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Transforming Maintenance Using Virtual Assembly

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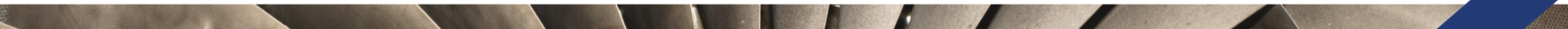
Education
BSME, Mississippi State University – 2012

Career
Machinery Engineer – Polyolefins, Plastics, Resins, Olefins (2012-2016)
Turnaround Lead – Olefins (2017-2021)
Machinery Innovation & Technology Lead – HQ (2022-Present)

Abstract

Virtual assembly is challenging historical maintenance paradigms by reducing durations up to 75%, while improving quality and safety. Turbomachinery can be virtually assembled to identify and address assembly issues prior to maintenance events. Internal clearances and component positioning can be optimized virtually, enabling the physical assembly of spare components months or even years before a maintenance event (i.e. spare rotor assembled with seals and bearings prior to a unit downtime). Greater than 50% of work scope typically conducted during maintenance events can now take place outside of the unit downtime window.



Agenda

- Overview and Objective
- What is Virtual Assembly?
- Solution Overview
- Schedule Improvement
- Virtual Assembly Walkthrough
- Execution Results

Overview and Objective

Objective:
- Reduce maintenance event duration and associated costs
- Improve quality and safety by simplifying maintenance
- Increase predictability of schedule and cost

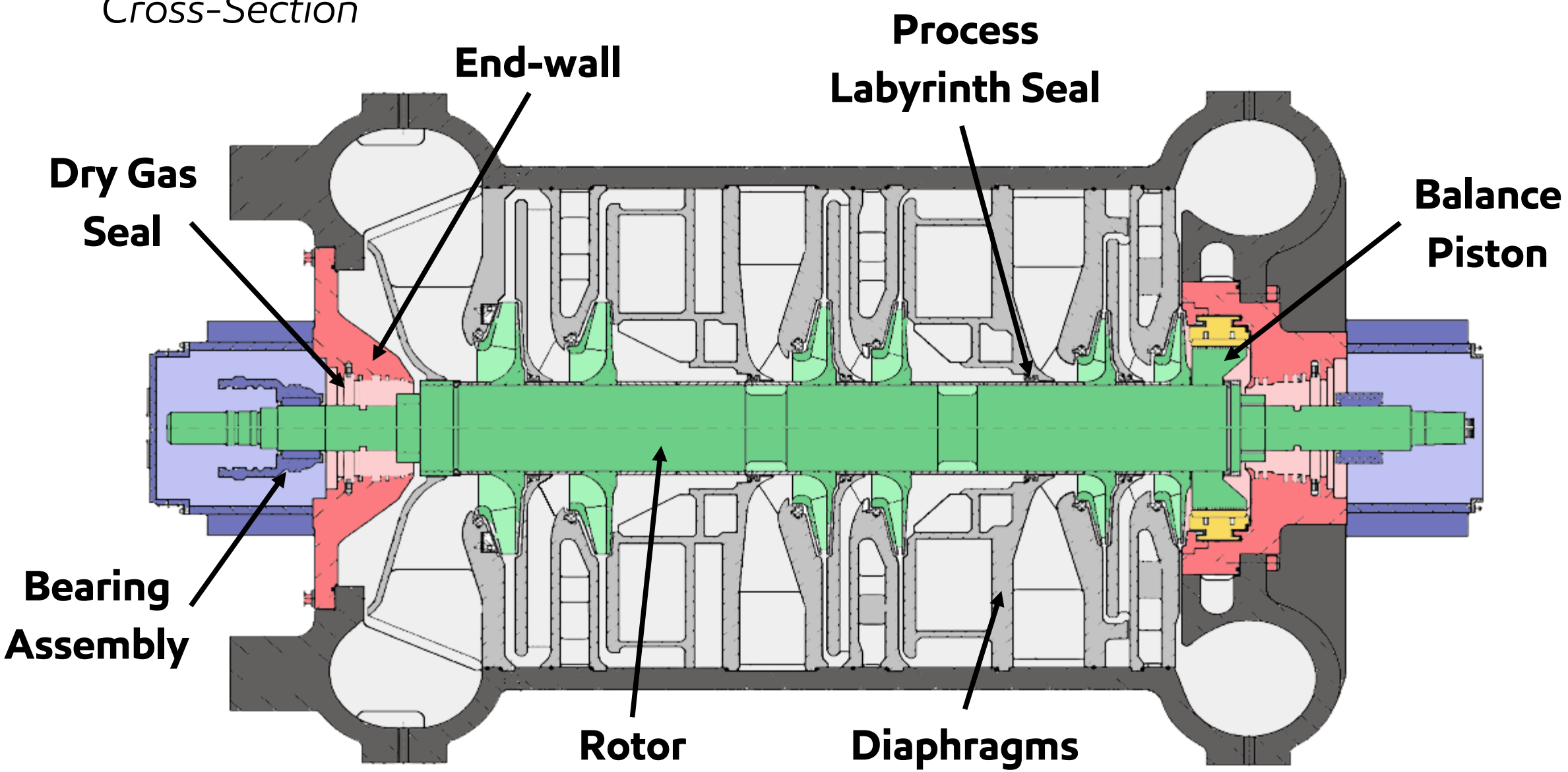
How:
Virtual assembly

Equipment:
Centrifugal Compressor

Maintenance Scope:
- Rotor swap
- Diaphragm removal and cleaning
- Radial and thrust bearing replacement
- Dry gas seal conversion (oil seal replacement)
- Casing end-wall replacement

Centrifugal Compressor

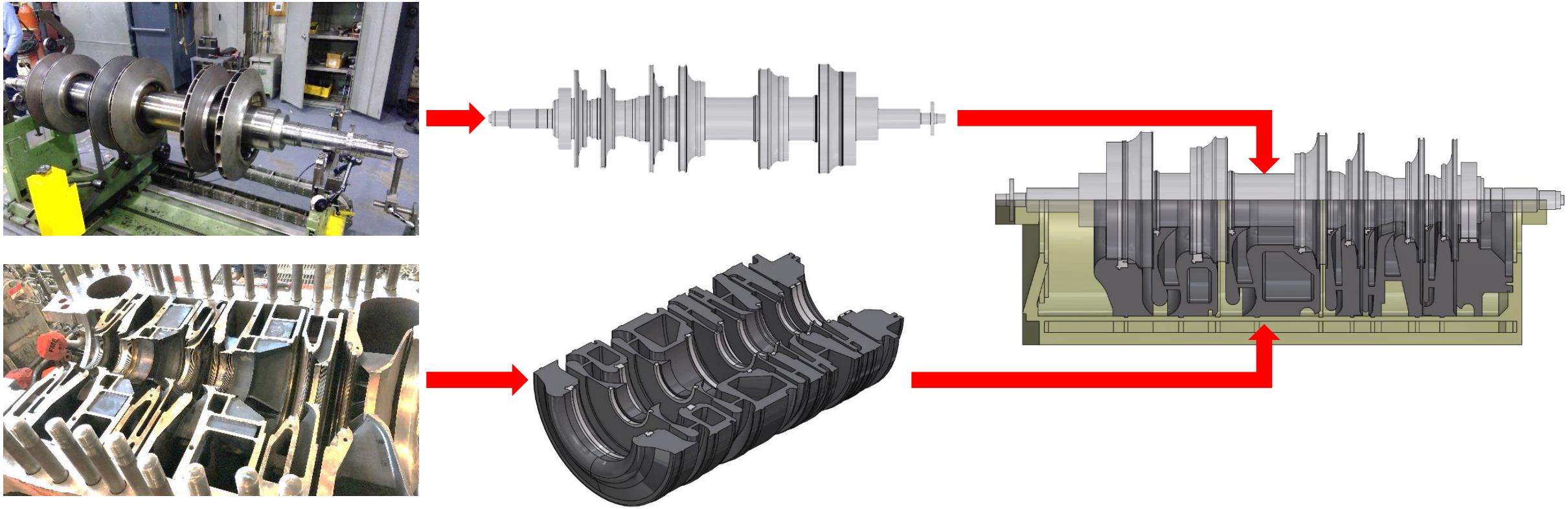
Cross-Section



Virtual Assembly

What is it?

- Digitally map critical geometry on both rotating and stationary components
- Assemble components virtually, creating a replica of the physical assembly
- Optimize component alignment within the digital model



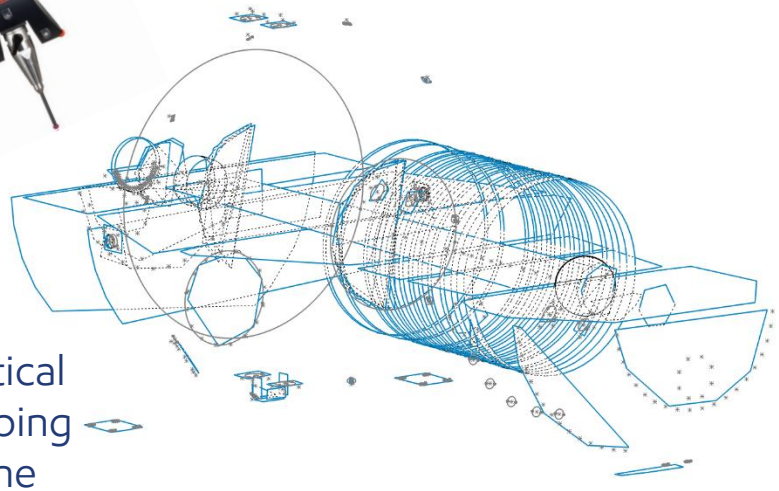
Virtual Assembly

How is the data captured?

- High accuracy probing (0.001" accuracy)
- Focus is on critical geometry, including datums, fits, and interfaces
- Can be integrated w/ laser scanning for larger and/or complex use cases

Laser Tracker

Measurement Probes



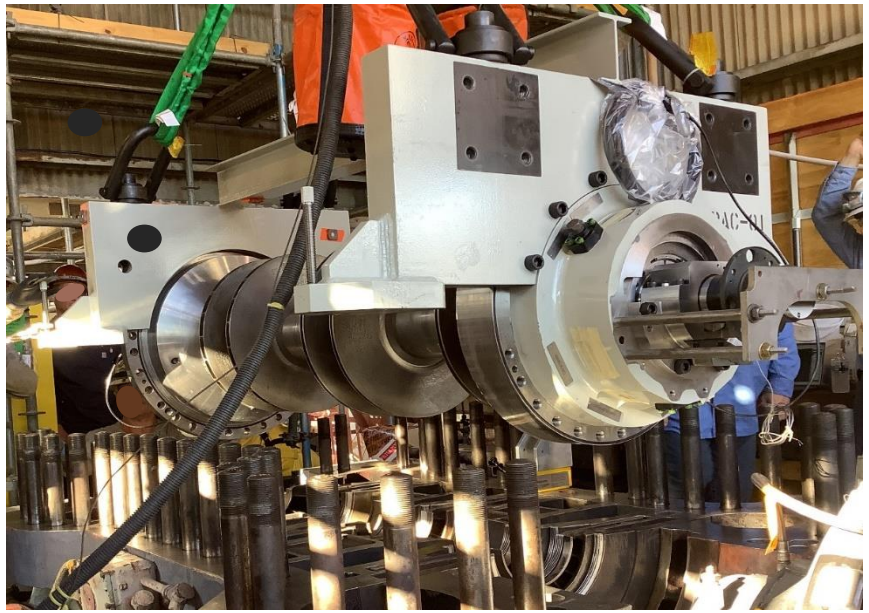
Example of Critical Geometry Mapping for Gas Turbine

Video and images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence

Virtual Assembly

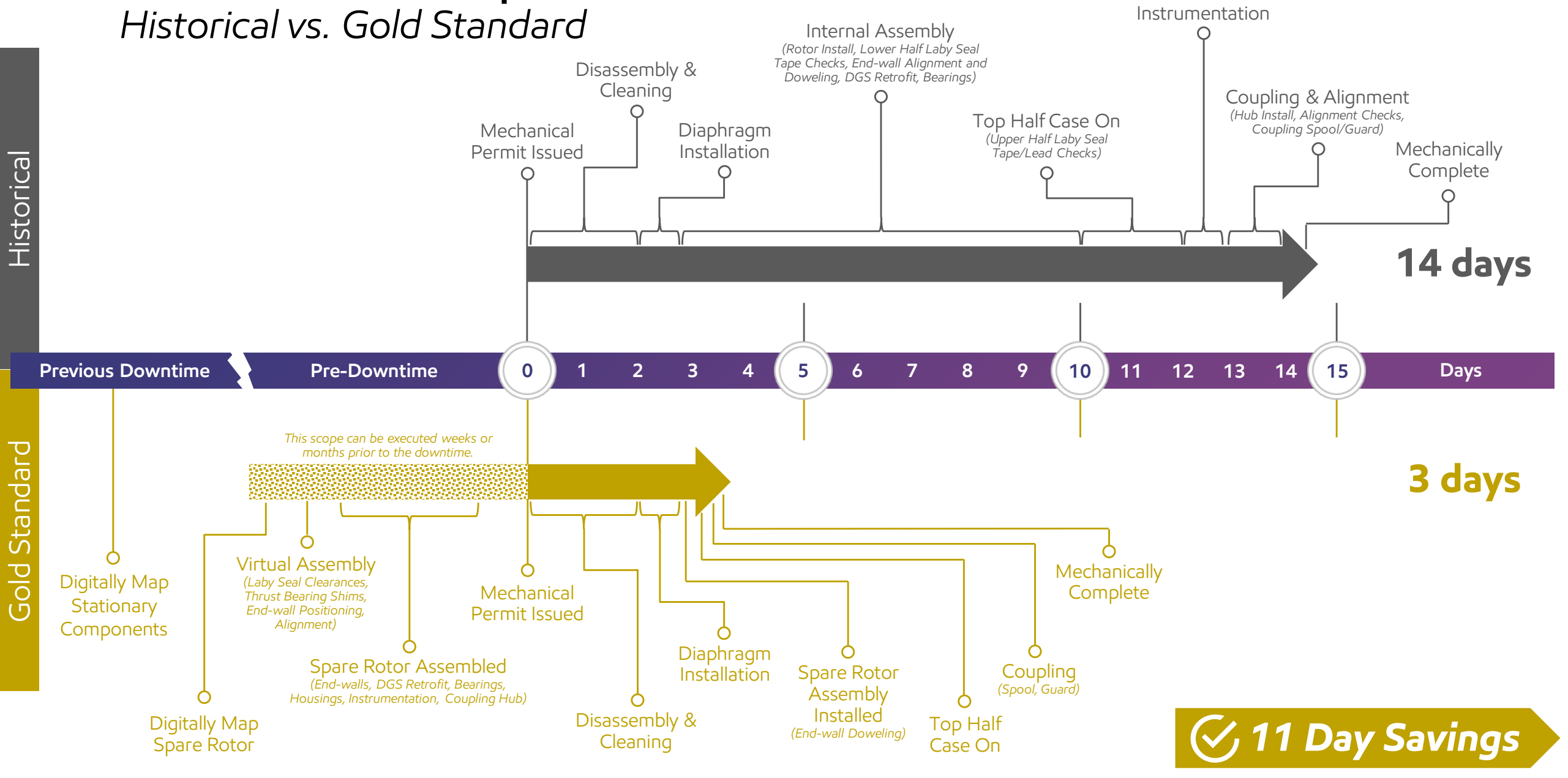
Solution Overview

- Virtually assemble equipment to enable the pre-downtime physical assembly of spare parts
  - Optimize rotor axial position (impeller to diaphragm gas path alignment)
  - Install casing end-walls and dry gas seals in correct axial locations
  - Assemble radial and thrust bearings with appropriate shims at running position
  - Determine impeller and shaft labyrinth seals clearances
- Design innovative tooling to facilitate pre-downtime assembly and associated field installation



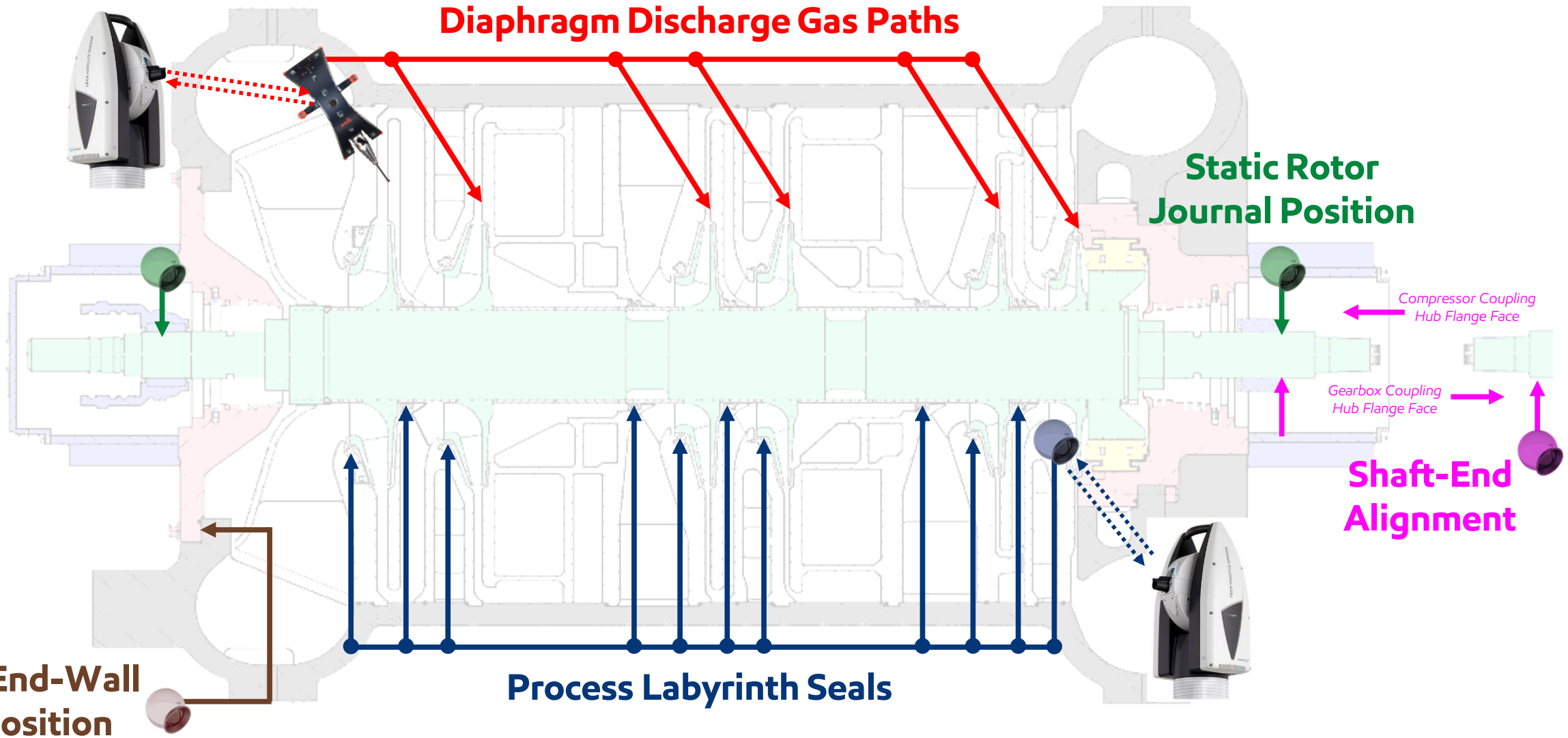
Schedule Improvement

Historical vs. Gold Standard



Previous Downtime

① *Digital Mapping (Stationary Internals and Rotor Position)*



Images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence

Previous Downtime

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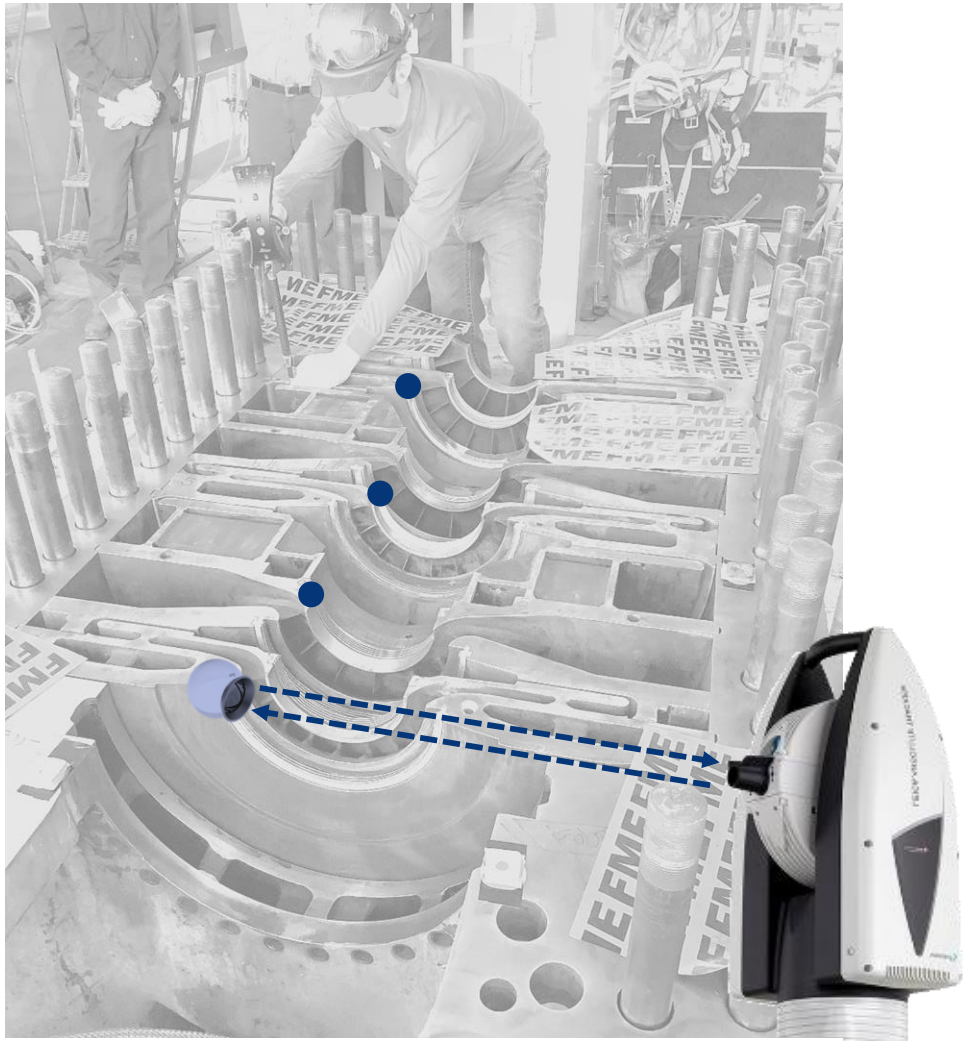
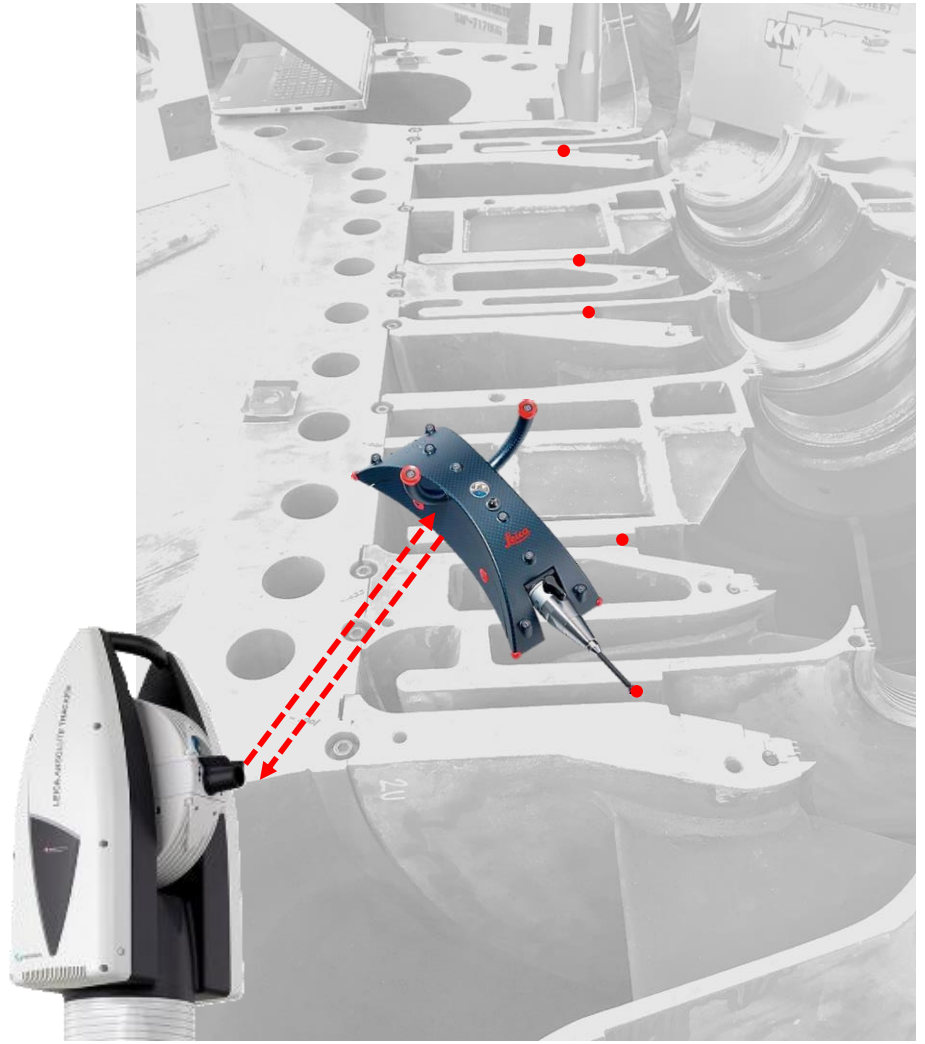


Process Labyrinth Seals



Diaphragm Discharge Gas Paths

Images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence

Pre-Downtime Efforts

② *Digital Mapping (Spare Rotor)*

Laser Tracker

Balance Piston

Process Labyrinth Seal Areas

Bearing Journal

Rotor Stand

Rotor Stand

Images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence

Pre-Downtime Efforts

② *Digital Mapping (Spare Rotor)*

Laser Tracker

Impeller Discharge Gas Paths

Rotor Stand

Rotor Stand

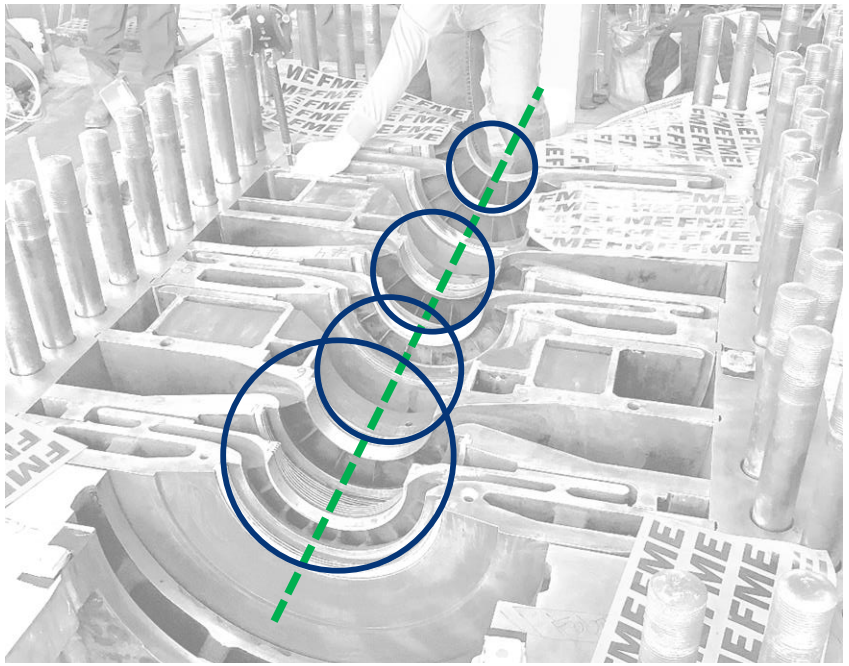
Images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence

Pre-Downtime Efforts

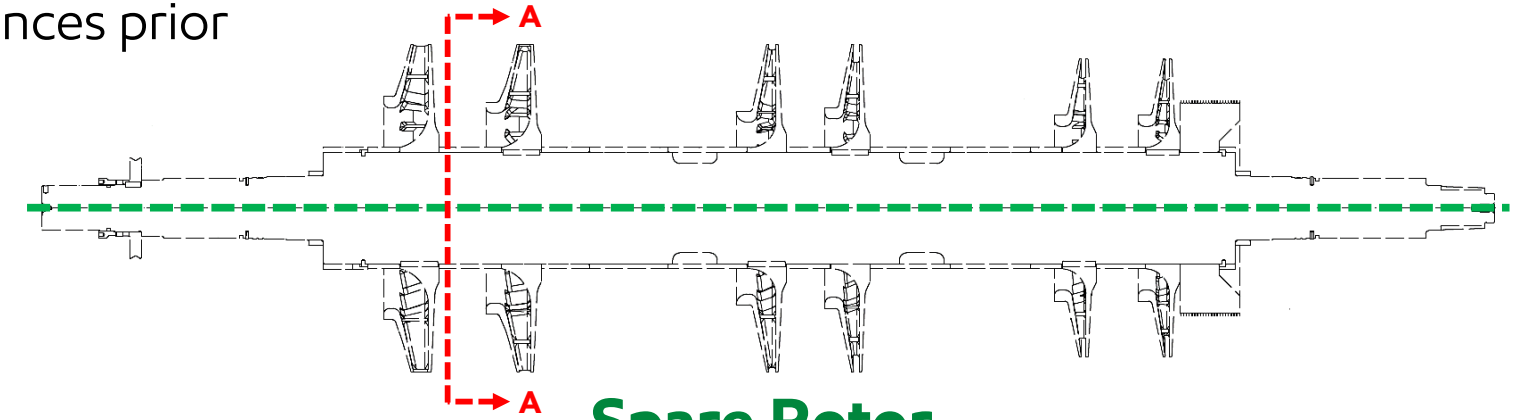
③ *Virtual Assembly (Process Labyrinth Seals)*

Virtually overlay the spare rotor with the stationary internals.
Place the rotor in the static position (bottom of bearings).

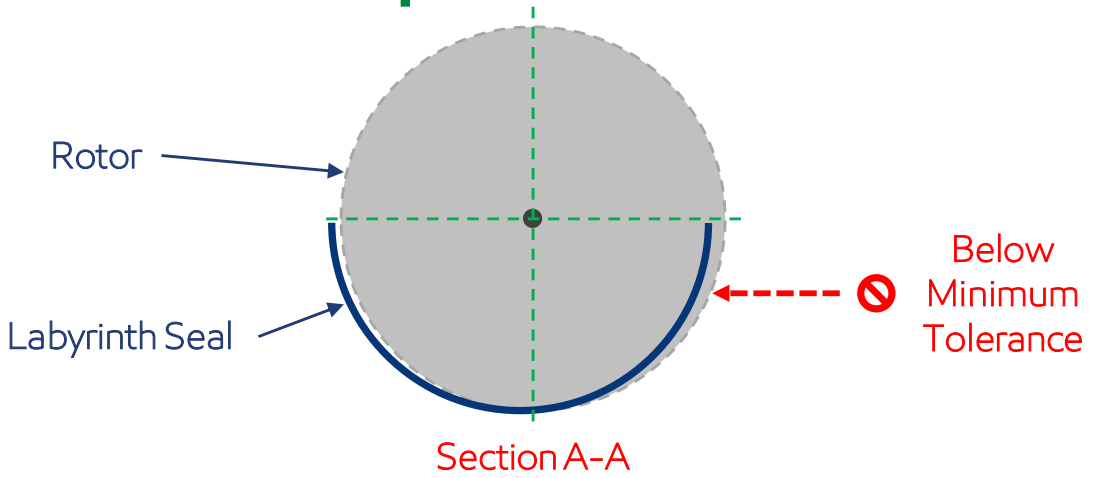
Goal: Determine labyrinth seal clearances prior to the maintenance event.



Stationary Internals



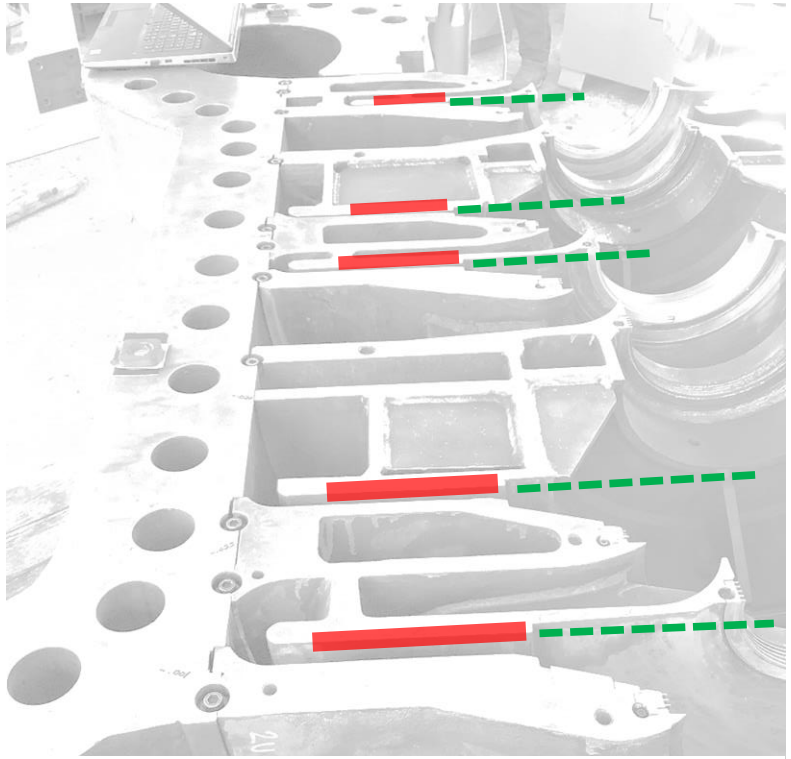
Spare Rotor



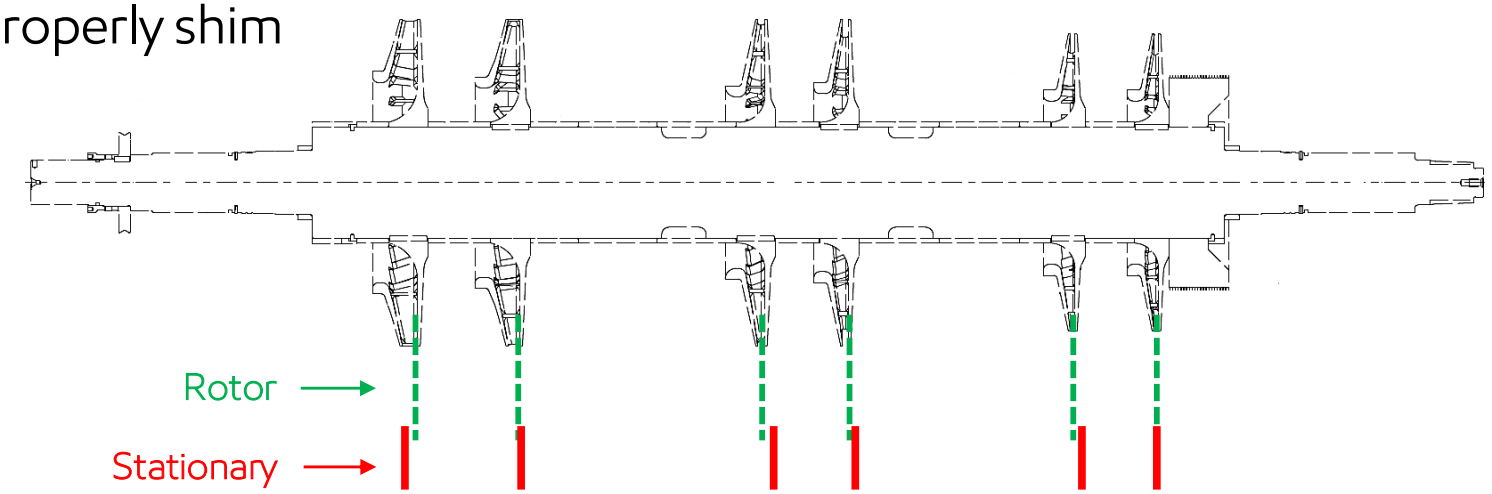
Pre-Downtime Efforts

③ *Virtual Assembly (Gas Path Alignment)*

Goal: Optimize gas path alignment. Properly shim and install thrust bearing prior to the maintenance event.

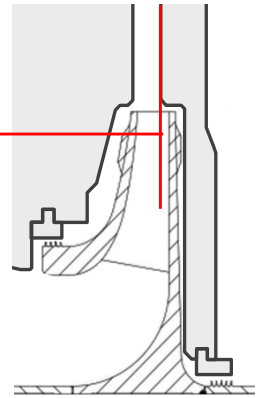


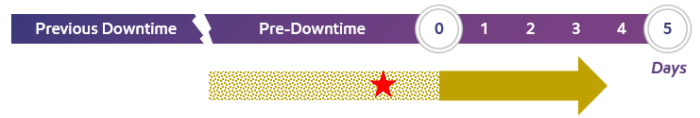
Stationary Internals



Spare Rotor

Projected Gas Path Alignment	
1st Stage	0.008″
2nd Stage	-0.002″
3rd Stage	-0.010″
4th Stage	-0.005″
5th Stage	-0.009″
6th Stage	0.000″





Pre-Downtime Efforts

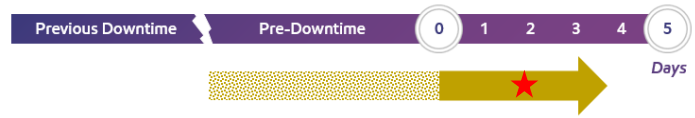
④ *Spare Rotor Assembly*

Virtual assembly enables a transformational approach to maintenance.

Utilized a custom-built tool to facilitate the assembly of spare components prior to the maintenance event.

Executed >50% of scope prior to the maintenance event, assembling the spare rotor with end-walls, seals, bearing assemblies, instrumentation, and coupling hub.

All assembled spare components were locked into optimal position for field installation, requiring no further adjustments.



Compressor Disassembly

⑤ *Service Rotor and Diaphragm Removal*

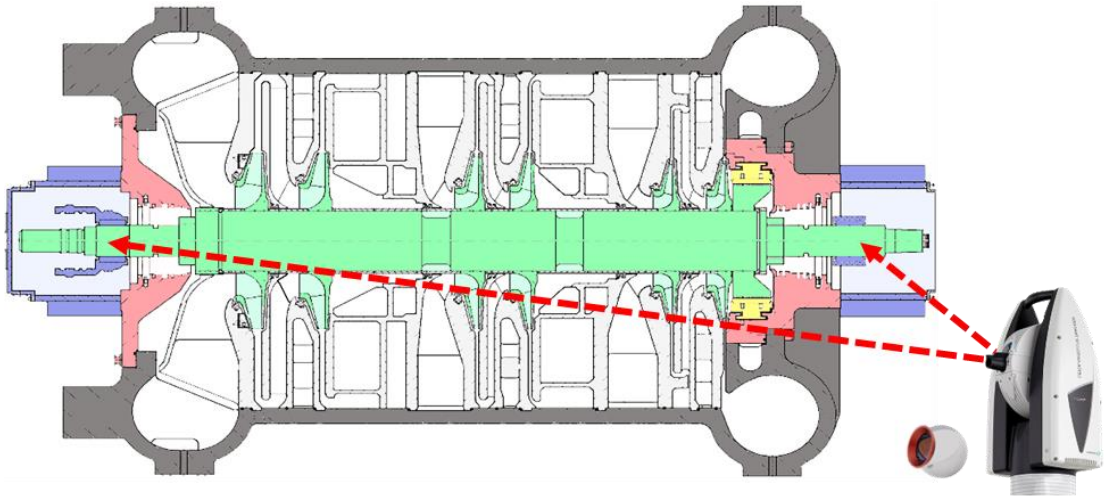
Before removing any internal components, verify that the diaphragm positions match their positions from the previous maintenance event.

Diaphragm positions were captured manually (diaphragm split-line to casing split-line height).

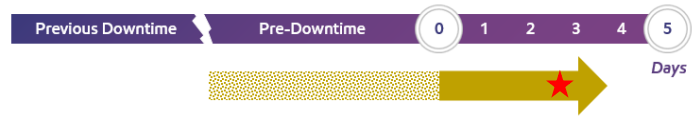
Use the laser tracker to obtain as-found rotor journal positions. Verify this matches the data captured during the previous event.

Goal: Use the as-found diaphragm positions when reinstalling diaphragms to ensure final positions match.

Use as-found, static rotor position when installing the new rotor assembly (match concentricity of rotor journals).



Images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence



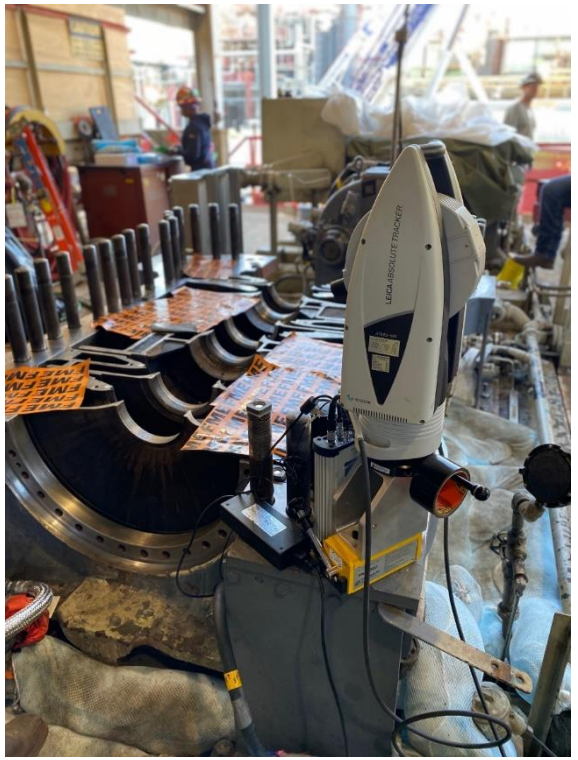
Compressor Assembly

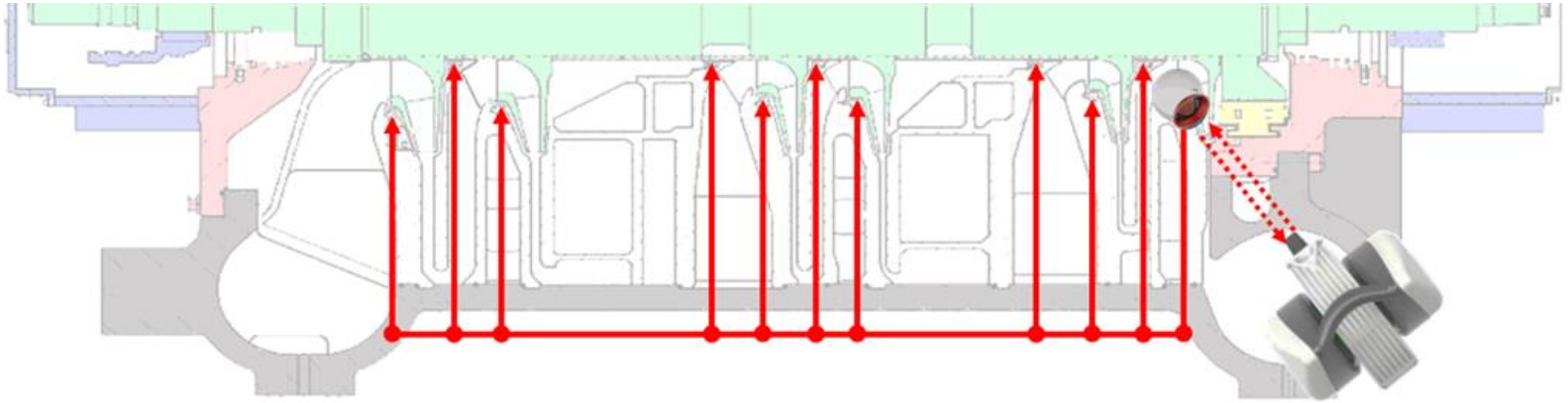
⑥ *Diaphragm Installation and Laby Seal Validation*

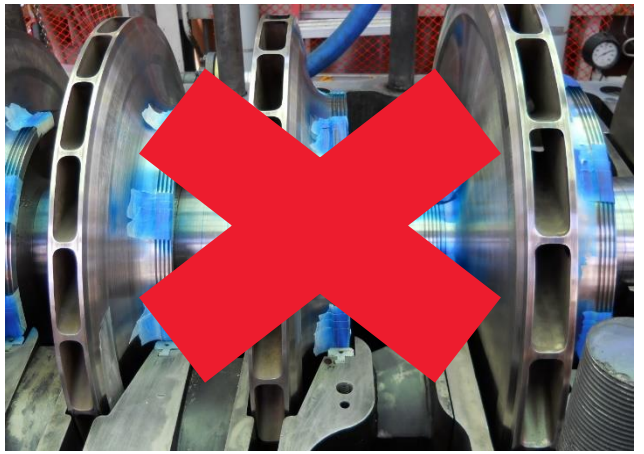
Without installing the rotor, make adjustments to the labyrinth seals based on the pre-downtime virtual assembly.

Use the laser tracker to validate adjustments to seals in real-time, feeding that data into the virtual assembly.

If any labyrinth seals were replaced, digitally map those seals at this time to immediately determine adjustments necessary to obtain the desired clearance.





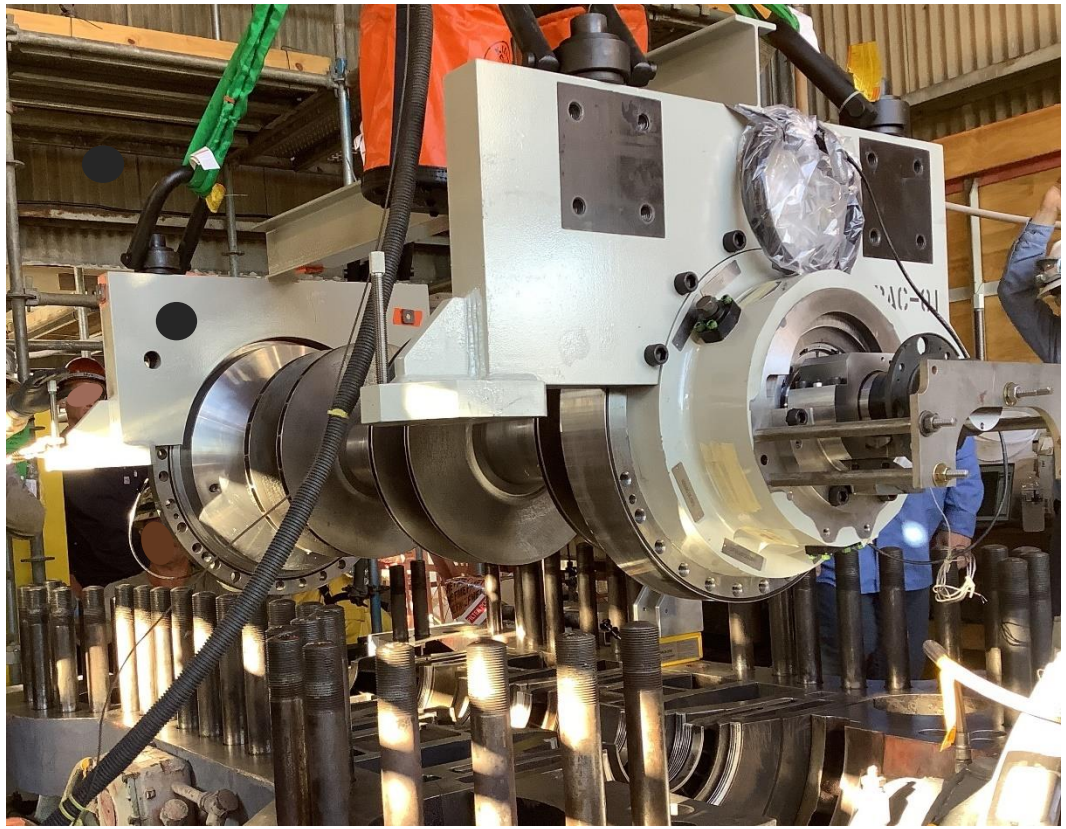


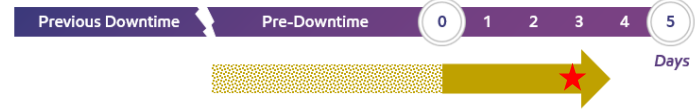
Images of laser tracker/measurement probe from: Hexagon Manufacturing Intelligence

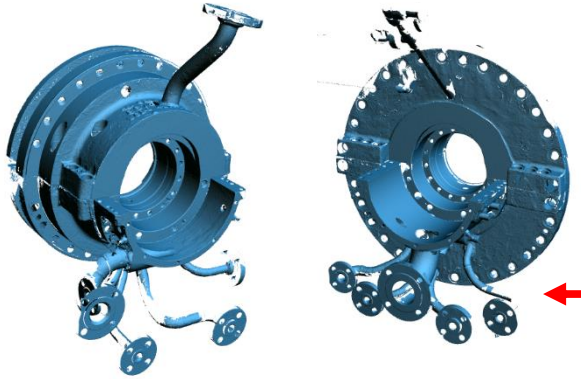
Compressor Assembly

⑥ *Installation of Pre-Assembled Rotor*

While lowering the pre-assembled rotor into the casing, the laser tracker and virtual assembly process was used to match the position of the new rotor w/ the old rotor to align the end-walls for doweling.

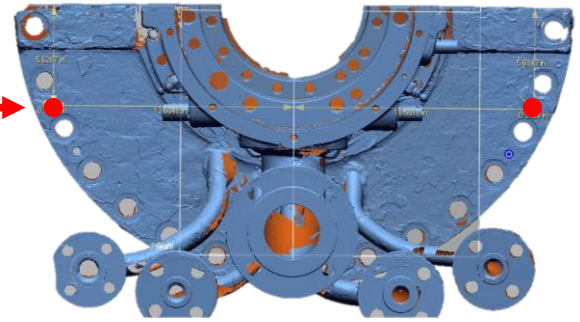


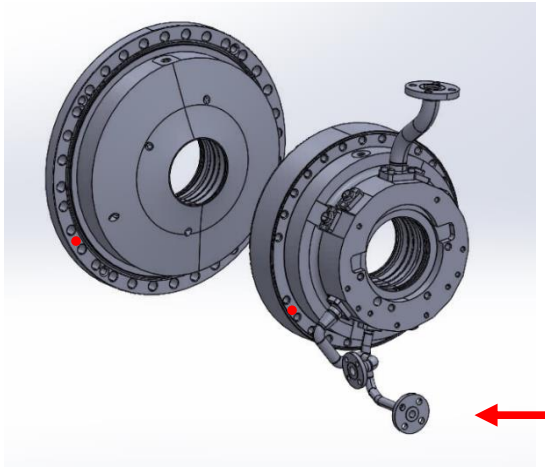




Old End-wall Scans

Determining Existing Dowel Positions





Pre-Drilled Pilot Dowel Holes in New End-Walls

Compressor Assembly

⑥ *Upper Half Casing Installation and Final Assembly*

Install the pre-assembled rotor with a single lift, aligning the rotor journals and end-walls per the virtual assembly guidance.

Dowel the end-walls to the lower half compressor casing.

Perform assembly confirmation checks:

- Visual check of gas path alignment
- Thrust rotor
- Roll rotor
- Lift check

Install the upper half casing with a single lift.

Results of Virtual Assembly

- Successfully executed job w/ no startup or operational issues
- Realized the following benefits
  - ~75% reduction in duration vs. historical
  - ~50% of scope executed pre-downtime
  - ~50% reduction in overhead and contract labor costs
  - ~80% of machinery lifts eliminated
- Pre-downtime work significantly reduced risk of execution errors and delays from assembly issues
- Critical work executed pre-downtime, where most qualified resources could provide oversight w/ no pressure to rush or take unnecessary risks
- Virtual assembly is not plug-and-play
- Requires extensive technical oversight to execute successfully