investment 13) Customer Satisfaction 14) Continuous Improvement 	<p>G</p>		<p>Self Assessment Gap Analysis Using EPRI Recommendations Document # 1001032</p> <p>The Catawba PdM program falls in the higher percentile (8.9 out of 10). However, improvements can be made. Benchmarking performed during this review period resulted in 21 areas for improvement. These areas for improvement are included in PIP # 07-1619.</p> <p>Actual Self Assessment Ratings</p> <table border="0" style="width: 100%;"> <thead> <tr> <th style="text-align: left;">Key PdM Area</th> <th style="text-align: right;">Rating</th> </tr> </thead> <tbody> <tr><td>1) PM Task Basis</td><td style="text-align: right;">8</td></tr> <tr><td>2) Technology Application</td><td style="text-align: right;">8</td></tr> <tr><td>3) Process Flow Definition</td><td style="text-align: right;">8</td></tr> <tr><td>4) Program Leadership and Coordination</td><td style="text-align: right;">7</td></tr> <tr><td>5) Organization, Roles, and Responsibilities</td><td style="text-align: right;">9</td></tr> <tr><td>6) Information Management and Communication</td><td style="text-align: right;">10</td></tr> <tr><td>7) Equipment Condition Assessment and Decision Making</td><td style="text-align: right;">10</td></tr> <tr><td>8) Training and Qualifications</td><td style="text-align: right;">8</td></tr> <tr><td>9) PdM Work Prioritization and Scheduling</td><td style="text-align: right;">9</td></tr> <tr><td>10) Work Closeout and Maintenance Feedback</td><td style="text-align: right;">10</td></tr> <tr><td>11) Goals and Performance Metrics</td><td style="text-align: right;">10</td></tr> <tr><td>12) Cost-Benefit and Return on Investment</td><td style="text-align: right;">10</td></tr> <tr><td>13) Customer Satisfaction</td><td style="text-align: right;">9</td></tr> <tr><td>14) Continuous Improvement</td><td style="text-align: right;">9</td></tr> </tbody> </table> <p>Average Rating = 8.9</p> <p>Measures (From EPRI document)</p> <p>Green: 8-10 Yellow: 5-8 Red: < 5</p>	Key PdM Area	Rating	1) PM Task Basis	8	2) Technology Application	8	3) Process Flow Definition	8	4) Program Leadership and Coordination	7	5) Organization, Roles, and Responsibilities	9	6) Information Management and Communication	10	7) Equipment Condition Assessment and Decision Making	10	8) Training and Qualifications	8	9) PdM Work Prioritization and Scheduling	9	10) Work Closeout and Maintenance Feedback	10	11) Goals and Performance Metrics	10	12) Cost-Benefit and Return on Investment	10	13) Customer Satisfaction	9	14) Continuous Improvement	9
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CSORE Report

Tech	EquipmentDescription	Sev	ProblemDescription	Disposition	Data Date	SchResDate
Vib	2C LOWER CONTAINMENT VENTILATION UNIT (LCVU-2C)	2	Vibration amplitudes on both fan and motor are close to alarm limits (amplitude = 0.36 in/sec with and alarm at 0.4 in/sec). Balancing brought levels down during the Unit 2 EOC 14 RFO; however, several stationary inlet vanes are missing, causing flow imbalances to the fan. A WO exists to replace both the fan and inlet vanes during the next Unit 2 RFO.	5/07/07: Amplitude is constant at about 0.33 in/sec over the past few months. 3/26/07 WC, Maint., Eng met to discuss outage plans. New fan rotating assembly will not fit through fan room access window. Current plans are to replace only the missing stationary inlet vanes.	4/23/2006	9/25/2007
Vib	All Cooling Towers	2	Vibration instrumentation problems resulting in cooling tower fan trips. In one instance, a 6 % unit load reduction occurred for several hours. The instrumentation vendor quit supplying parts and service for our system in 2003. NSMs CN-11426 and 214126 will handle replacing the bulk of the system and they are scheduled for 2009.	Instrumentation obsolescence	8/30/2006	12/31/2009
Vib	1A CONTROL ROD DRIVE MECHANISM VENTILATION FAN MOTOR	2	Vibration increase at 1X fan running speed. Amplitude is at 0.35 in/sec, much higher than other CRDM fans. Replace fan with factory balanced fan.	Replace fan with factory balanced fan	12/24/2006	6/20/2008
Vib	1B CONTROL ROD DRIVE MG SET	2	Motor OB bearing vibration has trended up since Dec., 2006. Spectral harmonics are indicative of looseness. OB bearing temperature is about 25 deg. F higher than other MG motors.	Motor, OB bearing to be replaced.	2/16/2007	5/17/2007

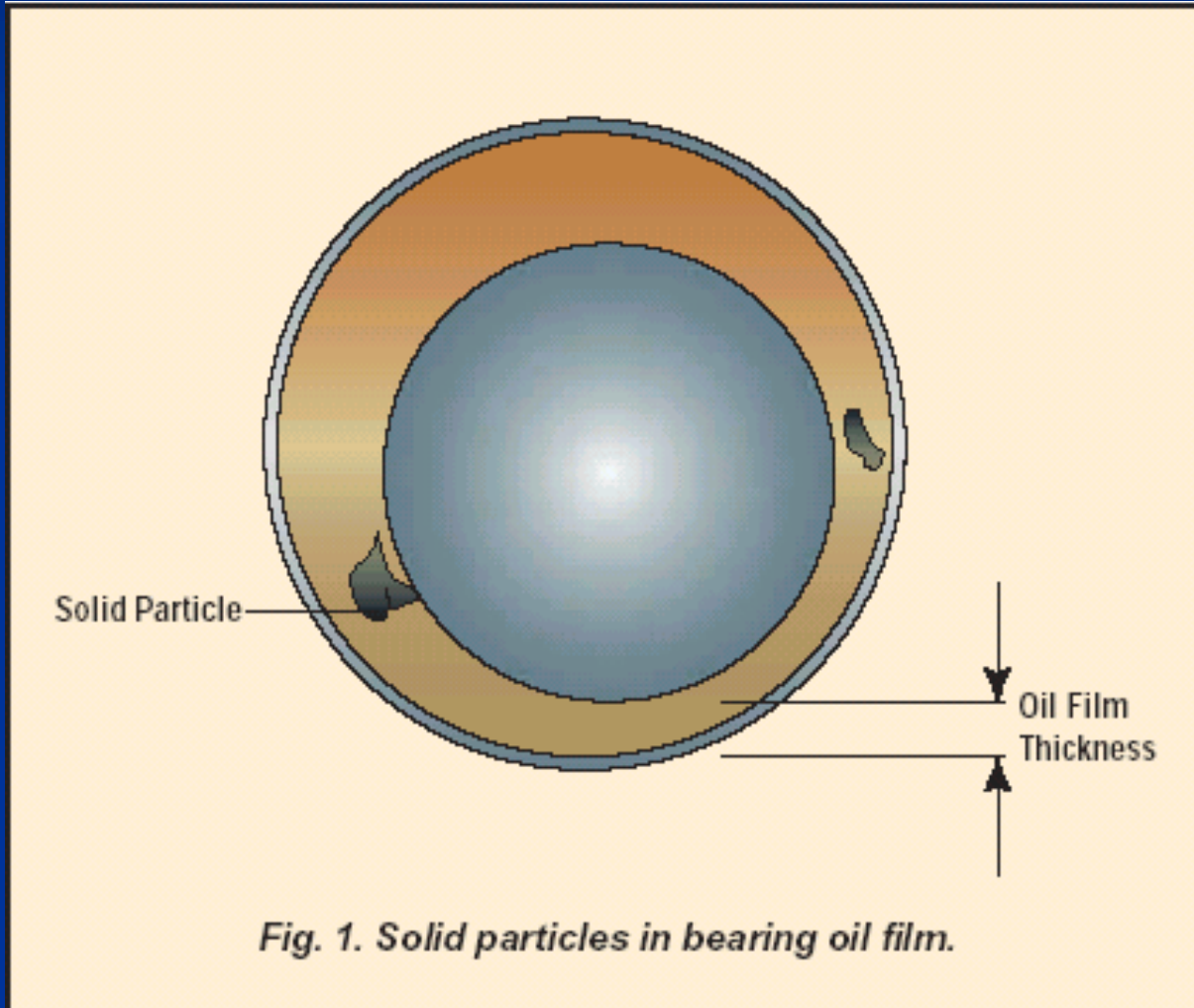
Good is Not Good Enough

Cleaning Up
New Oil At
Catawba



Why We Started to Clean Up Our Oil

*Particles and Contamination Effect on Fluid Film
(picture obtained from Noria Website)*



Something Was Not Right!!!

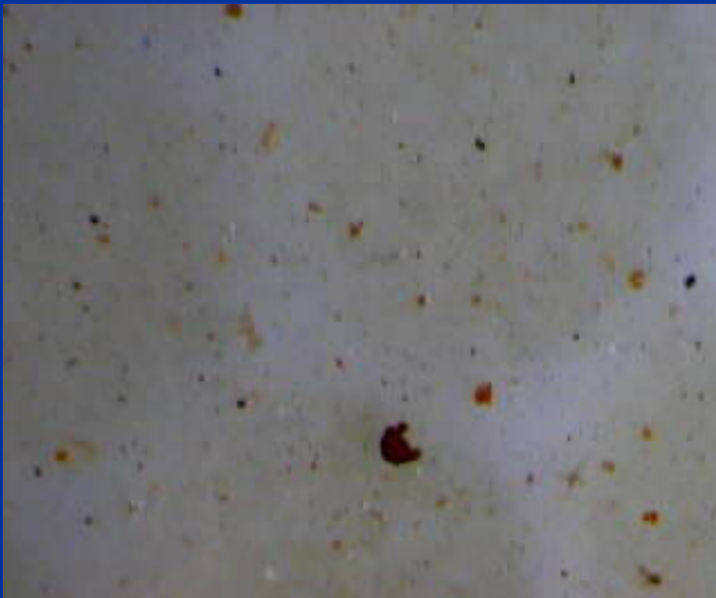


- Sometimes, even after oil changes, Catawba was seeing higher than desired particle counts
- These levels, in some cases, were near our threshold for oil changes

The oil was new

The particle counts were high!

Filter Patches of Oil Samples Showing Trash and Contaminants



2A RC Pump



A RL Lower

New Oil Contamination

- Testing showed new oil ISO contamination levels to be unacceptable
- New oil samples were averaging about 18/17/14 or higher
- Cleanliness targets for new oil needed to be at least 16/14/12
- Filtration was the answer

Cleanliness targets

element	ISO Target
Roller bearing	16/14/12
Journal bearing	17/15/12
Industrial gearbox	17/15/12
Mobile gearbox	17/16/13
Diesel engine	17/16/13
Steam turbine	18/15/12
Paper machine	19/16/13



Satellite Storage and Oil Filtration Equipment

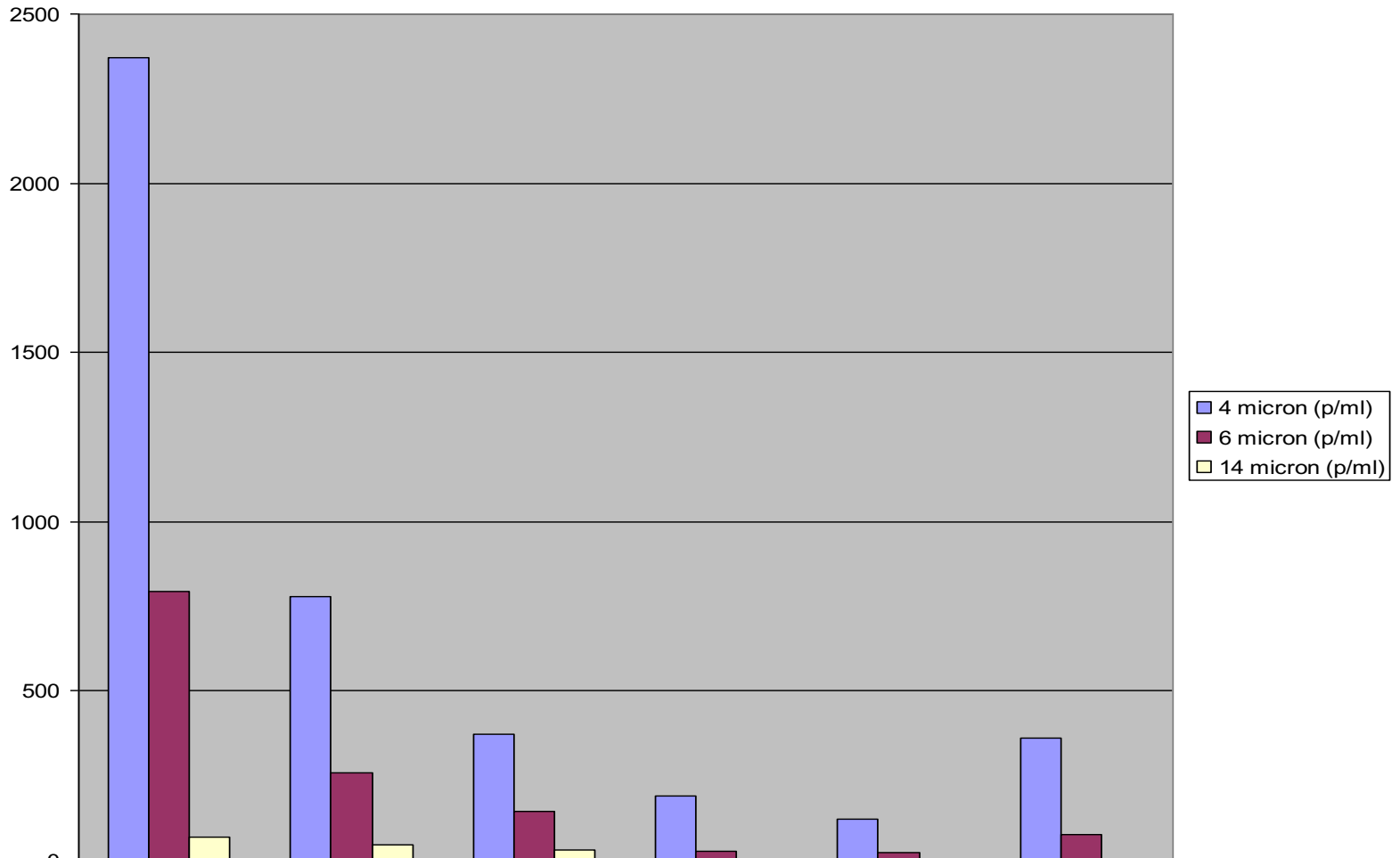
- 3 micron, Beta 200 particulate filter
- Water filter
- Drum adapter kit with dessicant breather



Warehouse Oil Storage and Filtration



ISO 68 Filtration Results



	0	0.5	1	2	2.5	3
4 micron (p/ml)	2371	778	373	191	122	361
6 micron (p/ml)	793	259	146	28	22	76
14 micron (p/ml)	70	45	30	5	2	4

Oil Filtration Results: Cleanliness Code Ratings

Oil Tested	New Oil	Filtered 3 hours
ISO 32	18/16/13	16/14/11
ISO 46	17/16/13	15/13/11
ISO 68	18/17/13	16/13/09

Good is Never Good Enough: Proactive Maintenance, PdM and PM

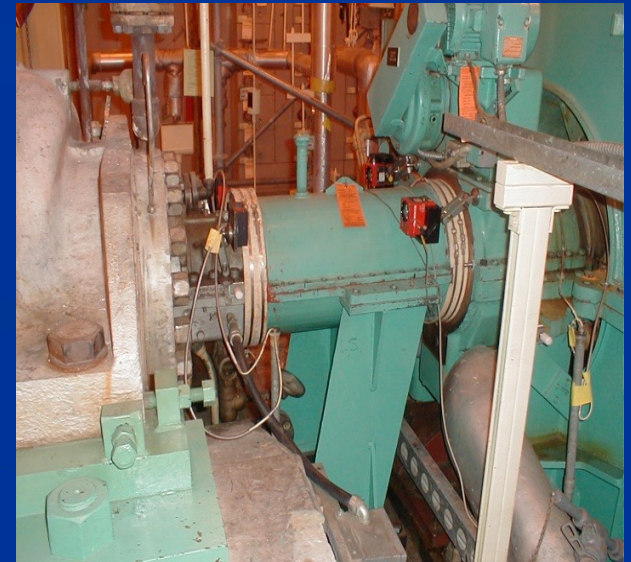
- Proactive Maintenance takes PdM and PM to the next level
- Proactive Maintenance is a philosophy of precision in all maintenance evolutions
- Examples include:
 - Precision balancing of rotating assemblies
 - Hot alignment to compensate for thermal growth
 - On site training mockups and flow loops
 - Filtration of new oil before use

PdM and Proactive Maintenance



*Precision
Balancing*

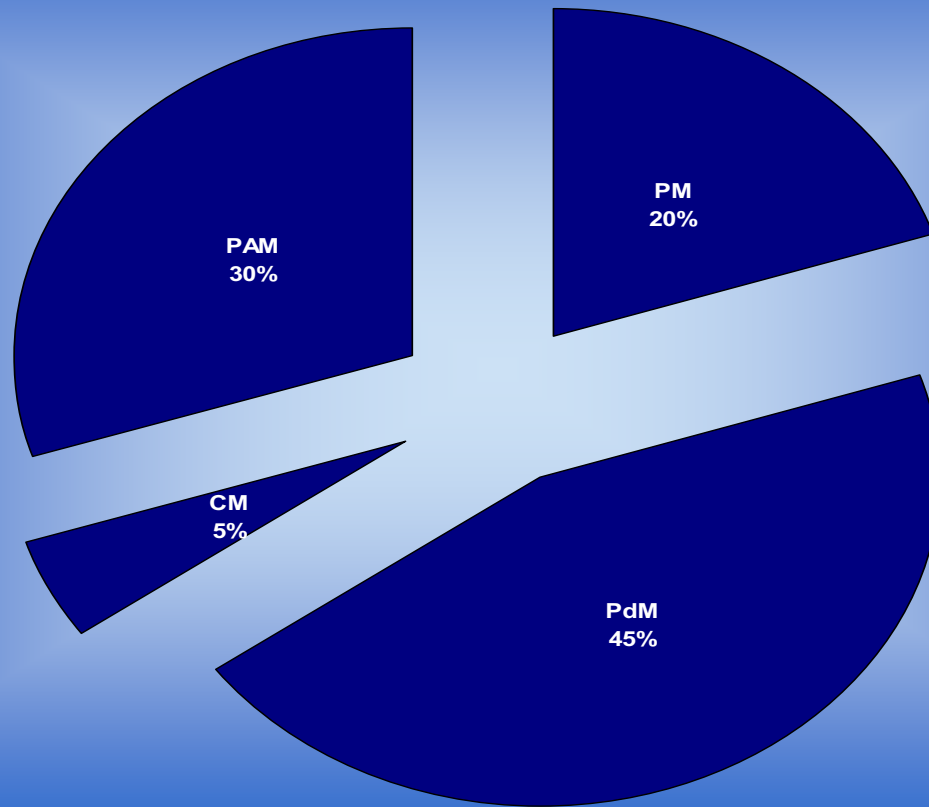
Hot Alignment



New Oil Filtration

Vision for Excellence

Percent



6th Key

Success Breeds Success

*A good PdM program will
advertise itself (with a little
help)*

Success Breeds Success

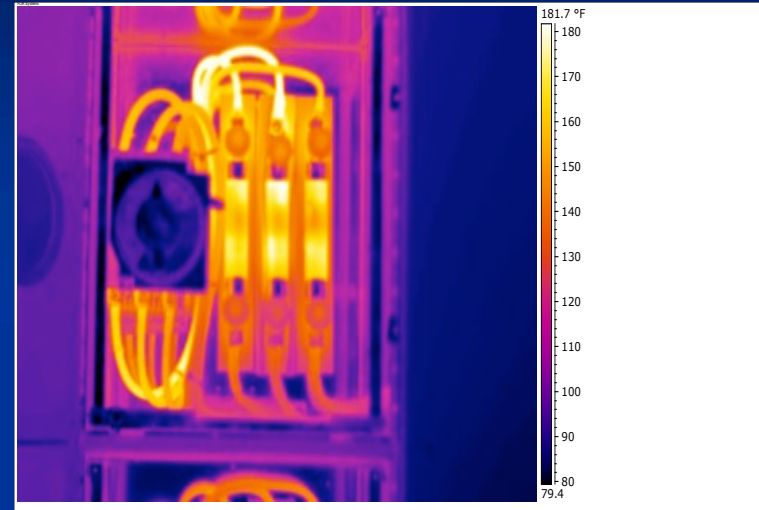
- Document PdM catches via “Hit Lists” and share this information with all plant groups
- Since the PdM program is focusing on critical plant equipment, this “hit list” is going to be valuable for all of the PdM customers
- When a plant problem occurs and PdM can help resolve the problem, offer up diagnostic help

CSORE Report "Hit List"

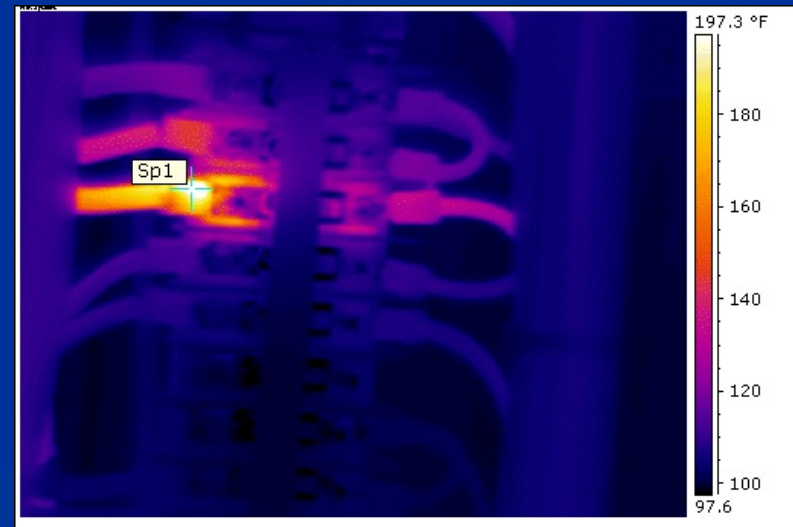
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Success Breeds Success: Document Findings

- 1PHP1D F02C,
Loose connections
X,Y Phase on breaker

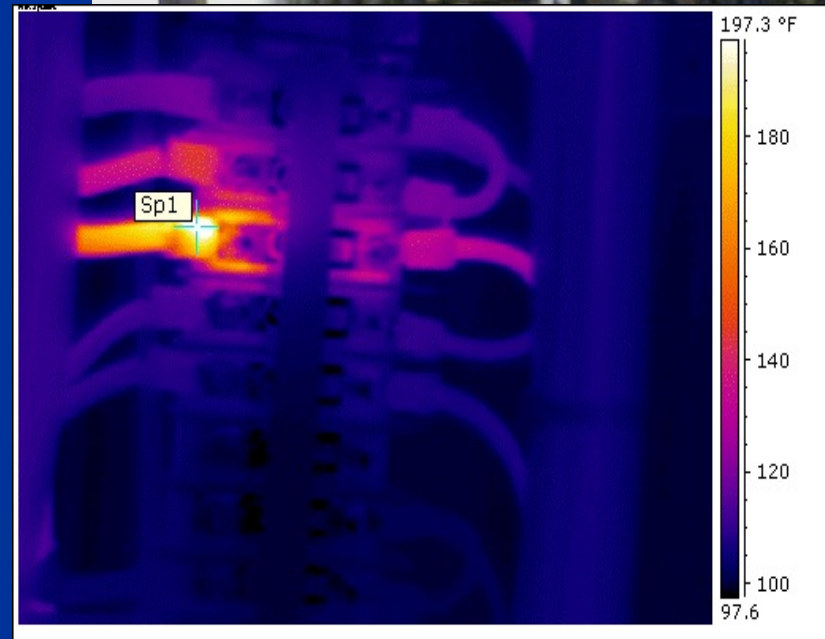
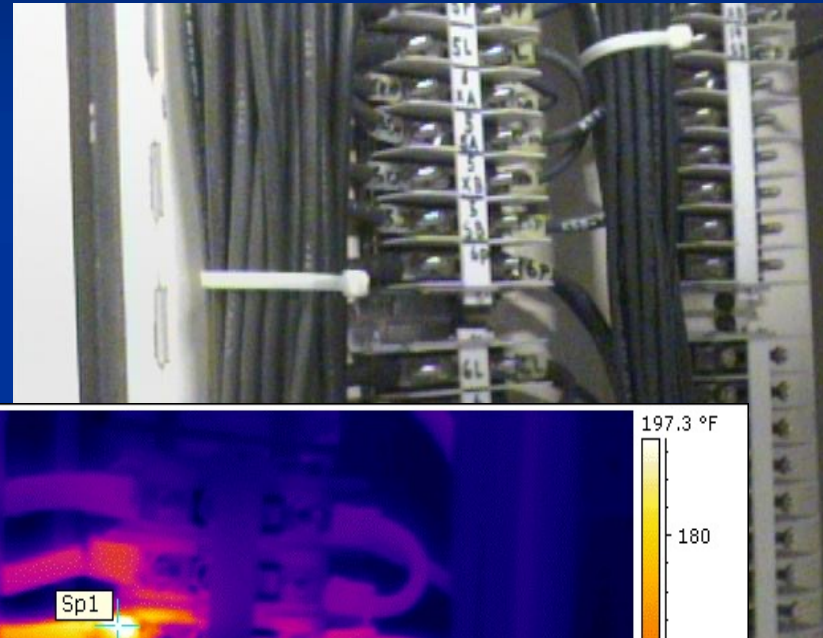


- 1CTCCSA CA Heat
Trace, Bad
Connection, Spot
temp of 206 deg F

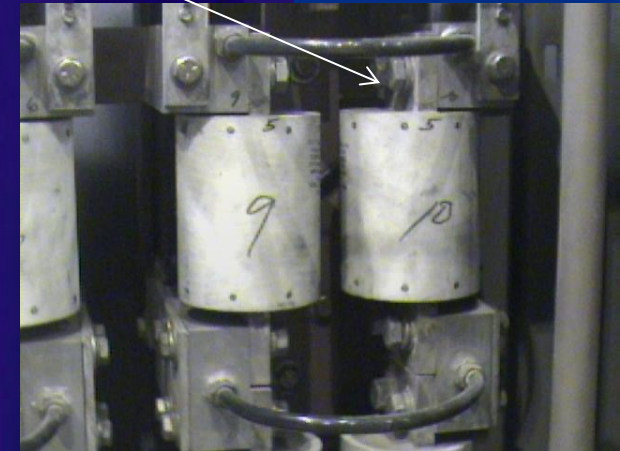
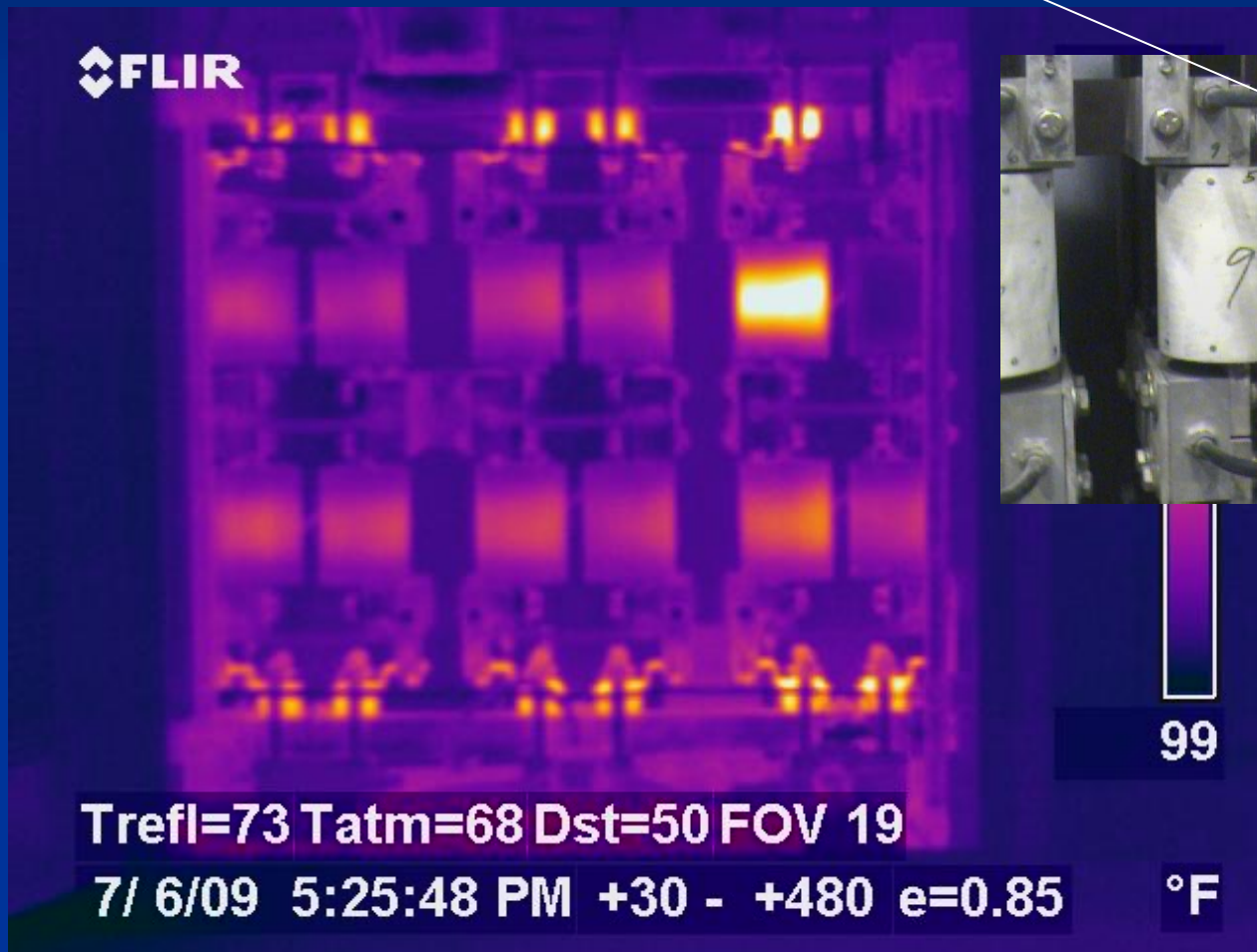


Thermography

- 1CTCCSA CA Heat Trace
- Bad Connection, Spot temp of 206 deg F
- WR # 929411, Nov., 2007

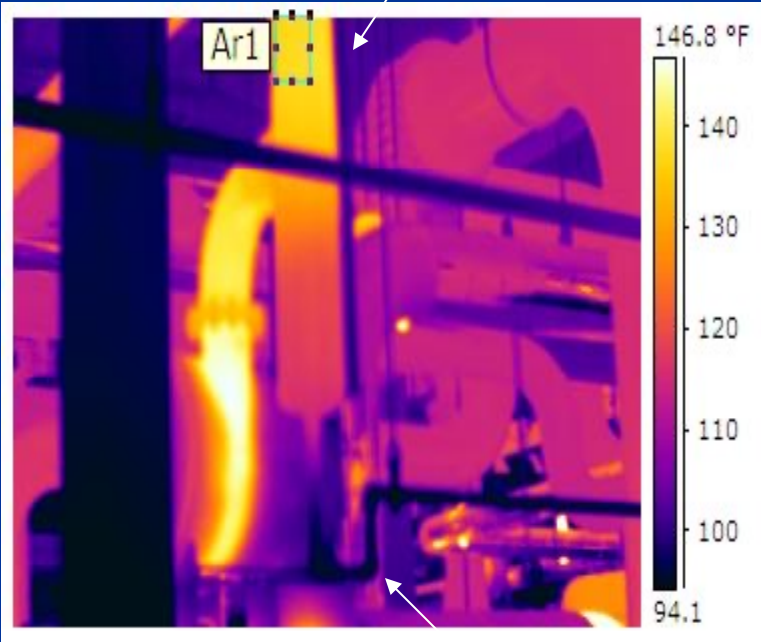


Unit 1 Exciter Rectifier Fuses Showing Unequal Loading (loose connection on #10)



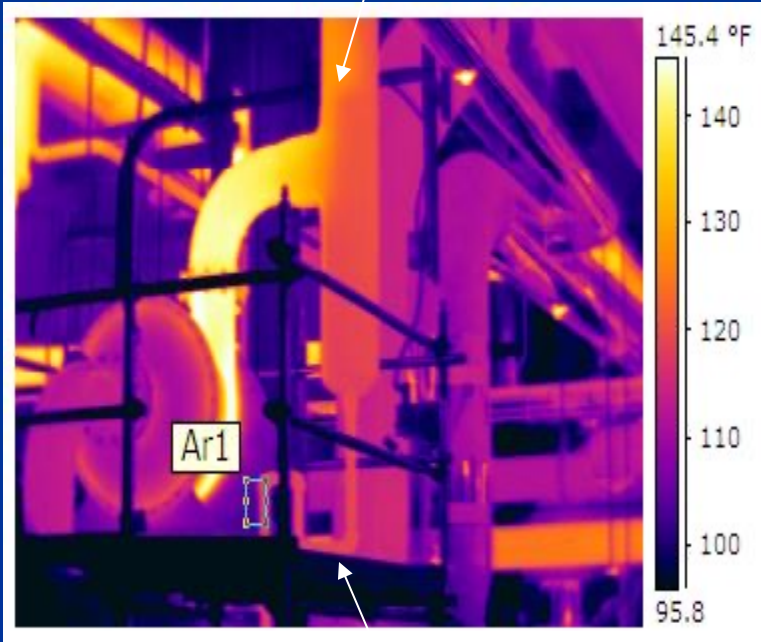
Document Findings: Unit 2 Steam Packing Exhauster (Blocked Discharge)

U1 SPE: Note Hotter Discharge Temp



Loop seal normal temp

U2 SPE: Note Cooler Discharge Temp



Loop seal temp high, indicating Blow-by

Document Findings: Oil Analysis

- Increased particle count and increased Fe (iron) along with changes in vibration spectra.
- 2C5 RC fan gearbox broken teeth



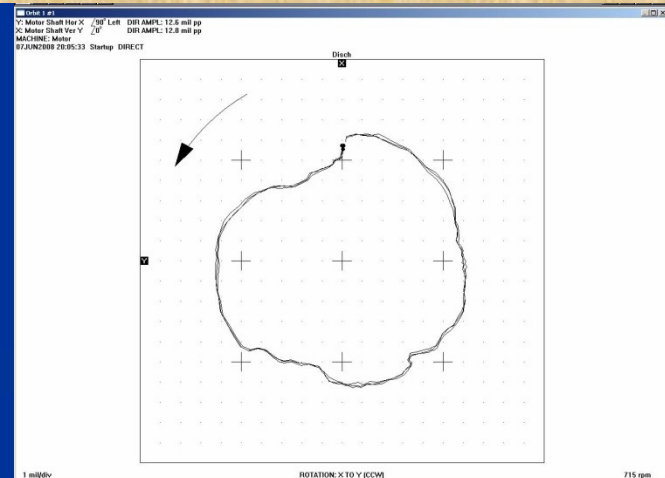
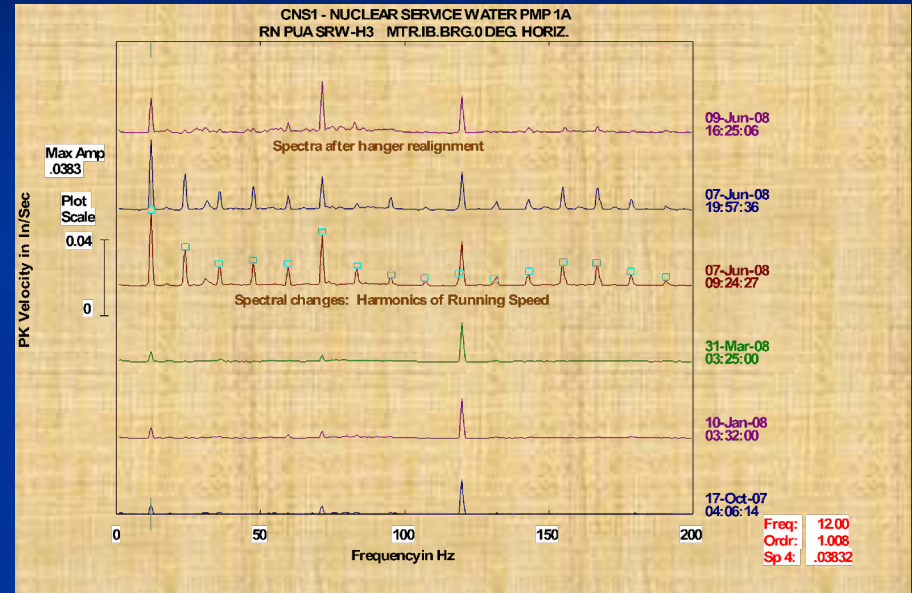
Document Findings: 1A Nuclear Service Water Pump Hanger Misalignment



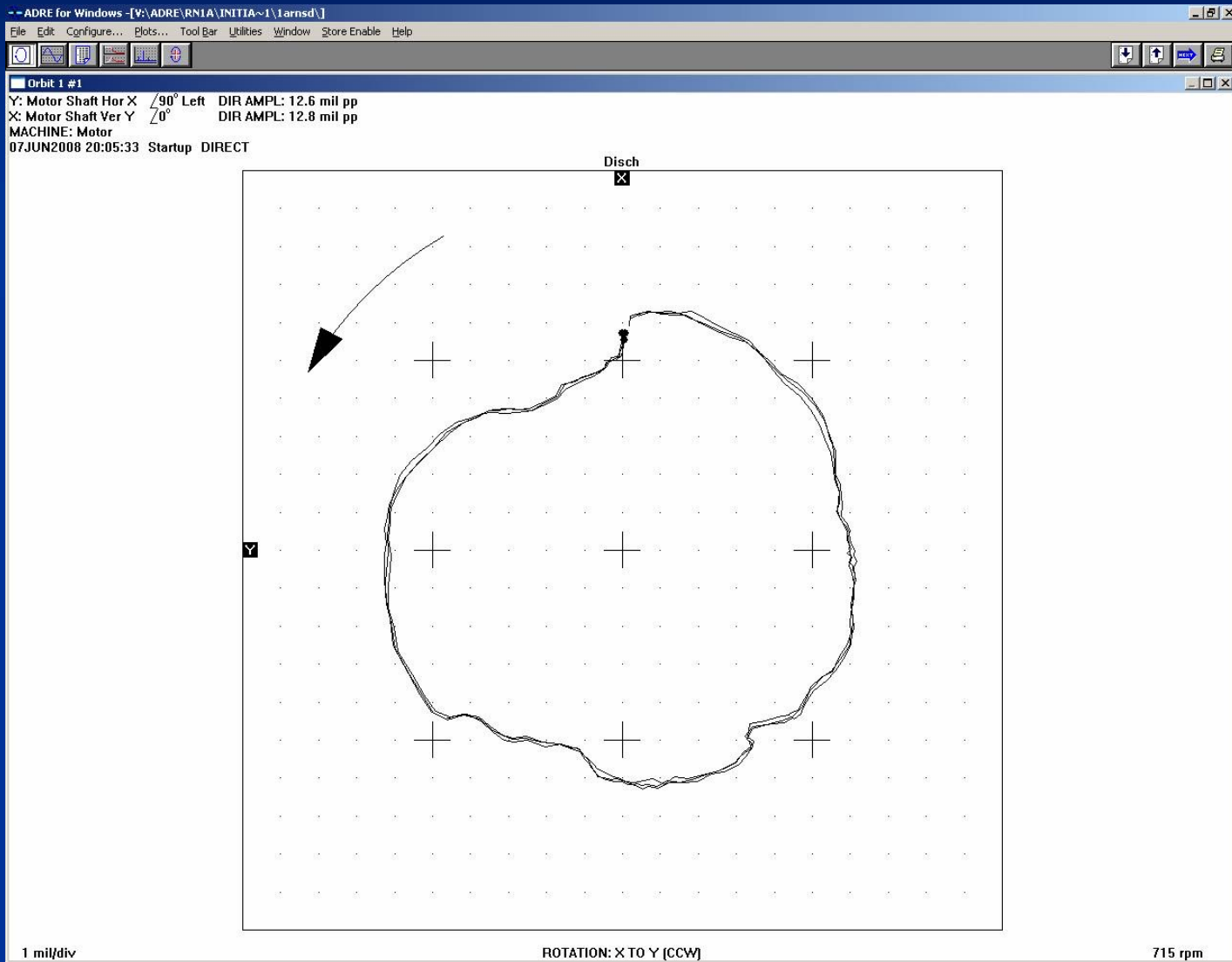
Hanger
Supports

Document Findings: Vibration.....1A Nuclear Service Water Pump

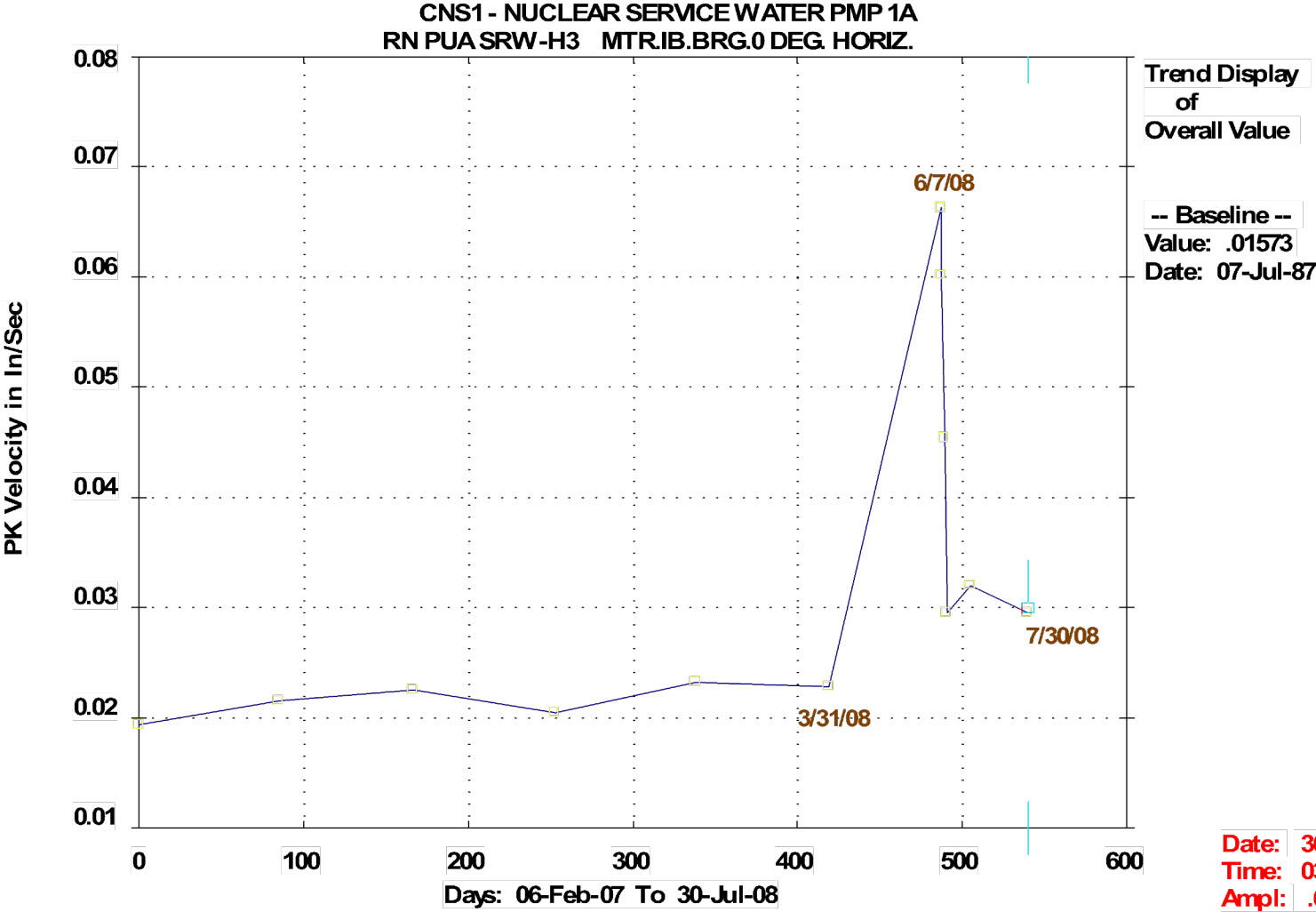
- Sulzer deep draft pump refurbished after about 15 years of service. New pump installed in May, 2008
- Startup data on June 7, 2008 showed ~4X increase in overall amplitudes
- Orbit shape should be circular to slightly elliptical. At about 10-12 o'clock position, the orbit appeared to be restrained.



Normally, the orbit shape should be circular to slightly elliptical. At about 10-12 o'clock position, the orbit appears to be restrained.

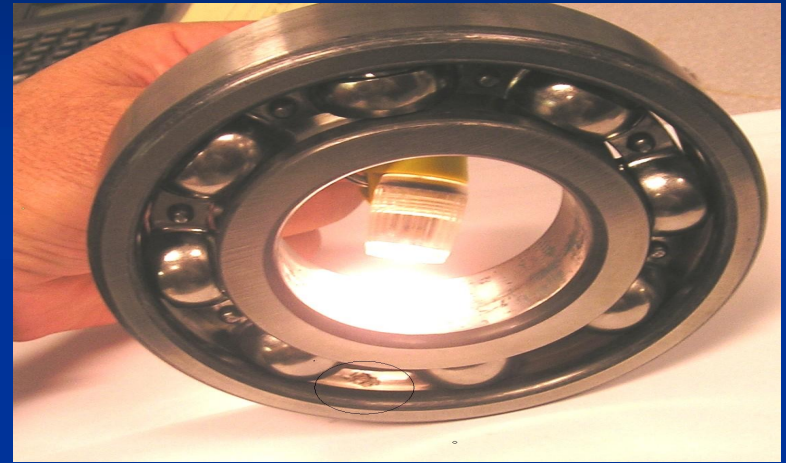


Plot of overall amplitude. Upper hanger readjustment led to a decrease in overall amplitude. Harmonics of running speed went away. We suspect the misalignment was causing a rub in one of the pump bushings.



Document Findings

- 2A Lower Containment Ventilation Fan Motor Inboard Bearing Defect



- 2Z1 IPB Outer Race Spall



2Z1 IPB Outer Race Spall



Success Breeds Success

Ring your own bell....Advertise your program successes externally

- Uptime Magazine (Overall PdM, Oil, Vibration, Thermography, ultrasound, motor testing)
- ICML (Augustus H. Gill and John Battle Awards) for lubrication excellence
- Outside groups such as INPO, EPRI, Vibration Institute

7th Key

*Never Mistake Vibration For Forward
Movement*

*Keep the program moving
forward by continuing to
strive for improvements*

Moving Forward: PdM Training

- Develop a long range training program
- Vibration Certification: Catawba has individuals certified as follows:
 - Category I: 4
 - Category II: 2
 - Category III: 1
 - Category IV: 2
- Thermography: Catawba certifications are as follows:
 - Level I – 1
 - Level II – 5
 - Level III - 2

Our long range plan includes certifications in oil analysis (MLA through ICML)

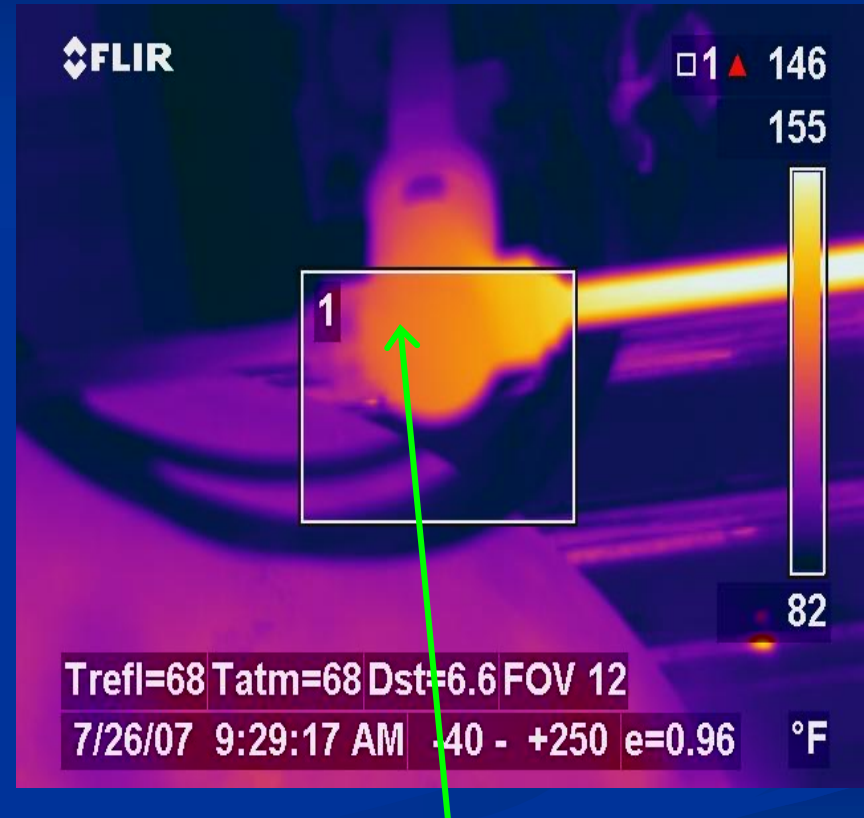
Moving Forward: Thermography

- Installation of Infrared sightglasses



Moving Forward: Flow Accelerated Corrosion Inspection Optimization

- Infrared thermography used to optimize FAC inspections
- If valves are closed, downstream piping UT inspections for pipe erosion are not needed
- Reduces labor intensive UT inspections by an average of 25 inspections/18 month cycle
- Savings
\$3,000 X 25 inspections=
\$75,000/cycle or \$50,000/year



High Pressure Steam Extraction Valve 2HA-06 (Closed)

Moving Forward: Thermography

- Infrared camera for checkout by all system and plant engineers for walkdowns

Moving Forward: Oil Analysis

- Just finished a bar coding labeling project
- Catawba needs to install more oil sampling ports

Moving Forward: Vibration

- Continue to improve on-line monitoring systems by replacing obsolete BN and SKF systems
- Install permanent accelerometers on more components that are enclosed



7 Keys to PdM Success

1) Never mistake activity for achievement

Develop a PdM process and stick to it – For Catawba, AP-913

2) Time must be cherished

Focus time monitoring the most important components

3) Learn from mistakes and failures

Perform root cause analysis to improve PdM knowledge base

4) Others are smarter than you

Attend training and Benchmark Others

7 Keys to PdM Success

5) Good is never good enough

Develop Meaningful Metrics and Proactive Maintenance Measures

6) Success Breeds Success

A good PdM program will advertise itself (with a little help)

7) Never mistake vibration for forward movement

Seek out new PdM methods, equipment, processes to continuously improve the program and move forward

Questions?

