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Improvement of Rotating Equipment Reliability Using Optical Metrology

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Presenter/Author bios

Dale Winterhoff, Flowserve

Accomplished Technical Manager with a diverse background in a variety of disciplines that include 10 years in nuclear power generation, 15 years in petroleum refining, and 5 years in fine chemical production.

Currently Dale is the Manager, Technical Solutions for North America within the Flowserve Services group. He concentrates in providing value to clients through comprehensive field reliability audits and by resolving critical and/or complex system problems through the execution of technically challenging and unique field assessments. Dale has had a lead role in the development and application of Flowserve's IPS Wireless Technology.

He holds a Bachelor of Science in Mechanical Engineering from the University of Illinois and specialized in direct energy conversion processes.

Presenter/Author bios

DJ Winterhoff, Trilion

Disciplined Applications Engineer specializing in the use of digital image correlation to solve complex problems in the Aerospace, automotive, power, and oil refining industries.

He focuses on collecting data in support of customer need for complex analytics. Routinely works to resolve production concerns to validate design in real life field scenarios. Have developed testing methods for long term structural monitoring.

He holds a Bachelor of Science in Physics with a concentration in nano-technology from Shippensburg University.

Abstract

Rotating Equipment Reliability Using Optical Metrology

- Extreme thermal piping displacements were thought to be the root cause for the observed failures at a large refinery, namely 9 mechanical seal failures in 3 months. Optical Metrology methods were used to identify failure modes of critical service vacuum bottoms pumps. The testing involved the use of both photogrammetry and digital image correlation to show how the large thermal displacements of the piping contributed to the mechanical seal failures. A high speed optical metrology rotordynamic study was also performed to observe the effects of the piping displacements on the operation of the pump.

Vacuum Bottoms Pumps

Problem Statement

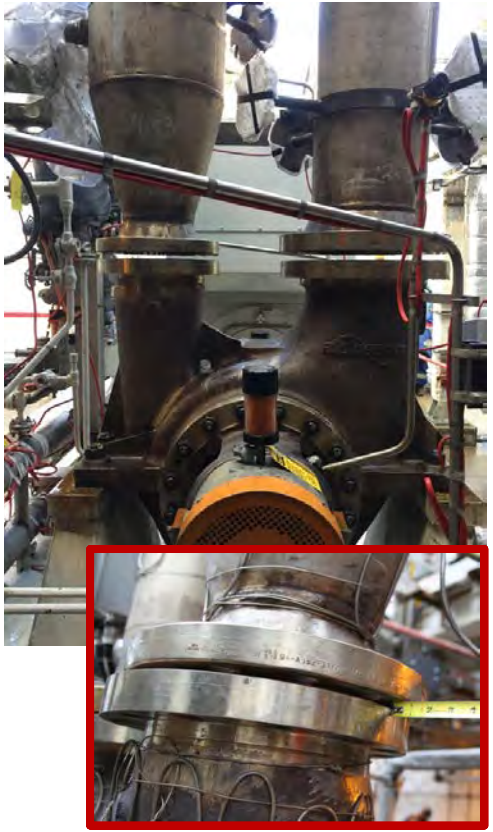
- One of the largest vacuum bottoms systems in the world, commissioned in 2010. The three identical top-top design, radial split, vacuum bottoms pumps experienced poor reliability of less than 12 mo. MTBF.
- Predominately seal failures, these would occur during warm-up operations with the off-line pump being warmed to 473F, affecting the running pump, catastrophic failure during start-up, or slow continuous leaks progressing to full failure.
- Majority of the seal failures followed a pattern of DE stationary face cracking at the drive pin, severe misalignment, photographing on the friction face, blistering SiC face, coning, and coking on the OB face

Above, seal faces that are cracked, blistered and contaminated with coke build-up

Vacuum Bottoms Pumps

Problem Statement

- All of the pumps exhibited severe piping alignment concerns. Typically 0.75" – 1.5" vertically and up to 1" offset.
- It was also determined that during original purchase the pumps were not specified to be stress relieved. High temperature pumps cast from 317L require stress relief or they will experience significant thermal distortion above 400°F.Normal casting procedures and manufacturing process do not normally perform a stress relief.
- Rumors of baseplate grout voids and poor installation practice compounded the situation.
- Hard credible data was missing to make actionable decisions on a path forward.

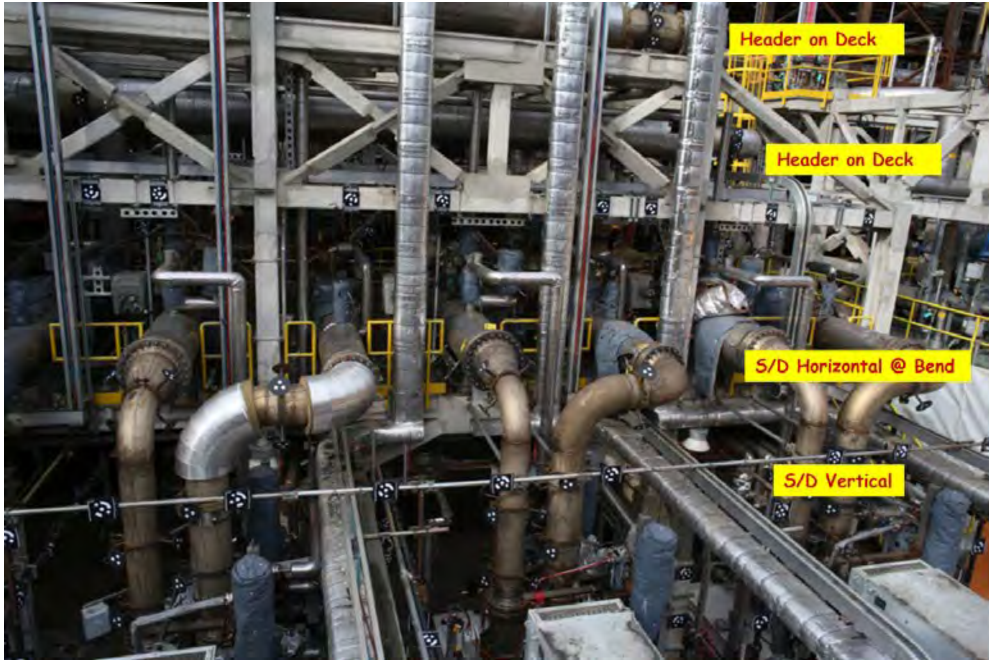


Above, severe pipe misalignment

Vacuum Bottoms Pumps

Monitoring Plan Objectives

- Data was collected from an Isolated Cold condition through hot standby and start-up
- Determine the direction and magnitude of displacement for the various system components including Piping & Structure, Pump, Motor, Baseplate
- Analysis of shaft torque and bending
- Strain capture for defined area for the pump nozzles and casing head
- Identify primary & secondary Root Cause factors



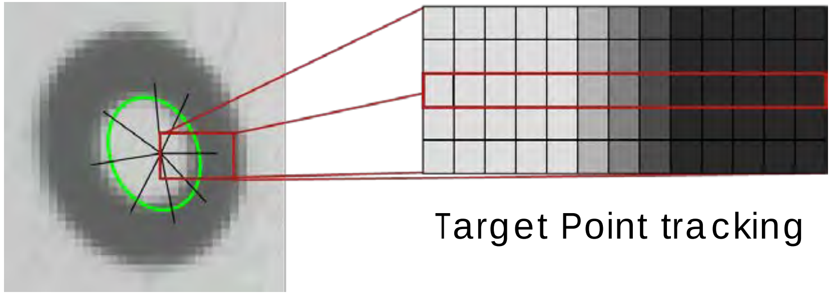
Above, shows an overview of the (3) pumps tested with the coded markers used by the optical metrology system. The label S/D refers to both suction and discharge piping

Vacuum Bottoms Pumps

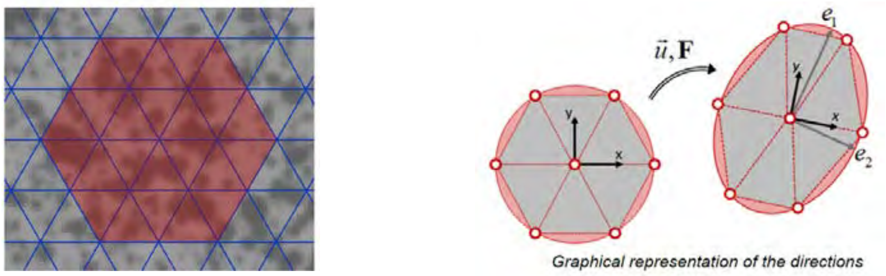
Optical Metrology

- Digital Image Correlation utilizes a stereo sensor pair that tracks a pattern or target point throughout the deformation cycle.
- Images from left and right sensor are correlated, rendering a 3D coordinate map or surface mesh
- Sampling rates range from elapsed time studies to high speed collection at millions of frames per second.
- High resolution sensors utilized are capable of measuring displacements on order of microns, strains accurate to 0.005%

ARAMIS Sensor



Target Point tracking

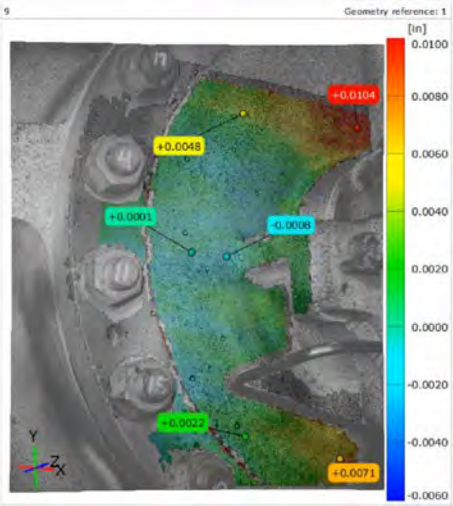


Surface Mesh Computation

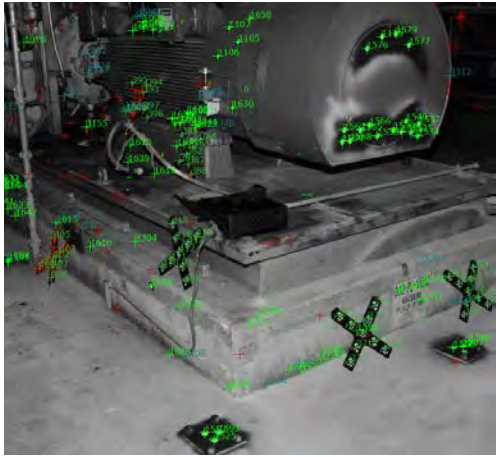
Vacuum Bottoms Pumps

Optical Metrology Data Collection

- Digital Image Correlation provides displacement, velocity, acceleration, extensometer, strain, shear and torque metrics displayed over a surface mesh or target dot similar to an FEA but is empirical.
- Photogrammetry data can provide 6 degree of freedom displacement data over a quasi-static test such as thermal growth for discrete points.

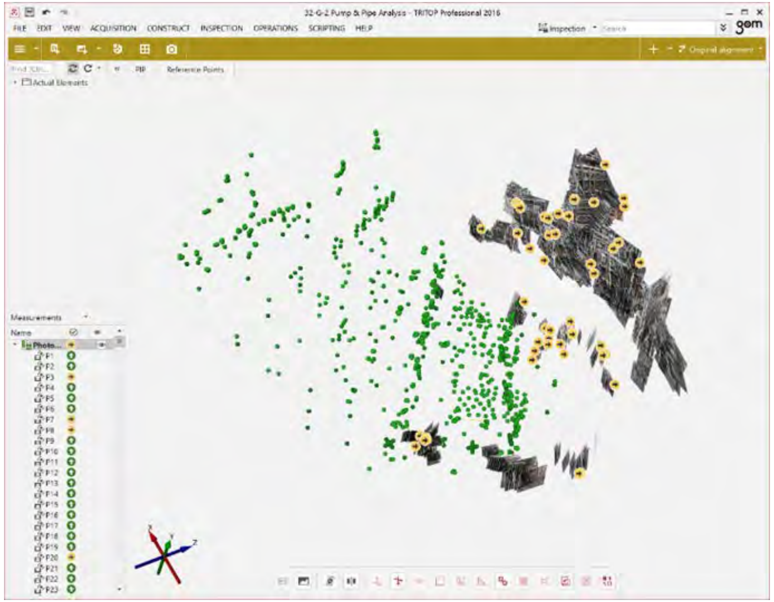


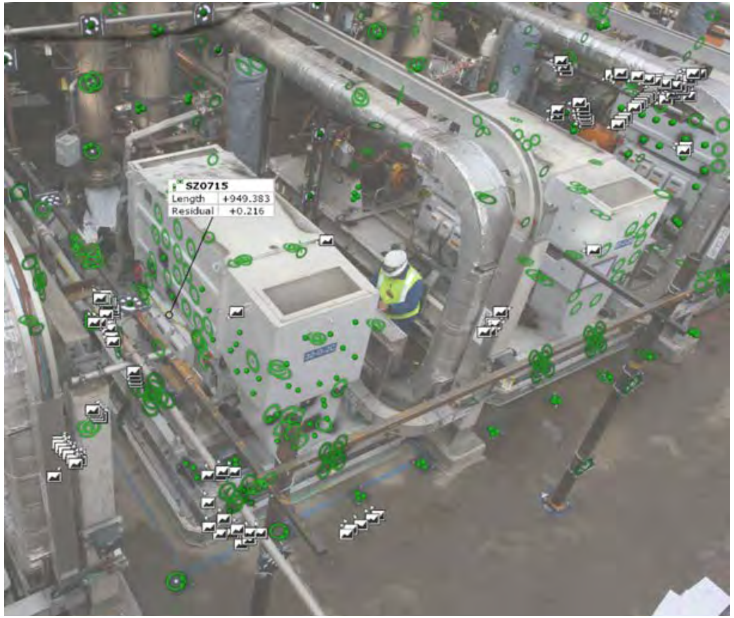
DIC data (left) shows axial displacement on pump head. Displacement and strain mapping possible with stereo cameras



Photogrammetry data (right) provides 6 Degrees of Freedom displacement data on all points seen

Vacuum Bottoms Pumps





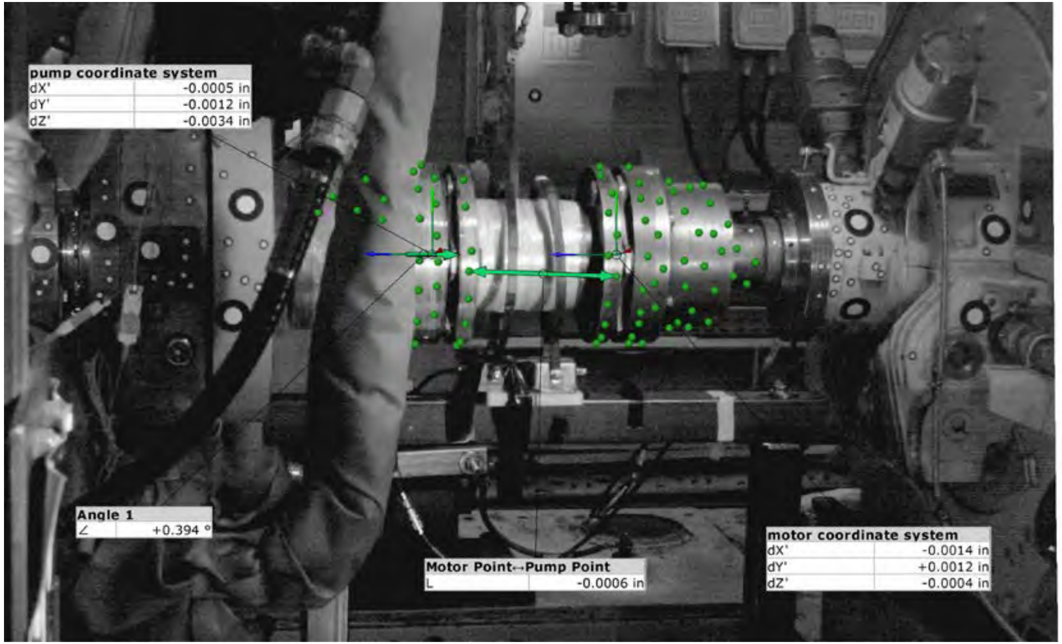
Optical Metrology was used to perform a time study from a cold condition through hot start-up to track movement of the piping, pump, motor, and baseplate to an earth reference. Total of 14 project files containing 10,852 pictures were then compiled to provide 3D coordinate analysis illustrating six degrees of freedom values for displacement.

Accuracy is National Institute of Standards and Technology certified to less than 0.001"

Vacuum Bottoms Pumps

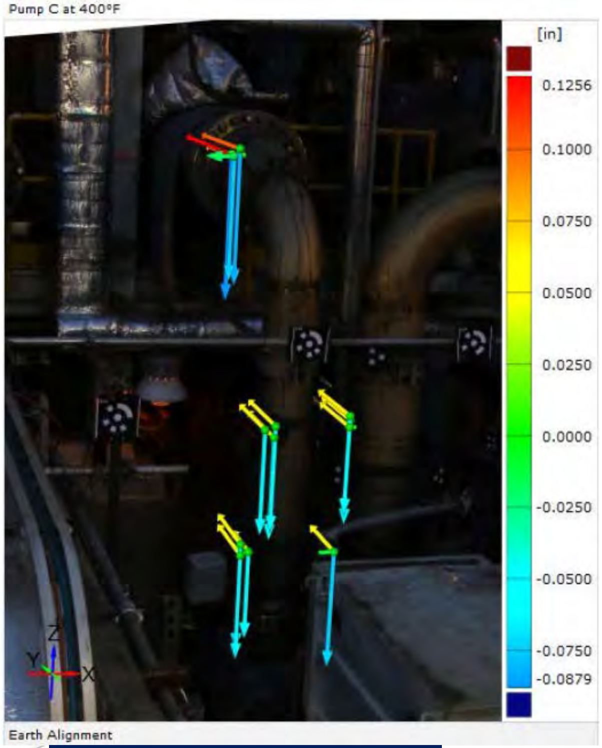
High Speed Optical Metrology

- Coded markers were also installed on the shaft, coupling, bearing housings and mechanical seal gland
- Shaft data was analyzed for conditions that would cause start-up failures
- Movie at right of a pump start-up illustrates the phase relationship across the coupling signifying significant angular misalignment is occurring

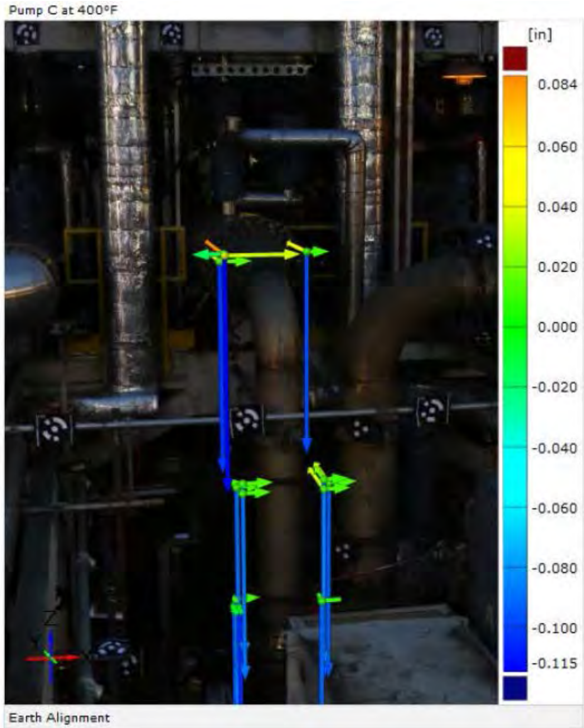


Vacuum Bottoms Pumps

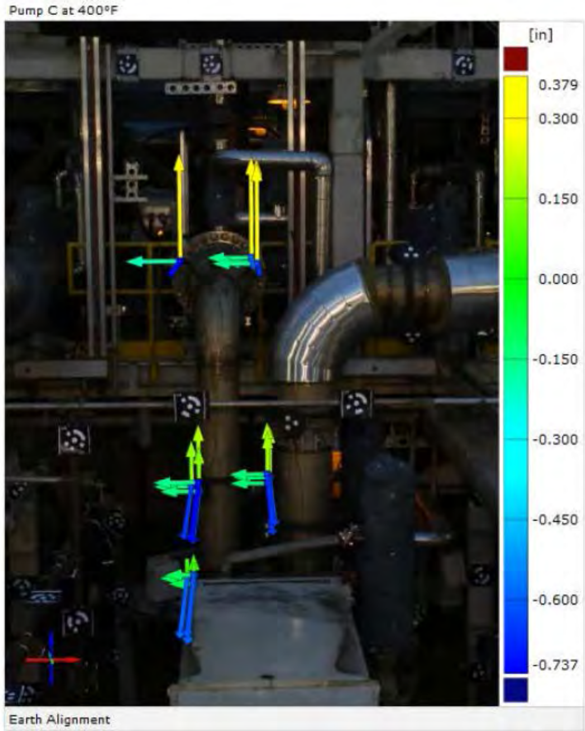
32-G2C Cold to 400°F - Suction Piping Vector Displacements



32-G2A Suction Piping while running



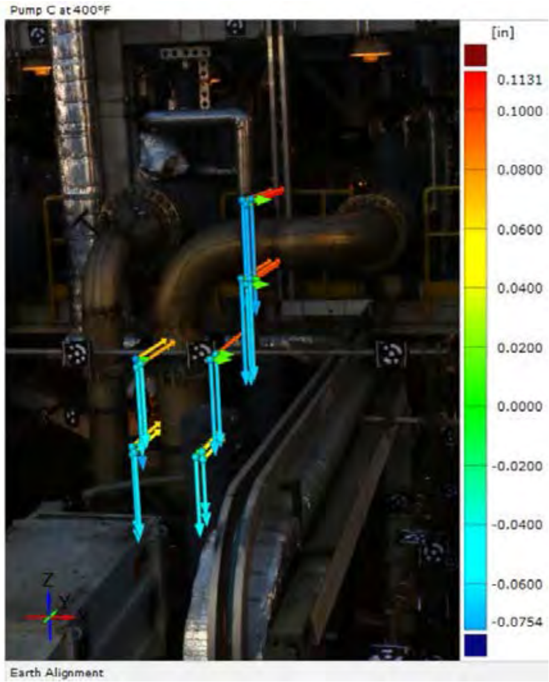
32-G2B Suction Piping, bolted but offline



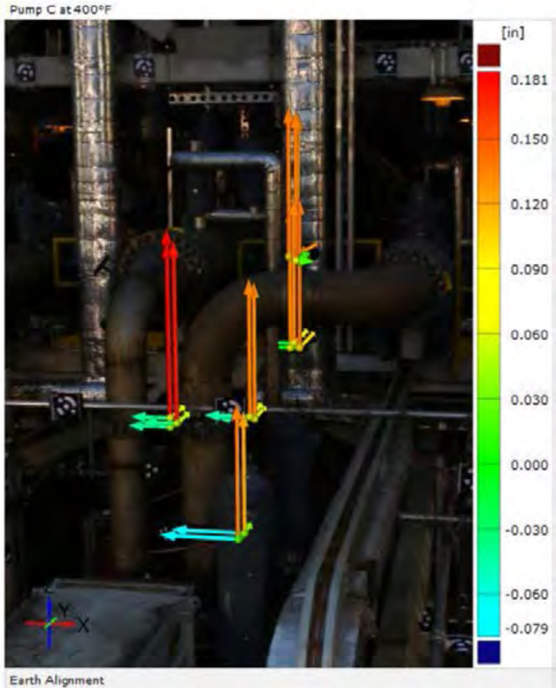
32-G2C Suction Piping being brought to temperature

Vacuum Bottoms Pumps

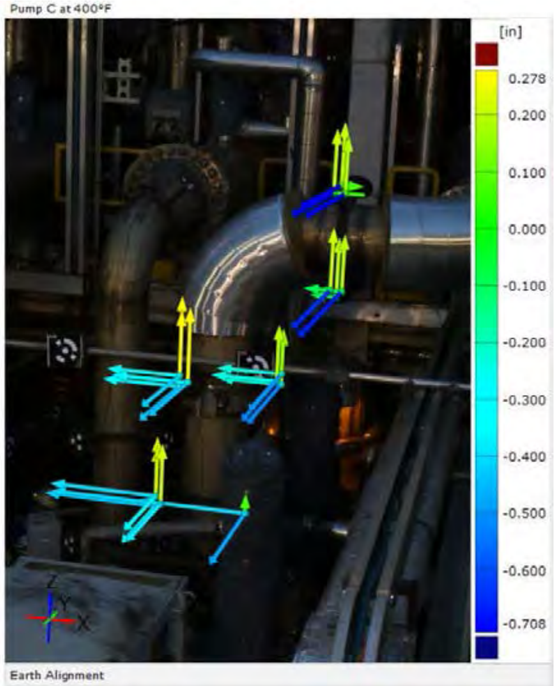
32-G2C Cold to 400°F - Discharge Piping Vector Displacements



32-G2A Discharge Piping while running

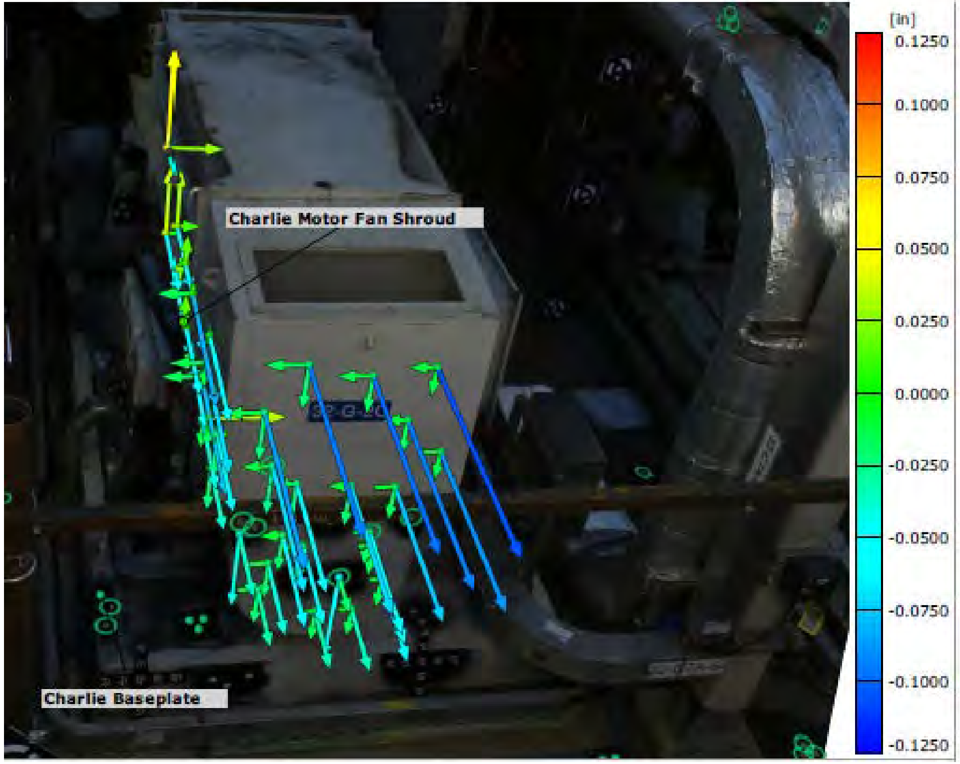


32-G2B Discharge Piping bolted but offline

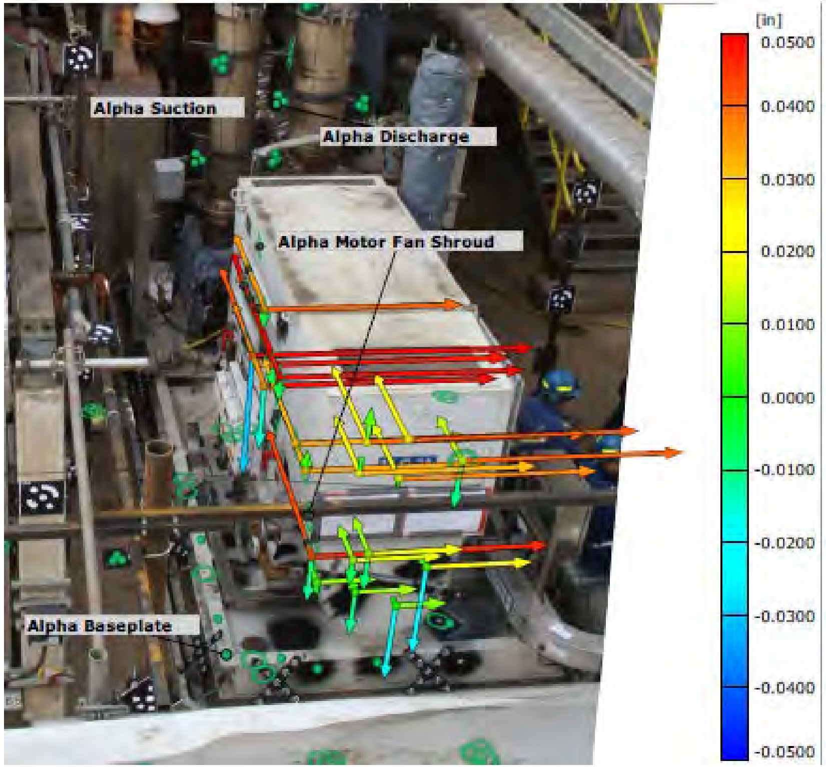


32-G2C Discharge Piping being brought to temperature

Vacuum Bottoms Pumps



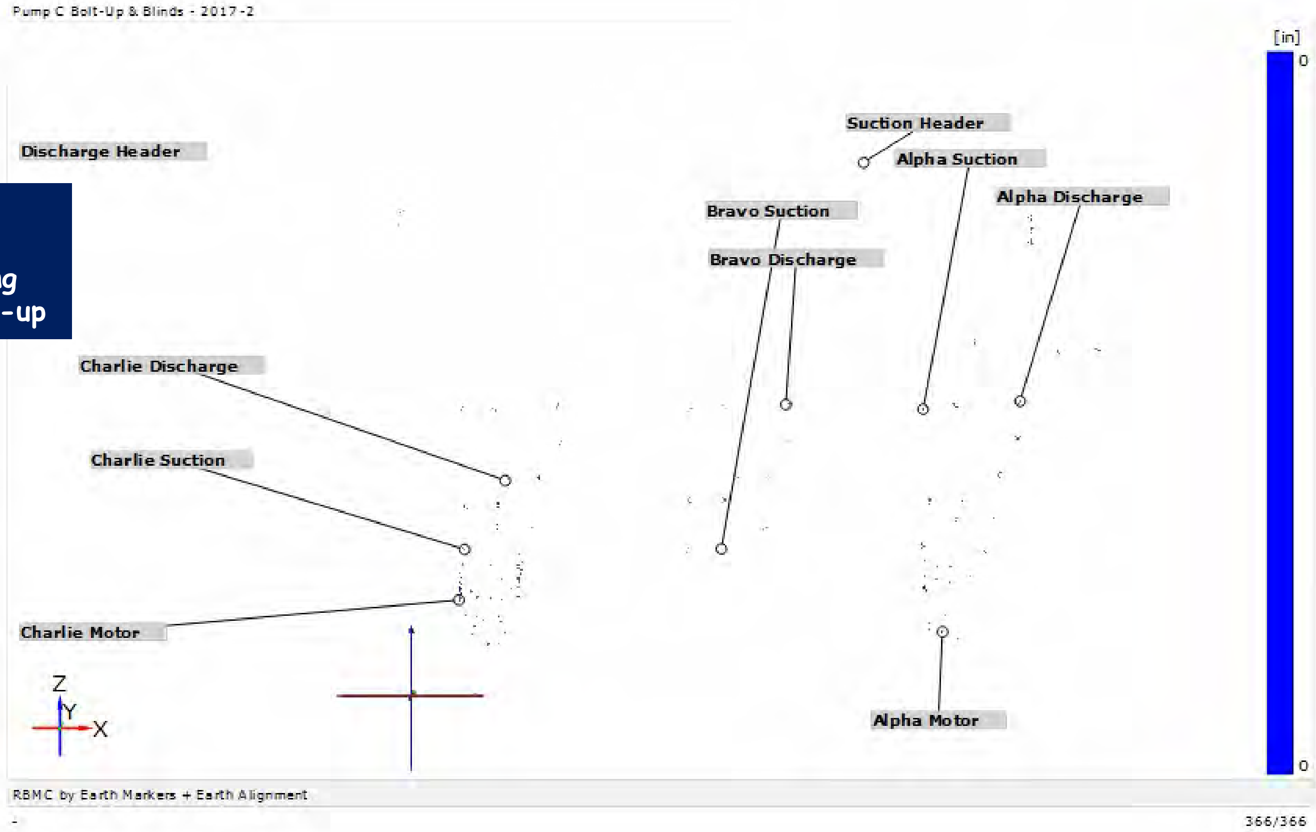
2C Motor displacement @ 400°F with 2A running



2A Motor displacement with 2A in Hot Standby

Vacuum Bottoms Pumps

Movie showing time lapse displacement of the piping through the various operating scenarios from cold to start-up



Nomenclature

32-G2A = Alpha

32-G2B = Bravo

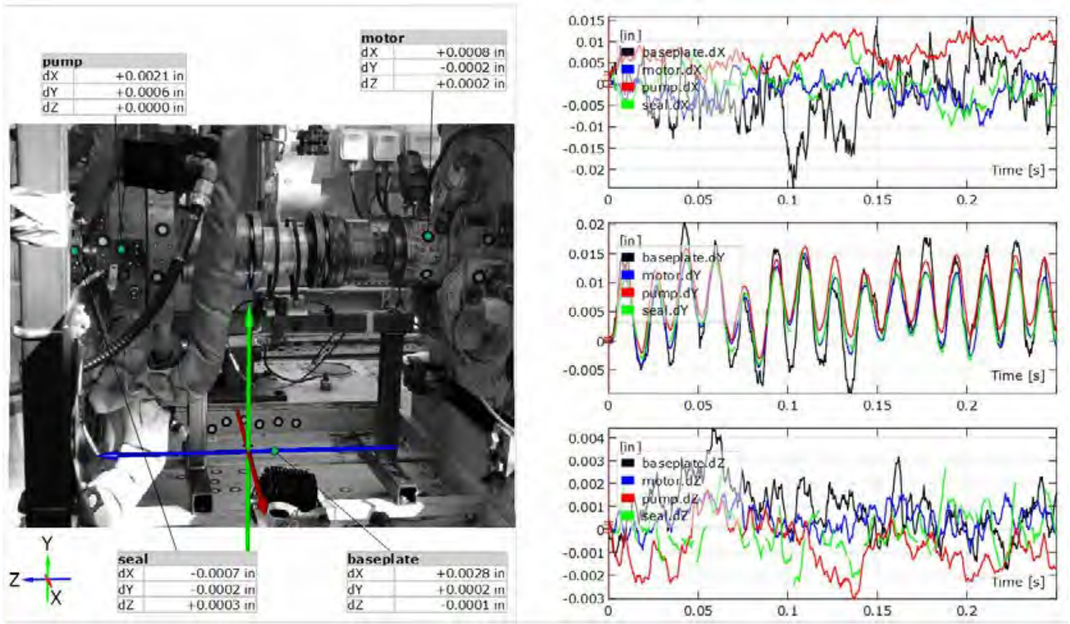
32-G2C = Charlie

Vacuum Bottoms Pumps

Optical Measurements

- Data collected during a Steady State Run using high speed optical metrology (3585 RPM, 473F)
- Movie at right provides full analysis
- X-axis (Horizontal axis), baseplate in and out of phase with the pump (top)
- Y-axis (vertical) all in phase (middle)
- Z-axis (shaft axis) baseplate & motor in and out of phase with the pump (bottom)

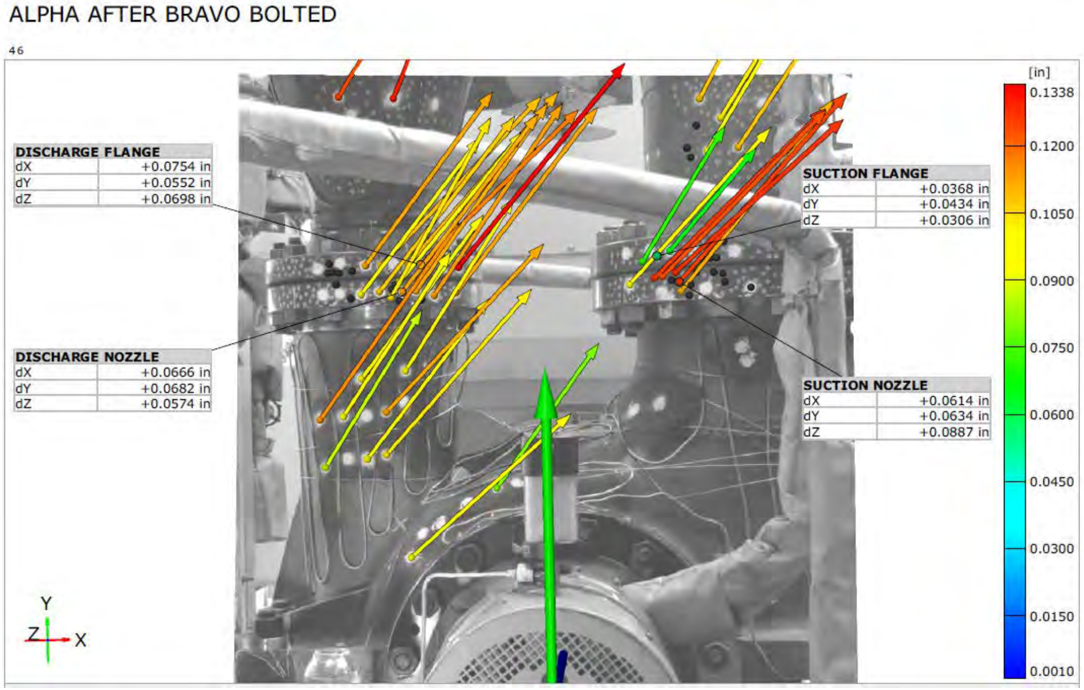
Displacement Tracking of key components during steady state run of Pump C



Vacuum Bottoms Pumps

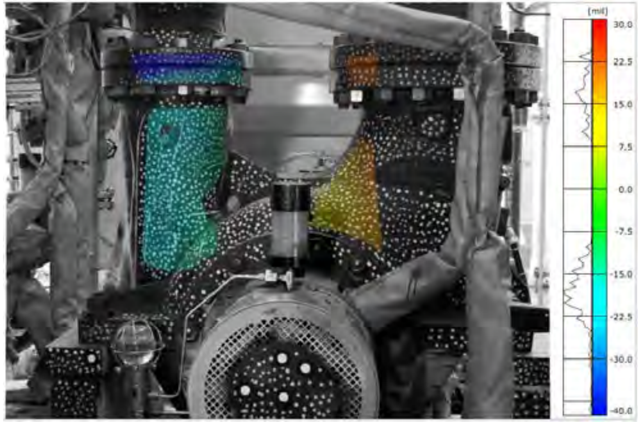
High Speed Data on 32-G2A

- Optical metrology used to look at the piping displacement on the 2A pump as a result of putting the pump back in service and warming to a hot standby condition
- 32-G2B was off line with the suction and discharge flanges bolted
- Resultant Vector Displacement showing movement of piping/ pump flanges and resultant stress in the pump

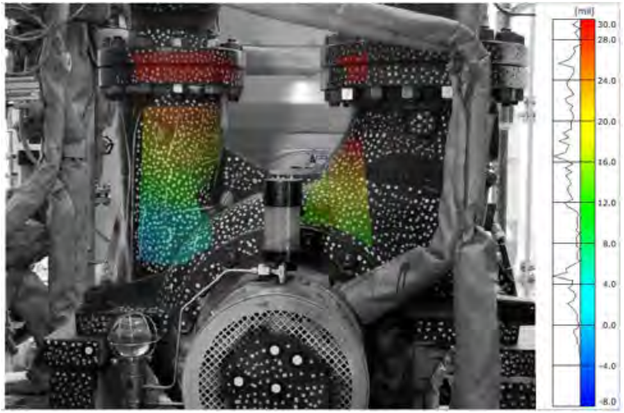


Vacuum Bottoms Pumps

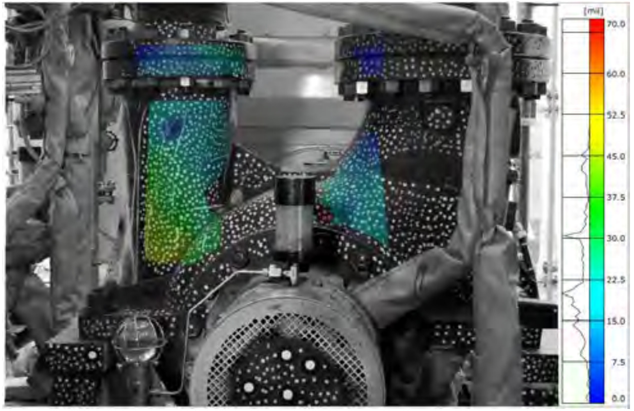
Pump 2C Displacement @ Running Temperature



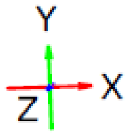
Horizontal X- direction



Vertical Y- direction



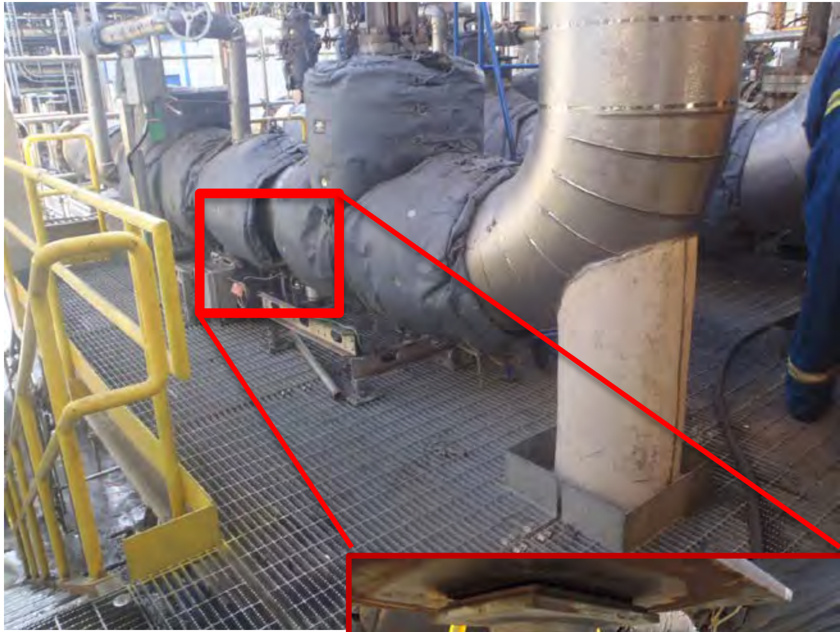
Axial Z- direction



Vacuum Bottoms Pumps

Conclusions

- Current piping forces displace pump nozzles, affect alignments, and distort the casing causing seal leakage
- No anchor points exist for the main headers or on the individual piping runs to the pumps
- Main headers shift when a pump is taken offline putting excessive stress on the pump / baseplate causing seal failures
- Pump baseplate was also inspected and found that grouting was deficient allowing distortion to occur

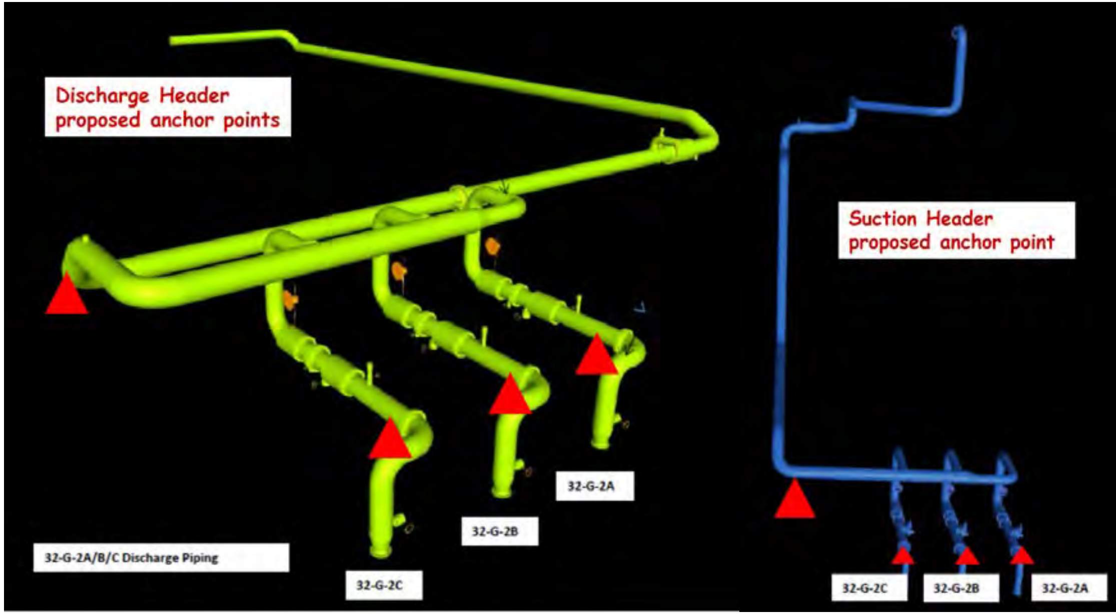


Friction plate pipe support with spring hanger base for main suction & discharge headers

Vacuum Bottoms Pumps

Recommendations

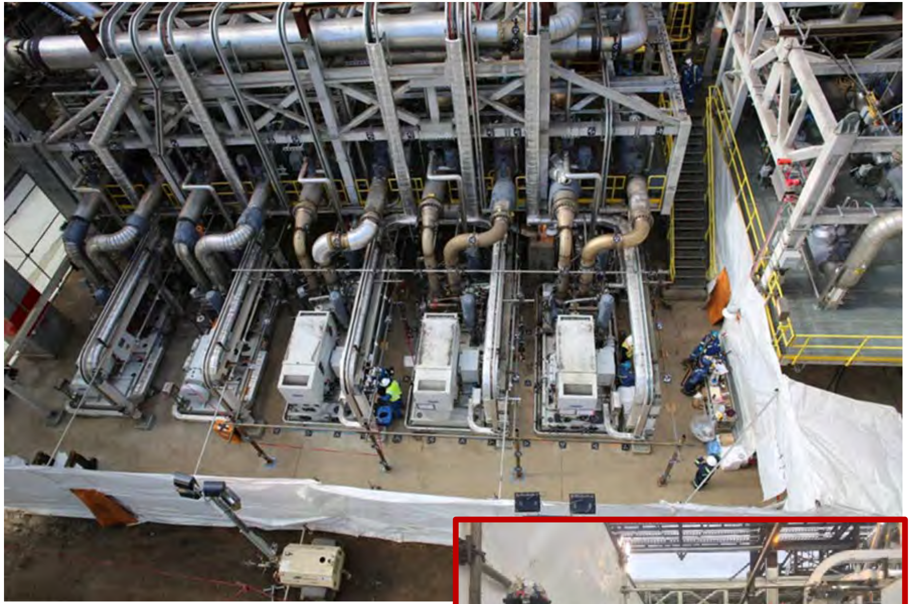
- New piping headers were designed and installed during fall 2017 scheduled plant shutdown
- Baseplates were pulled and grouted to best practice
- Pumps were rebuilt and stress relieved
- Pump pedestal bolts were replaced due to previous modifications
- Existing mechanical seal design was deemed acceptable & reused



Vacuum Bottoms Pumps

Status

- Scheduled plant shutdown system modifications were completed Fall of 2017
- Start-up experienced minor seal leakage on the 2C pump which was attributed to dirt in the barrier tank
- No further failures occurred, Operations has experienced substantially improved performance and has renewed confidence in the system.



Overview of work area and project team

Vacuum Bottoms Pumps

Lessons Learned

- The use of the cameras flash was not allowed due to the fire protection system. The use of large generator lights were employed which increased the logistical complexity
- A local ad-hoc network allowed for faster data computation on the post processing computer, which enabled us to have a near real time result while in the field

Photogrammetry target dots on piping going to headers. Fabricated fixtures to facilitate 360° viewing and standoff from insulation

Thank you for your Attention

Questions?