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M A R I N A B A Y S A N D S



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2 Case Studies on Unique Machinery Repair Techniques:

- Brush Plating Repair of Eroded Compressor Diaphragm
- Combining 2 Failed Gearboxes into 1 Functional and Reliable Gearbox

Presented by:

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- Karl Edward, Facilities Engineer

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Authors Bios



Chin Tze-Hur is currently a Mechanical Engineer in the Crane Group at EMEPMI. Prior to this position he has worked as a Systems Engineer within the Instrumentation Controls and Electrical Group and as a Machinery Engineer within the Machinery and Power Group at EMEPMI.



Stan Uptigrove is the Senior Machinery Advisor for EMEPMI. Prior to this assignment he was Team Lead for the Machinery, Automation and Power Group at ExxonMobil Upstream Research Company. He started his 34 year career at Nova Corporation In Canada where he was responsible for many of the world's first application of gas seals and magnetic bearings to turbomachinery. Mr. Uptigrove was one of the founders and senior management of Revolve Technologies who developed the first digital magnetic bearing systems. He also worked as the Global Director at Flowserve Corporation responsible for managing their gas seal and new unit pump seal business.



Karl Edward is currently a Planner for EMEPMI. Prior to this position he has worked as a Facilities Engineer for the Tapis Asset and as a Machinery Engineer within the Machinery and Power Group at EMEPMI.

Abstract

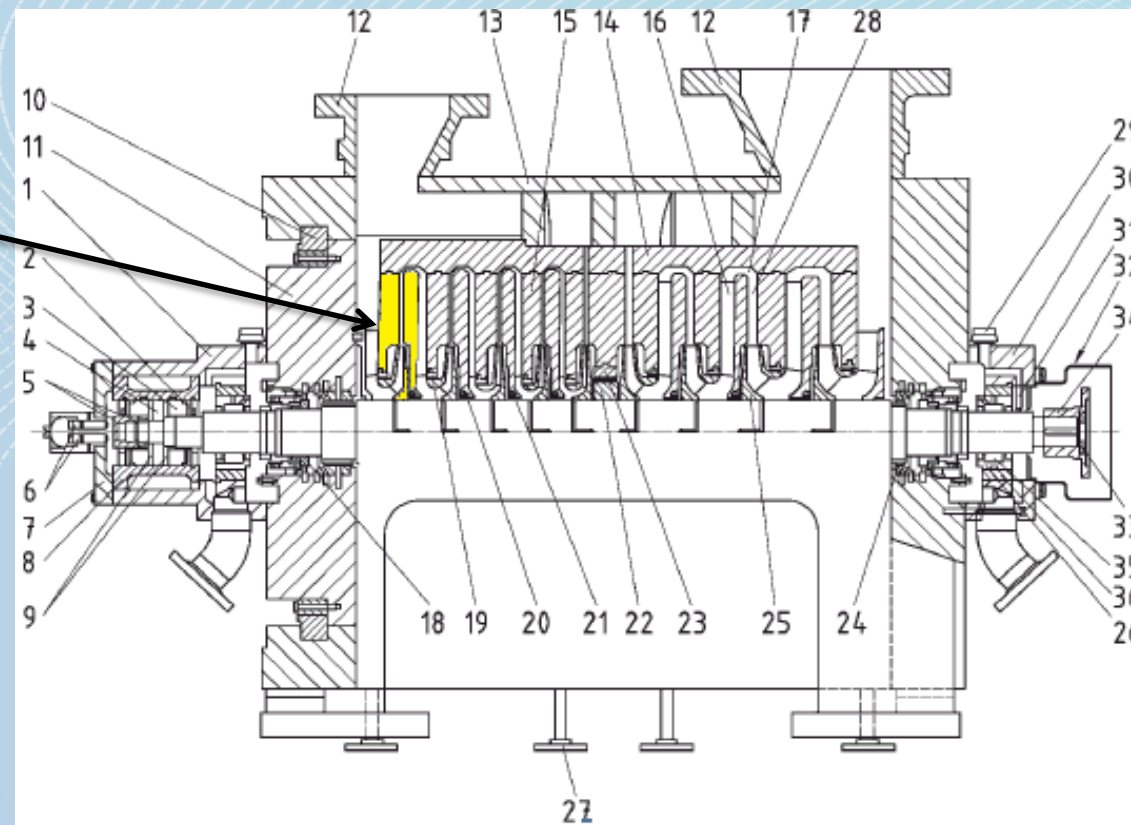
- When machinery challenges arise in aging equipment within declining oil and gas facilities it requires innovative solutions taking into account life expectancy, production impact and declining production to establish fit for purpose solutions
- With good engineering, unique repairs can help limit production impact, extend equipment life and provide a more robust solution for current operating conditions
- Two case studies of novel equipment repairs are presented to demonstrate these principles:
 1. Brush Plating Repair of Eroded Compressor Diaphragm
 2. Combining Two Failed Gearboxes into One Functional and Reliable Gearbox
- Focus was on restoring safe and reliable operation

Case Study 1 – Brush Plating Repair of Eroded Compressor Diaphragm

Background

- A compressor train removed for overhaul in June 2011 due to loss of compressor efficiency
- HP inlet diaphragm vanes found eroded (70% material loss) due to liquid carryover
- >6 months of lead delivery time for new diaphragm

*Inlet
Diaphragm
highlighted
in yellow*



Compressor Assembly Cross Section



HP Inlet Diaphragm (bottom)



HP Inlet Diaphragm (top)



Eroded Vanes(bottom half)



Eroded Vanes(top half)

Brush Plating Summary

Applicability

- Able to perform electroplating repair at localized damaged areas (eg. diaphragm vanes)
- Faster lead time (repair completed in approximately 6 weeks)
- Repair conducted at regional one-stop comprehensive engineering service provider shop

Methodology

- Rectifier provides direct current required for plating and anodizing
- One lead connected to plating tool (anode) vs other lead connected to part being plated (cathode)
- Circuit completed when plating tool touches work surface, allowing copper deposit onto surface
- Copper deposit was build up to around 2-3mm thickness while final nickel cap (bonding + hardness/erosion resistance) was plated to 0.5mm thickness



*Repaired Top Half of
Diaphragm*

Trial Run Conducted

Sample Bend Test

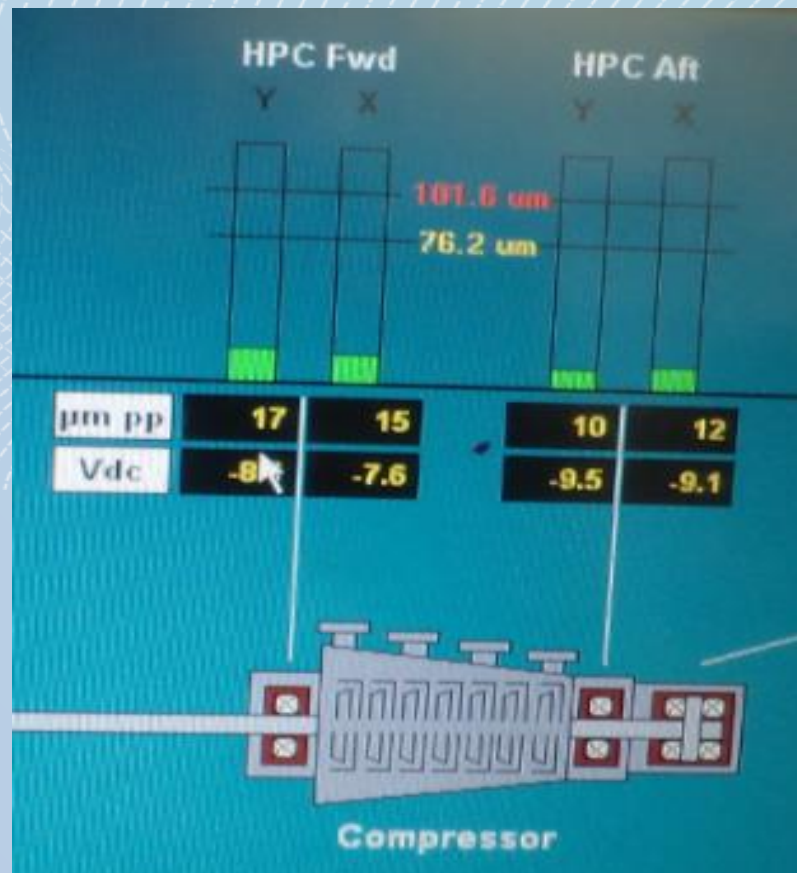
- Trial run conducted to ensure adhesion effectiveness
- 3 cast iron samples were plated with approximately 0.045mm of copper overlaid with 0.002mm to 0.003mm of nickel
- 3 samples were bent to approximately 80 degree on the inner radius
- After bending, all 3 samples were found with only micro cracks and no lifting or delamination of the brush plated copper.



***Bent Cast Iron with Copper
Nickel Plating***

Operation Concerns

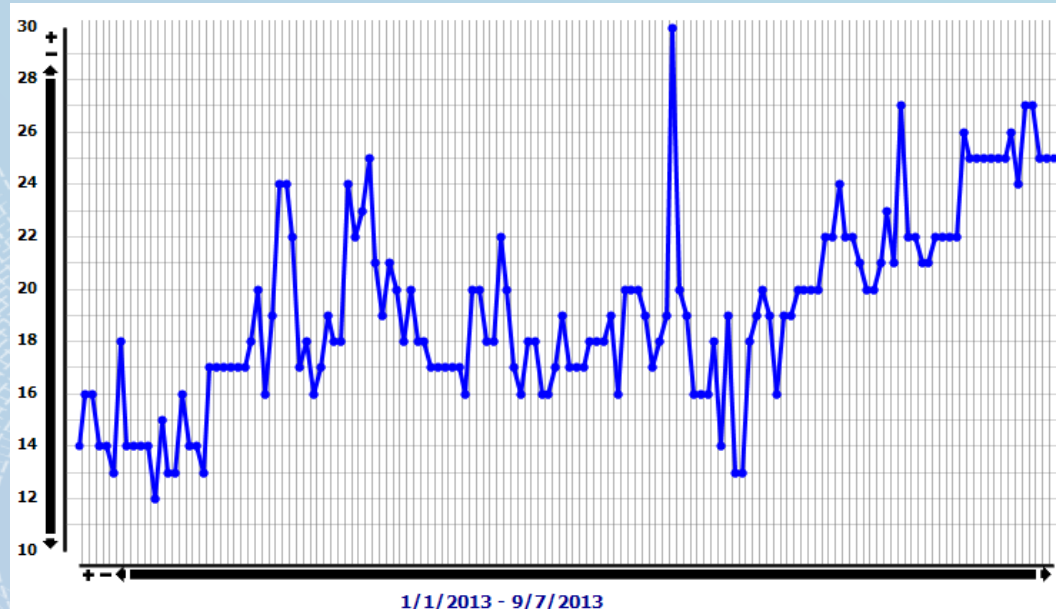
- Concerns that nickel copper plating may debond under normal operating conditions (high pressure + temperature)
- Potential to obstruct flow which may affect compressor efficiency or worst case subjected as FOD which may result in elevated vibration and potential premature compressor overhaul
- Consistent monitoring of compressor vibration channels trending for early signs of bonding failure
- Temporary solution until new diaphragms arrived



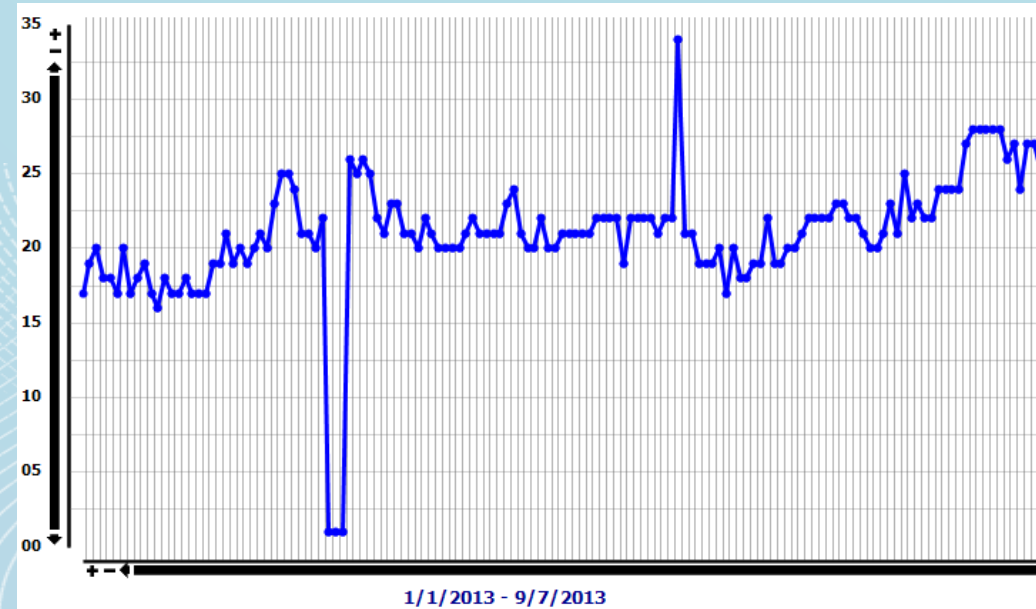
Screenshot of TCP HMI for compressor vibration channels

Vibration Channels Monitoring (after repair)

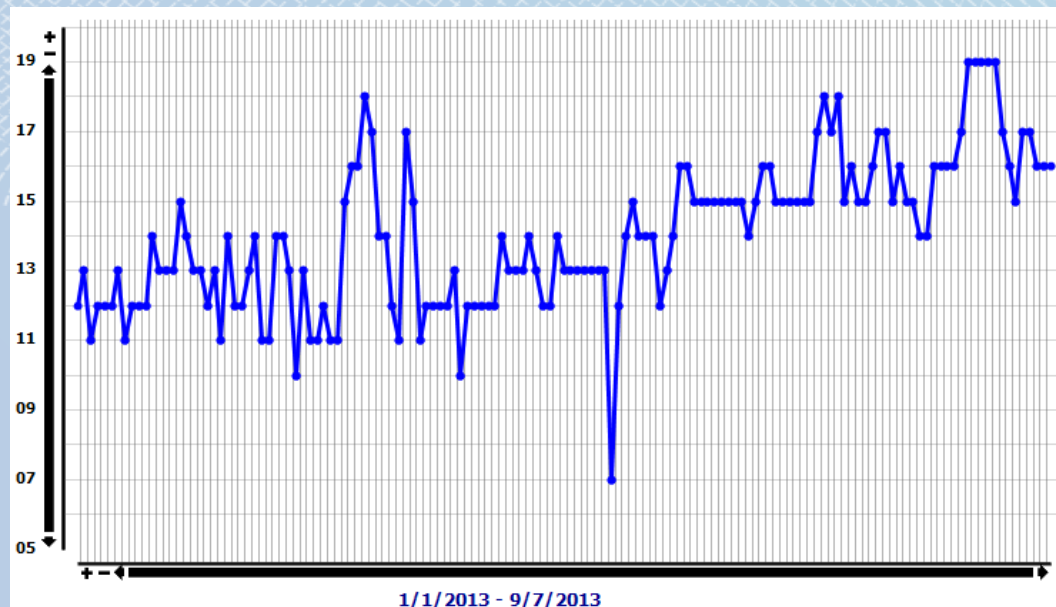
HPC Fwd/DE X axis vibration(um)



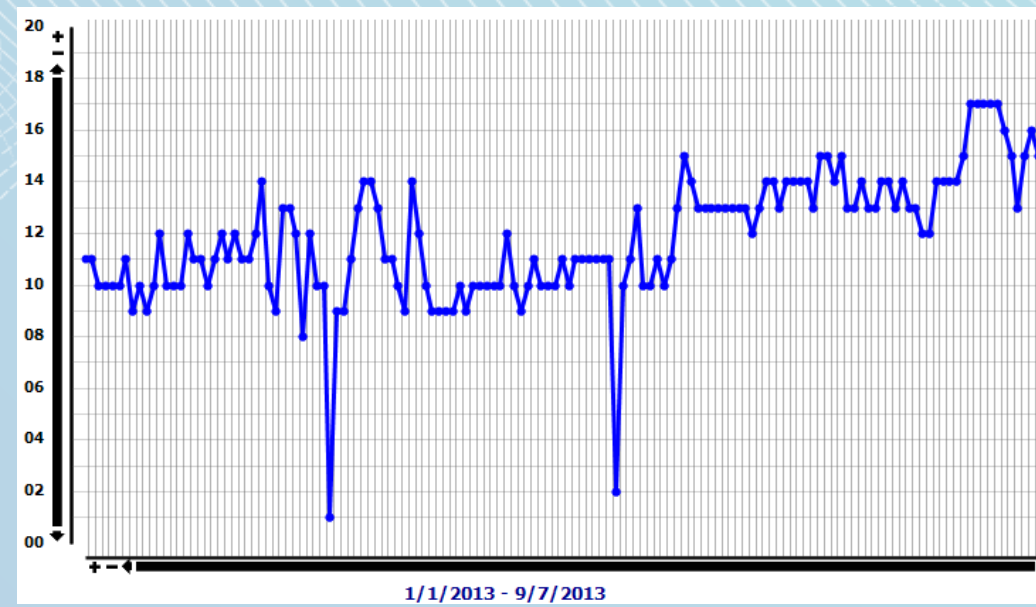
HPC Fwd/DE Y axis vibration(um)



HPC Aft/NDE X axis vibration(um)



HPC Aft/NDE Y axis vibration(um)



NOTE

- Alarm setpoint : 76.2um
- SD setpoint : 101.6um
- Trend extracted from Jan to Sep 2013

Findings Post 12,000 Run Hours

| Blade No. | Bottom Half Vane Dimensions | | | | | | Top Half Vane Dimensions | | | | | |
|----------------|-----------------------------|--------------------|----------------|--------------------|------------|--------------------|--------------------------|--------------------|----------------|--------------------|------------|--------------------|
| | Length | | Thickness (mm) | | | | Length | | Thickness (mm) | | | |
| | Pre-Repair | Post 12k run hours | Front | | Back | | Pre-Repair | Post 12k run hours | Front | | Back | |
| | | | Pre-repair | Post 12k run hours | Pre-repair | Post 12k run hours | | | Pre-repair | Post 12k run hours | Pre-repair | Post 12k run hours |
| 1 [^] | 49 | 53 | 2.91 | 4.00 | 4.50 | 8.20 | 45 | 53 | 1.88 | 3.82 | 6.08 | 7.56 |
| 2 [^] | 49 | 53 | 2.80 | 3.35 | 8.04 | 8.50 | 47 | 53 | 1.40 | 3.95 | 6.36 | 8.70 |
| 5 [^] | 49 | 52 | 1.80 | 3.40 | 7.30 | 8.30 | 50 | 52 | 0.80 | 4.00 | 5.32 | 8.50 |
| 6 [^] | 46 | 52 | 1.00 | 3.90 | 6.11 | 7.70 | 44 | 52 | 1.60 | 4.20 | 3.73 | 7.75 |
| 7 [^] | 45 | 52 | 1.37 | 4.60 | 4.00 | 8.30 | 42 | 52 | 1.48 | 3.75 | 3.81 | 8.50 |

- [^] blades selected for brush-plating due to severe erosion
- blade thickness is measured 2mm away from the edge



Diaphragm After Plating

Conclusion Case Study 1 – Brush Plating Repair of Eroded Compressor Diaphragm

- Successful pilot repair – 2 years of operation
- Reduced compressor downtime
- Adequate for continued operation
- Useful reference for similar turbo machinery repairs

Case Study 2 – Combining 2 Failed Gearboxes into 1 Functional and Reliable Gearbox

Background

- Gas turbine driven compressors used for re-injection of gas from oil producing wells, commissioned in 1979
- Compressors scheduled to run only 2 additional years due to depleting production
- Two separate failures a few weeks apart on two different parallel compressor trains caused by changes in gas composition, shaft misalignment and 30 years of operation
- Gearbox to compressor coupling failure resulted in collateral damage to connected equipment
- Damage to output shaft of high speed gear rotor

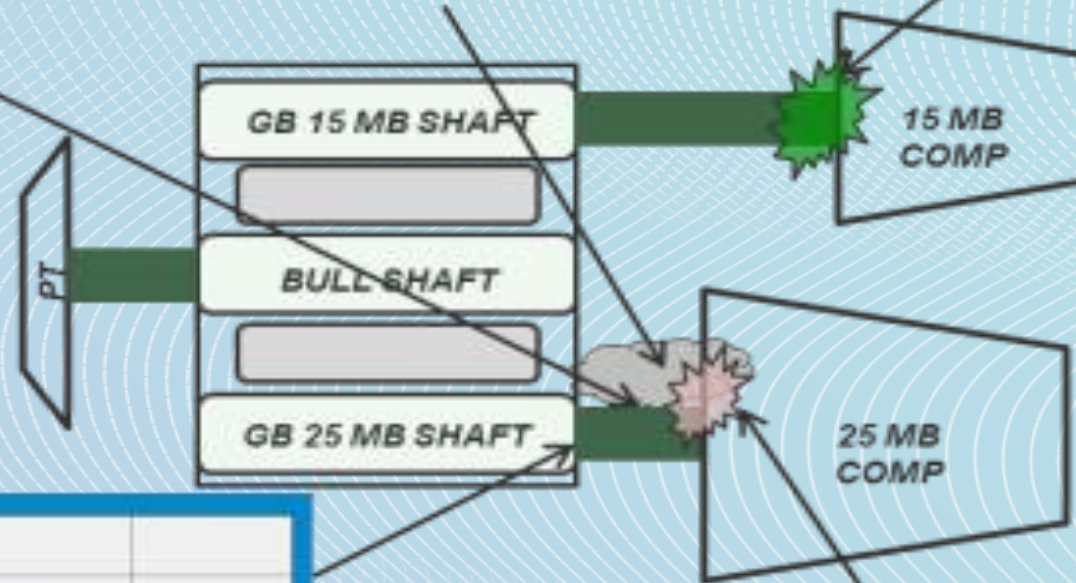


Location of debris



View inside the cover

Location of August 15 MB Coupling Failure



Section of Coupling Cover Broken



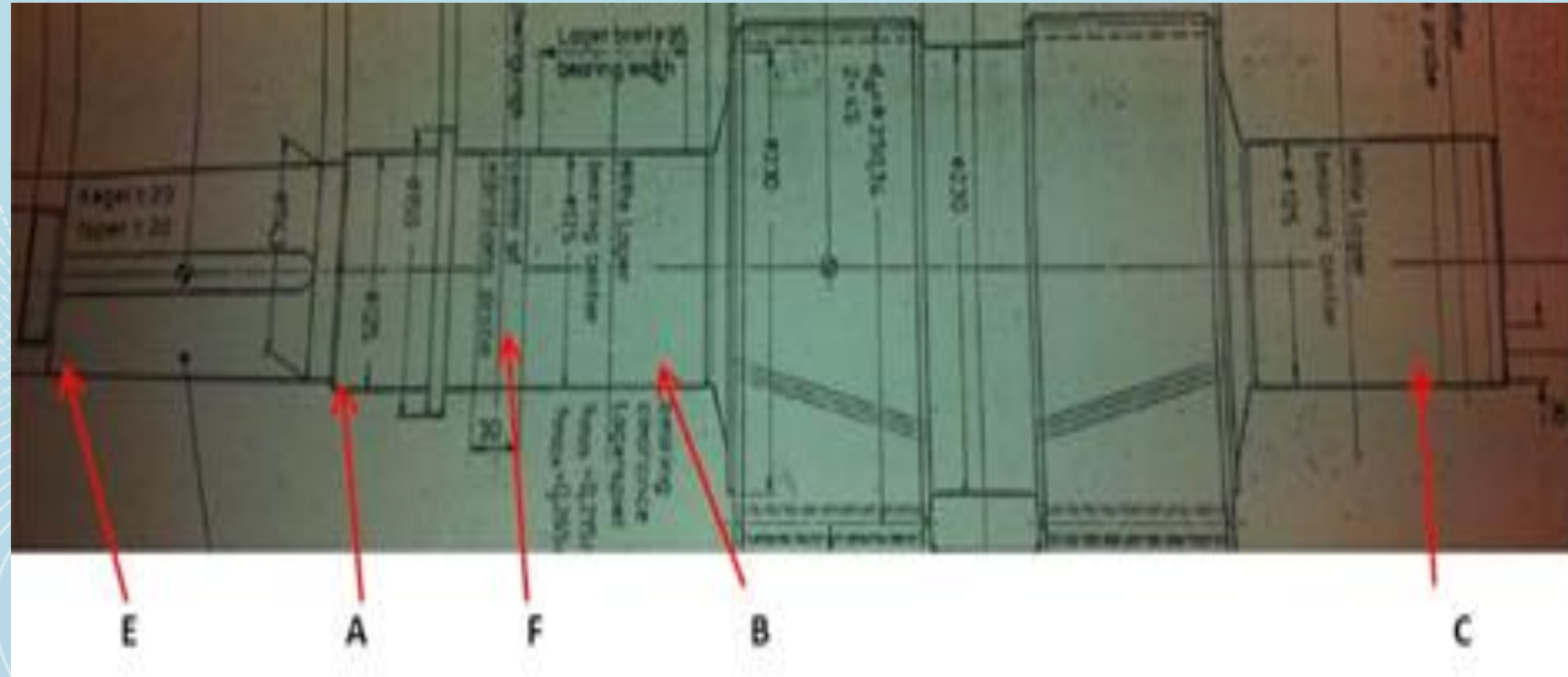
Location where vibration SD was Detected

High Speed Gear Rotor Set Overview

- 5 rotors: 1 input, 2 output and 2 intermediate shafts
- Input Shaft is driven by the PT and is the only shaft with a thrust bearing (gear double helical design)
- Speed Ratio is the same on both output shafts (1.489)
- Output Shaft 1 Drives a larger Low Pressure Compressor
- Output Shaft 2 Drives a Smaller High Pressure Compressor
- Operating speed for either Output Shaft is approximately 11,000 rpm

High Speed Gear Rotor Damage Assessment

- First coupling failure (Train A) led to bent output shaft 1 driving Low Pressure Compressor Coupling
- Second coupling failure (Train B) led to bent output shaft 2 driving High Pressure Compressor Coupling



| | A=Shoulder at Taper | B=DE Journal | C=NDE Journal | E=End of Taper |
|------|---------------------|--------------|---------------|----------------|
| TDC | 0.0 | 0.0 | 0.0 | 0.0 |
| 90° | -0.01 | 0.0 | +0.07 | +0.29 |
| 180° | -0.01 | -0.03 | -0.05 | +0.10 |
| 270° | 0.0 | -0.02 | -0.13 | -0.23 |

Dial Indicator Run-out Readings
(units in mm)

Procedure for Running-in Gear Rotors

Possibility to put together one set of gear rotors from remaining (undamaged) rotors

- Replaced damaged Output Shaft 1 from Train A with 'good' shaft from Train B

Potential for gear failure with over 30 years of wear in with different rotor

- Carried out tooth contact checks (verified 80% tooth contact area)
- Case-hardened gear tooth surfaces

Start-up Runs:

- Start up to Slow-roll (less than 1000 rpm)
- Start up to idle speed (approx 7000 rpm) for 24 hours with monitoring
- Start up to full load speed

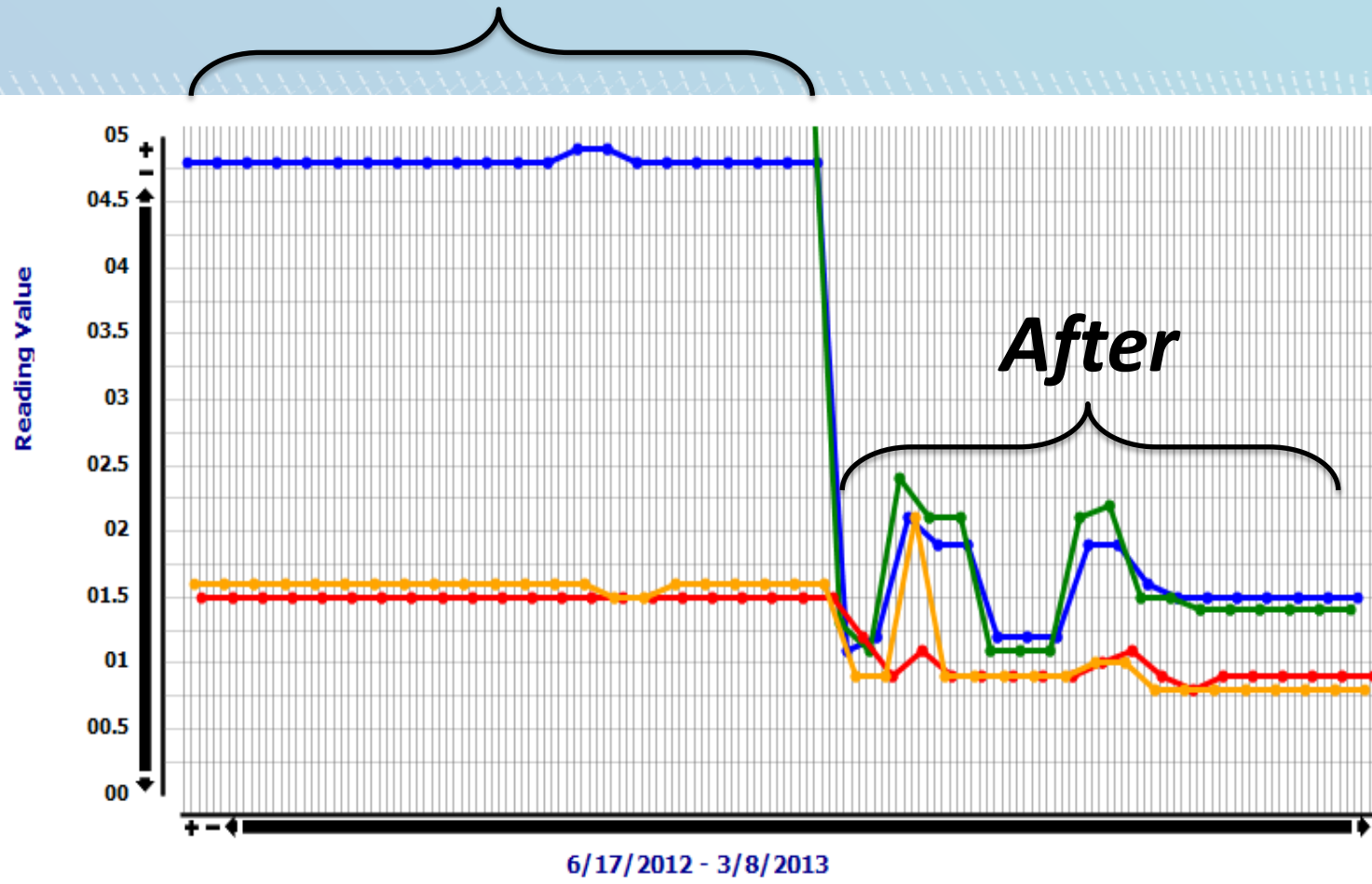
Successfully reinstated one compressor train



Assembly and set up for on-site gear tooth contact verification

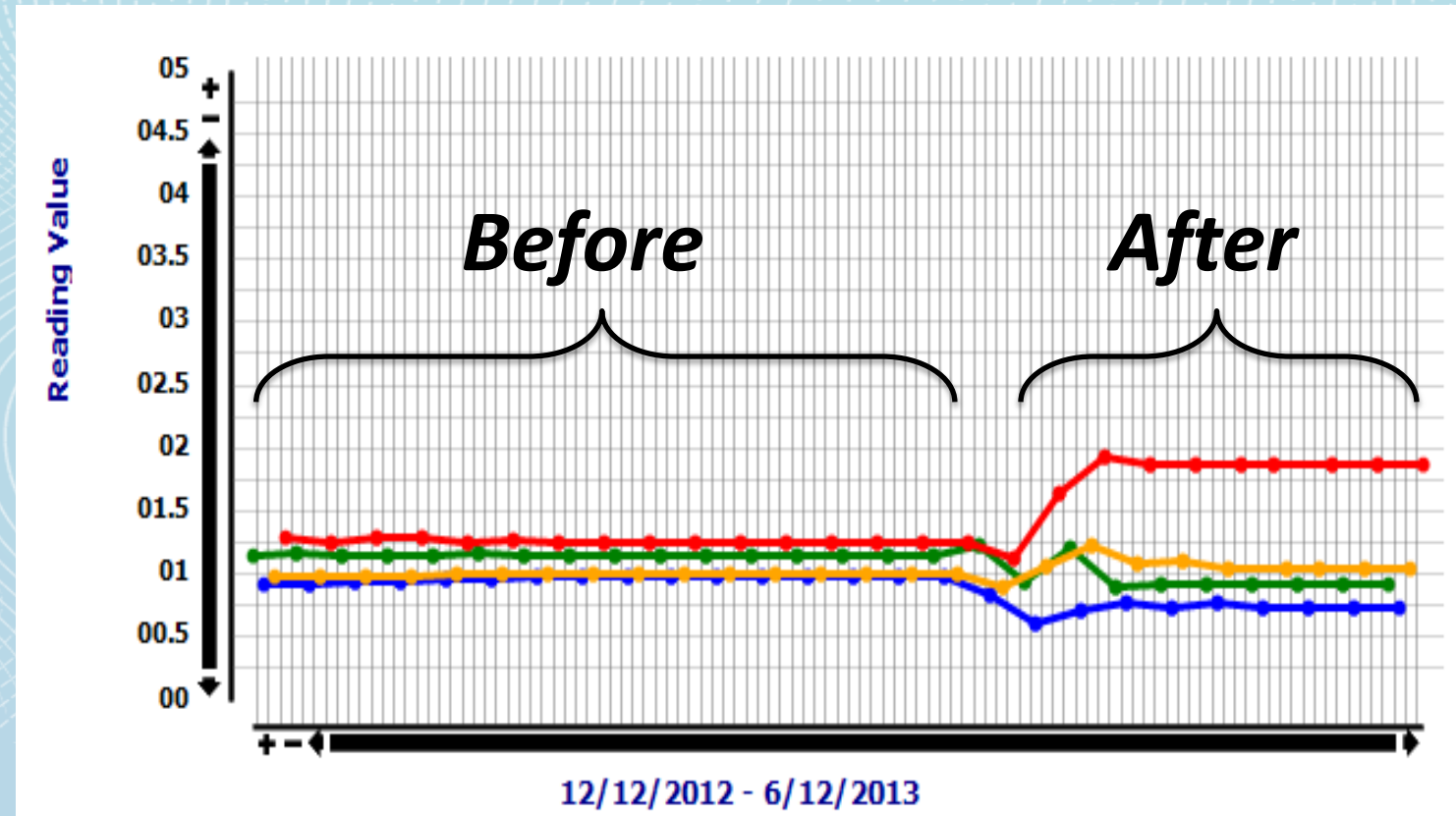
Running-in Gear Rotors (Vibration)

Before



“Before and After” Vibration Readings for GB Unit A

Before



“Before and After” Vibration Readings for GB Unit B

Workshop Background

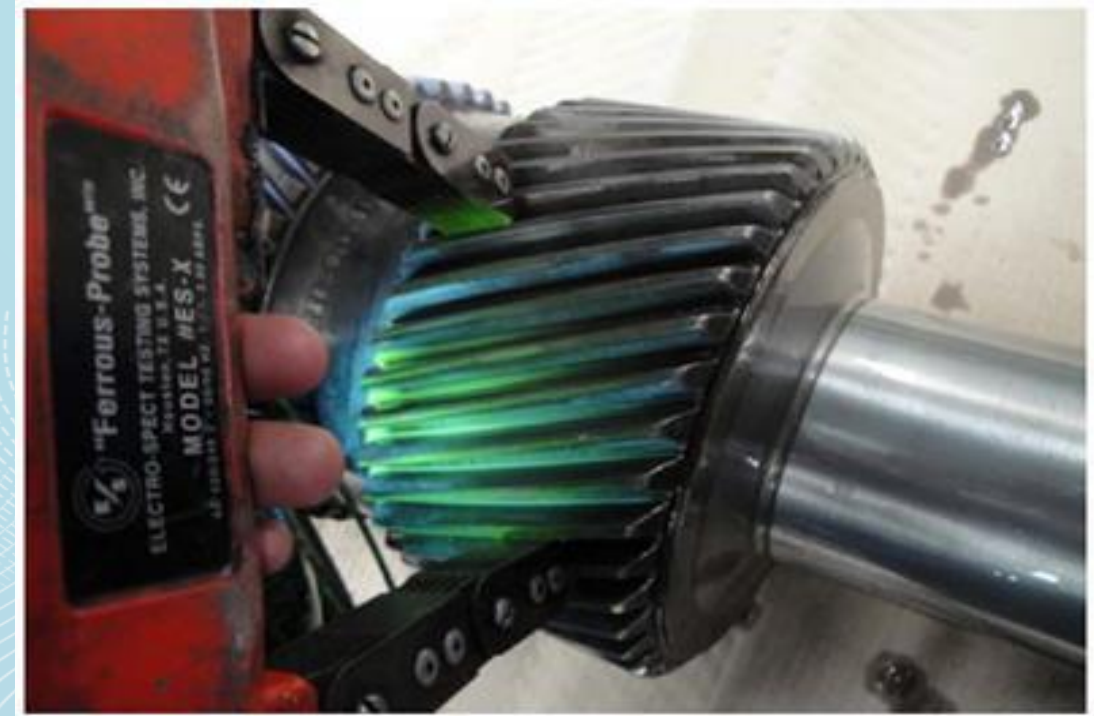
- Regional mechanical workshop specializing in turbomachinery overhauls and repairs, and other machining and metallurgical work
- Areas of expertise:
 - Assembly and disassembly
 - Thermal spray coating
 - PTA welding
 - Machining, grinding and turning
 - Cold work and build-up
 - Non-destructive tests



60 Ton Hydraulic Press

Detailed Damage Assessment on Bent Rotor

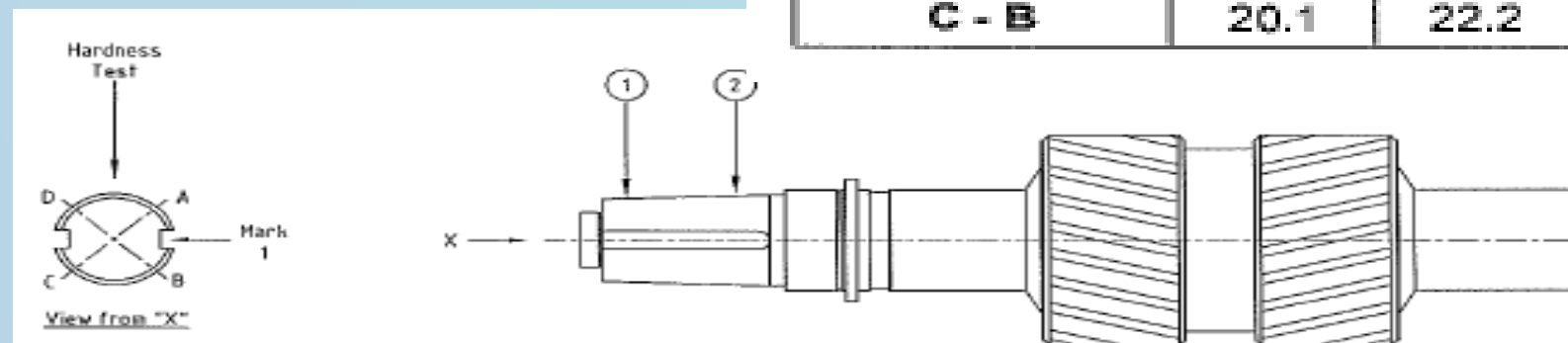
- Workshop run-out readings were almost identical to those at site (TIR approximately 0.2 mm)
- Balancing checks verified tapered shaft eccentricity
- Magnetic Particle Imaging (MPI) and Ultrasonic testing (UT) demonstrated no subsurface cracks or defects
- Rockwell Hardness to confirm material identity and yield stress
- **ASSESSMENT:** Rotor damage was confined to eccentricity thus repair options could be pursued



Above: MPI testing on gear teeth
Below: Hardness test location and results

Incoming Hardness Test, unit: HRC

| POSITION / NO. | 1 | 2 |
|----------------|------|------|
| A - D | 22.5 | 20.6 |
| C - B | 20.1 | 22.2 |



Repair Procedure and Execution on Bent Rotor

3 Step repair approach:

1. Hydraulic press to correct gross eccentricity
2. Surface grinding of shaft taper to restore 1:20 taper profile to coupling hub area
3. Full inspection to confirm no damage sustained in Steps 1 & 2

Outcome:

- Hydraulic press reduced shaft TIR from 0.2 mm to 0.05 mm
- Surface grinding successfully restored TIR to within 0.01 mm (shortened shaft by 1 mm)
- **SAFETY!:** Rotor balancing, MPI, UT and Die-penetrant tests showed rotor to be acceptable



Tapered Surface Grinding



*Completed Surface Finish
(roughness 0.266 micron)*

Conclusion Case Study 2 – Combining 2 Failed Gearboxes into 1 Functional and Reliable Gearbox

- Restored 1 Train to operation within 2 weeks
- Successful pilot repair on Low Pressure Compressor (LP) Gearbox Output Shaft
- Repeated Repair on HP Gearbox Output Shaft
- Both Compression Train Operating without gearbox issues for more than 18 months
- Useful reference for similar turbo machinery repairs

Overall Conclusions

These case studies highlight the need and benefit of innovative engineering for repairs of rotating equipment in aging oil and gas production facilities

- Focus was on restoring safe and reliable operation
- Taking into account life expectancy, declining production and production impact to establish fit for purpose solutions
- These factors drove the need to be open to unique engineered solutions that have proven to be successful
- Others can benefit from this experience in applications of these solutions to similar issues
- The support of the OEMs and repair shops played a key role in the success of these unique approaches

Acknowledgements - Case Study 1

25MB5/5I Compressor, Compressor Crosssection (1983). *Elliot Drawing W-856203*. United Technologies Elliott

YC Chan, Y. C. (2011). *Job Completion Report – 25MB5/5I Bundle with Diaphragms*, Singapore: Frontken Singapore Pte Ltd.

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Acknowledgements - Case Study 2

Heinz P. Bloch, F. K. (1999). Machinery Failure Analysis and Troubleshooting. Houston: Gulf Professional Publishing.

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