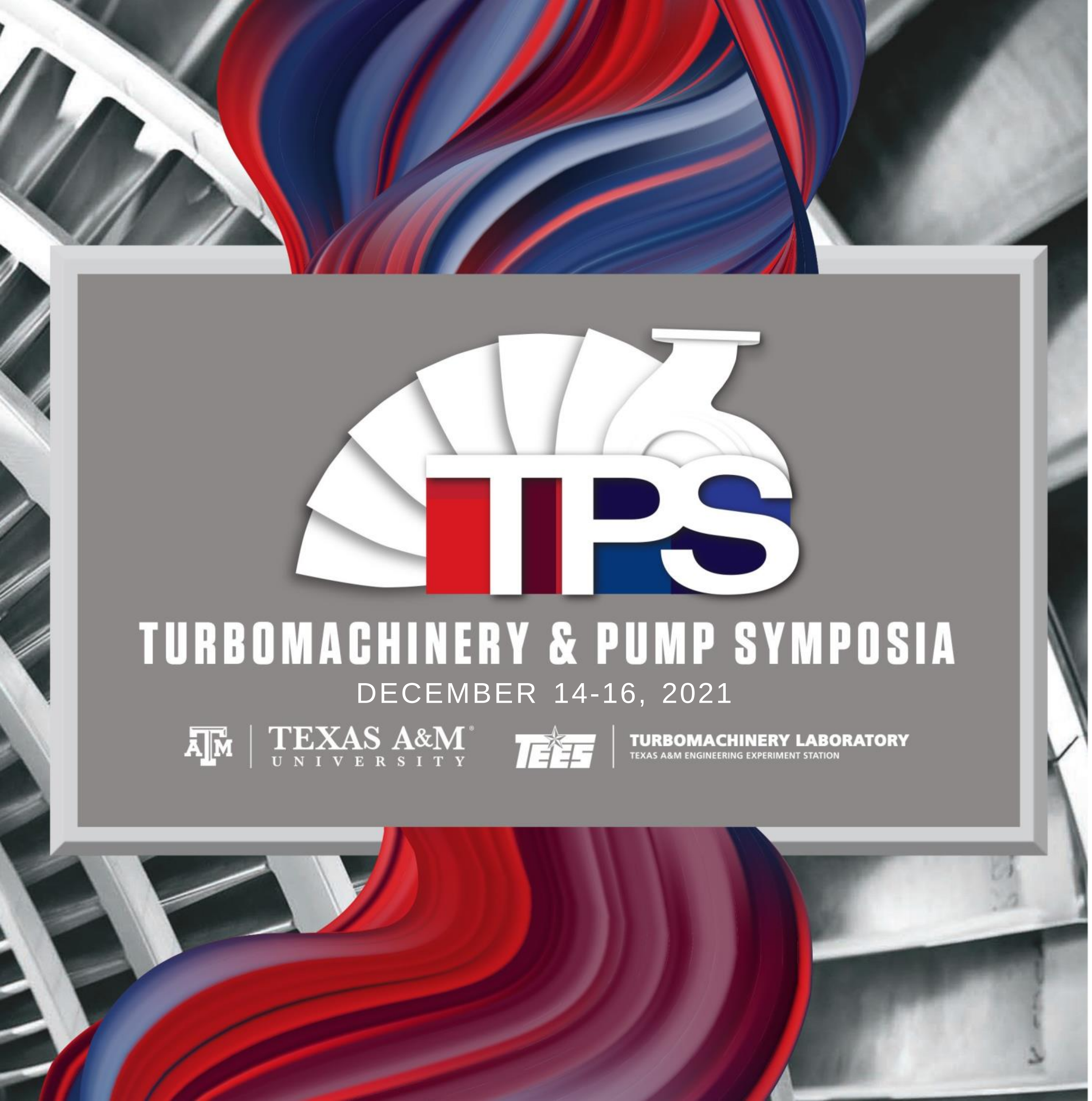

Aero-Derivative Gas Turbine Vibration Troubleshooting Comparing Traditional ODS and Motion Magnification Video Techniques

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Test ▪ Analyze ▪ Solve ▪ Design ▪ Products

Maki Onari, President

- Employed by Mechanical Solutions, Inc. since 2003
- Responsible for all MSI Turbomachinery Testing
- Previously with Petroleos de Venezuela (PDVSA) as Rotating Equipment Engineer
- B.S.M.E., Zulia University
- 25 years Turbomachinery Vibration Experience
- Co-Author Pump Vibration Chapter, McGraw-Hill Pump Handbook
- Member of ISO TC108/S2 Machinery Vibration Standards Committee

Abstract

A large aero-derivative gas turbine in electrical generation service was exhibiting high vibration at the LP compressor section (1.5 in/s peak) at low load operation. Thorough testing, using Experimental Modal Analysis (EMA) and Operating Deflection Shape (ODS) indicated that the vibration was due to a structural resonance (4-day testing). This excessive flexibility of the baseplate could have been detected immediately (one day) using Motion Magnification Video (MMV) testing technology. This involves a high speed video camera and related software, to magnify the motion of the engine and baseplate in slow motion. Unfortunately, MMV was not yet developed.

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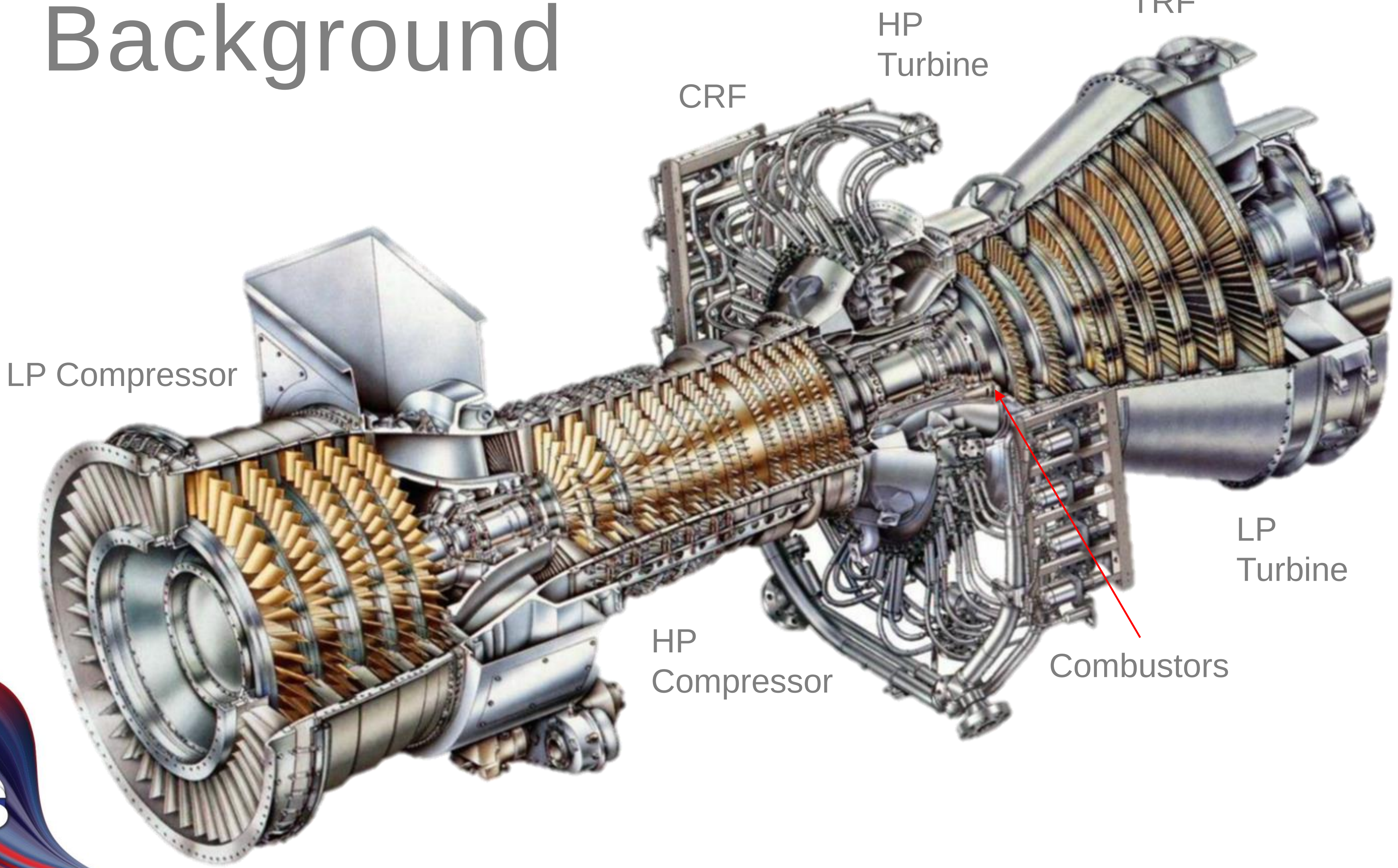
Background

- Combined Cycle Plant near Darwin, Australia
- 310 MW of installed capacity
- Rated capacity: 33 MW
- LP Rotor Speed: ~3625 rpm or 60.5 Hz
- HP Rotor Speed: 10,400 rpm or 173 Hz
- Synchronous Speed: 3,500 rpm through a gear reducer

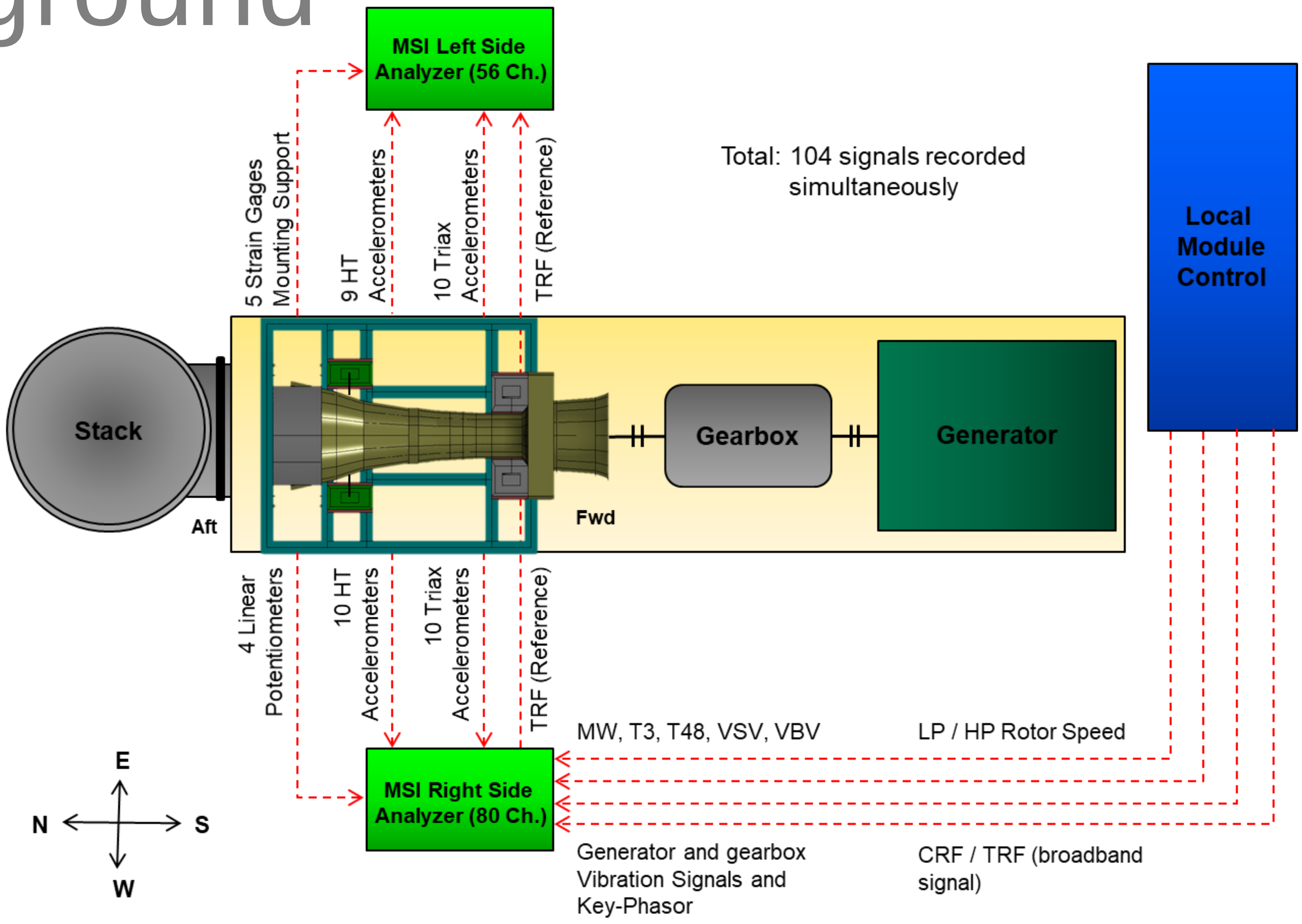
Background


TRF
HP
Turbine
CRF
LP Compressor
LP
Turbine
HP
Compressor
Combustors

Background

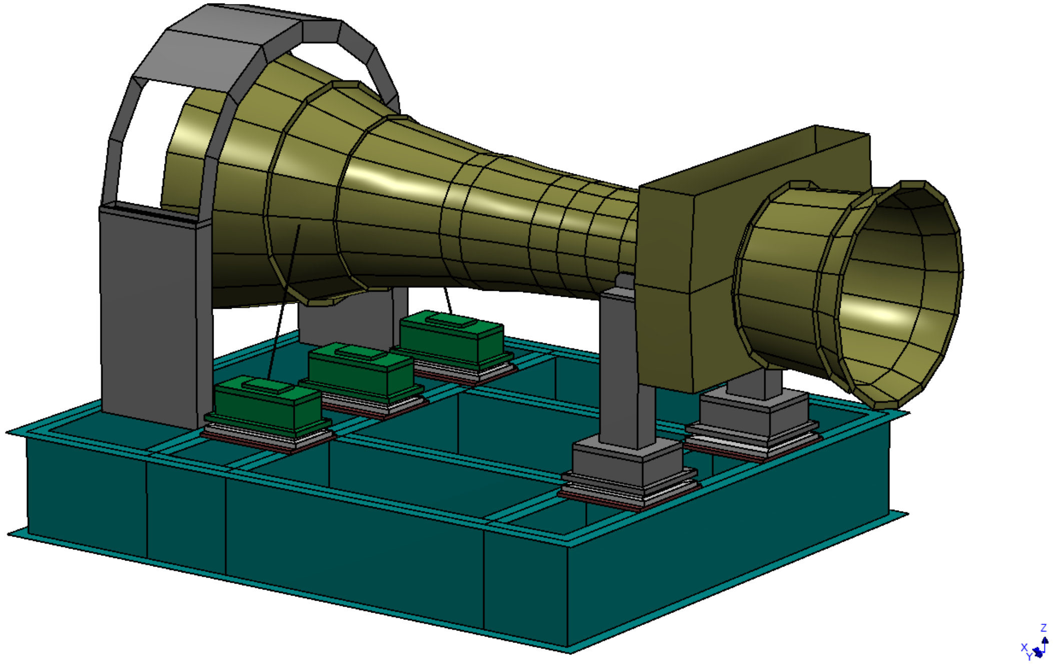
- Engine designed to operate for short durations at full power and long durations at low power
- Vibration at LP Rotor exceeded alarm and trip set points at 1.4 and 2.0 in/s peak filtered at 60 Hz
- Original package was modified at factory where engine mounts/ foot print were changed (longer than former units)
- Similar dynamic behavior (up to 1.5 in/s peak between 5 to 10 MW) with different leased engines
- Unsuccessful attempts to reduce vibration amplitude

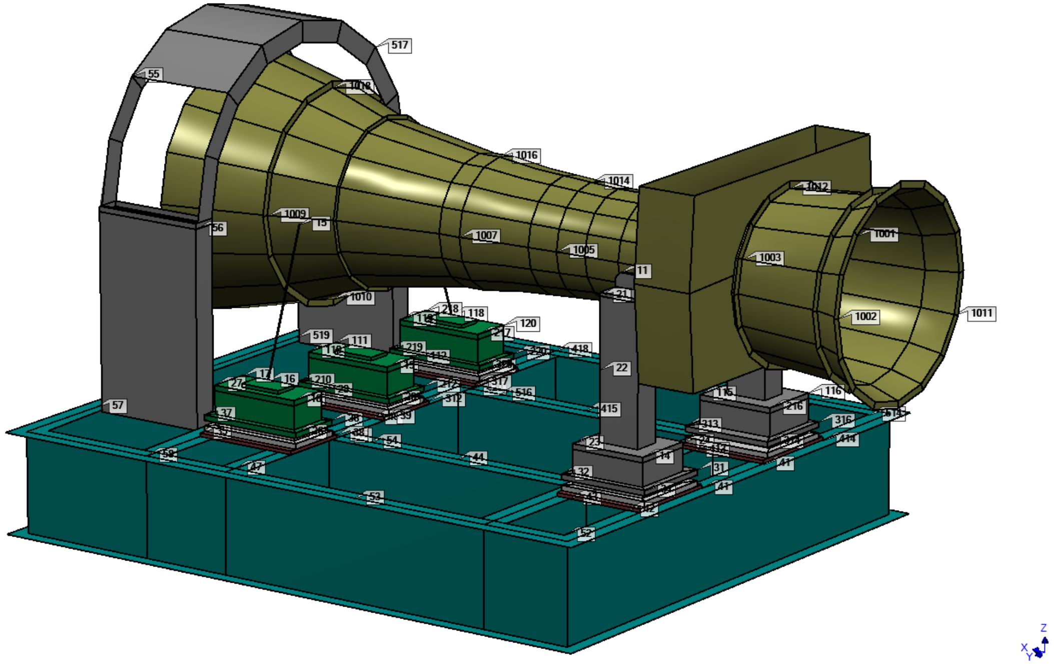
Background



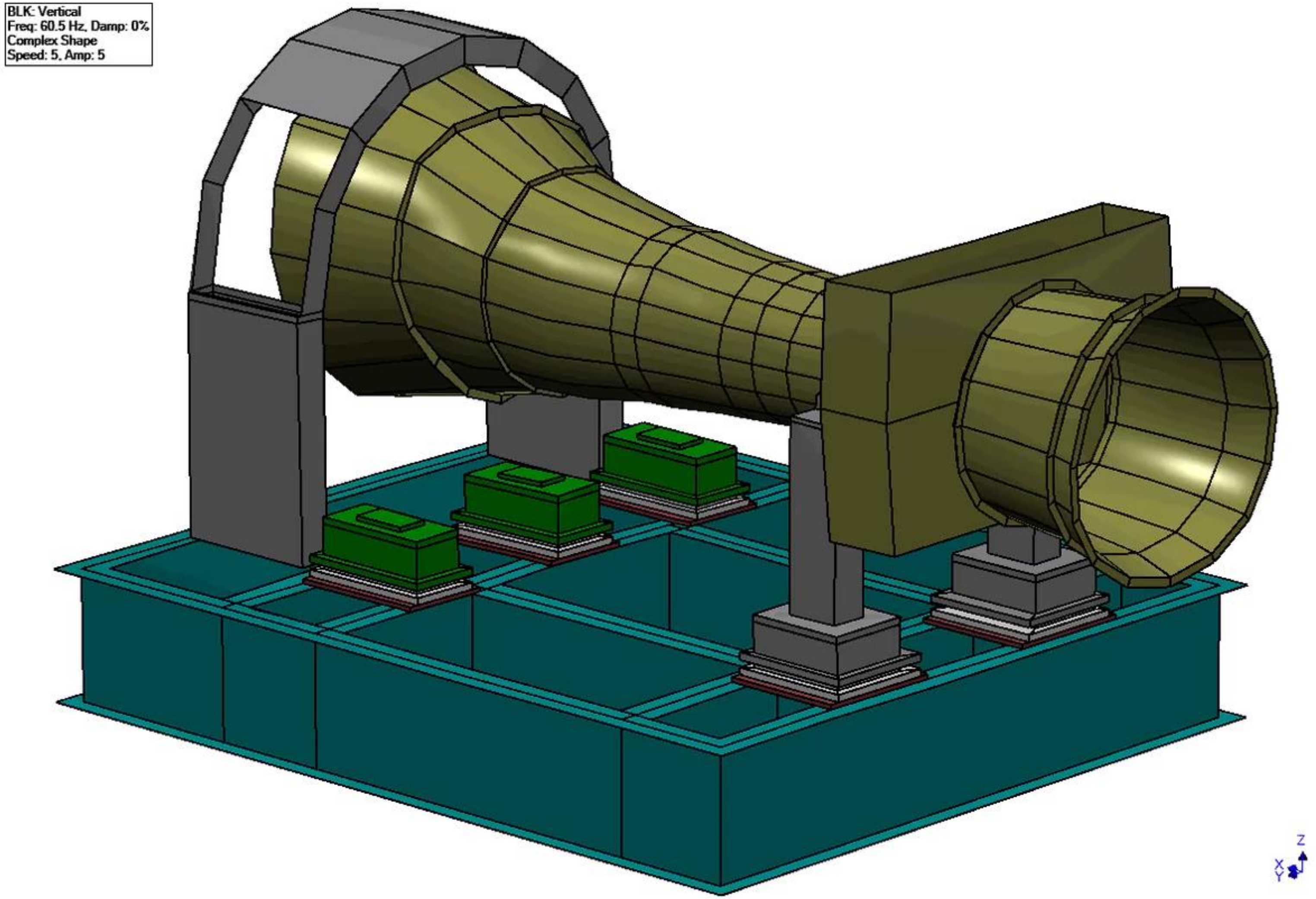
MSI Left Side Analyzer (56 Ch.)
5 Strain Gages Mounting Support
9 HT Accelerometers
10 Triax Accelerometers
TRF (Reference)
Total: 104 signals recorded simultaneously
Local Module Control
Stack
Aft
Fwd
Gearbox
Generator
4 Linear Potentiometers
10 HT Accelerometers
10 Triax Accelerometers
TRF (Reference)
MW, T3, T48, VSV, VBV
LP / HP Rotor Speed
MSI Right Side Analyzer (80 Ch.)
Generator and gearbox Vibration Signals and Key-Phasor
CRF / TRF (broadband signal)
E
N
S
W

Experimental Modal Analysis (EMA) Test

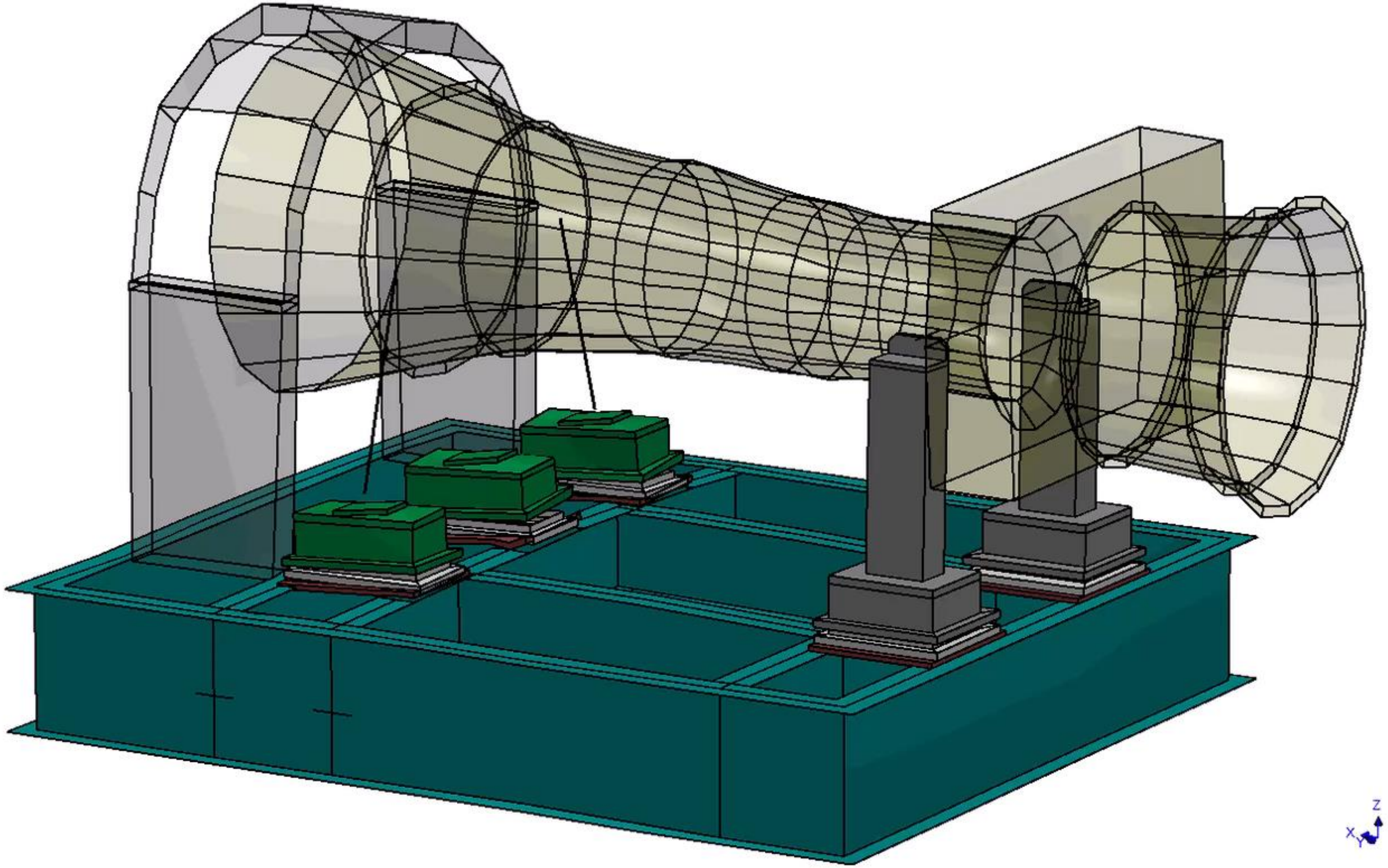




Experimental Modal Analysis (EMA) Test Results (64 Hz)



ODS at 60 Hz (5 MW Load)



Conclusions

1. Root cause of elevated vibration at low load operation (~8 MW) was due to a structural resonance of supporting system
2. Experimental modal analysis (EMA) test identified several structural natural frequencies near 1x rpm LP rotor speed mostly in vertical direction
3. Offending mode at 64 Hz (at rest) was tuning in and out depending on initial stiffness of support structure or mounts under load conditions
4. Change in frequency is not related to thermal loading – change in stiffness occurs suddenly as load applied through to Aft mounts changes

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Conclusions

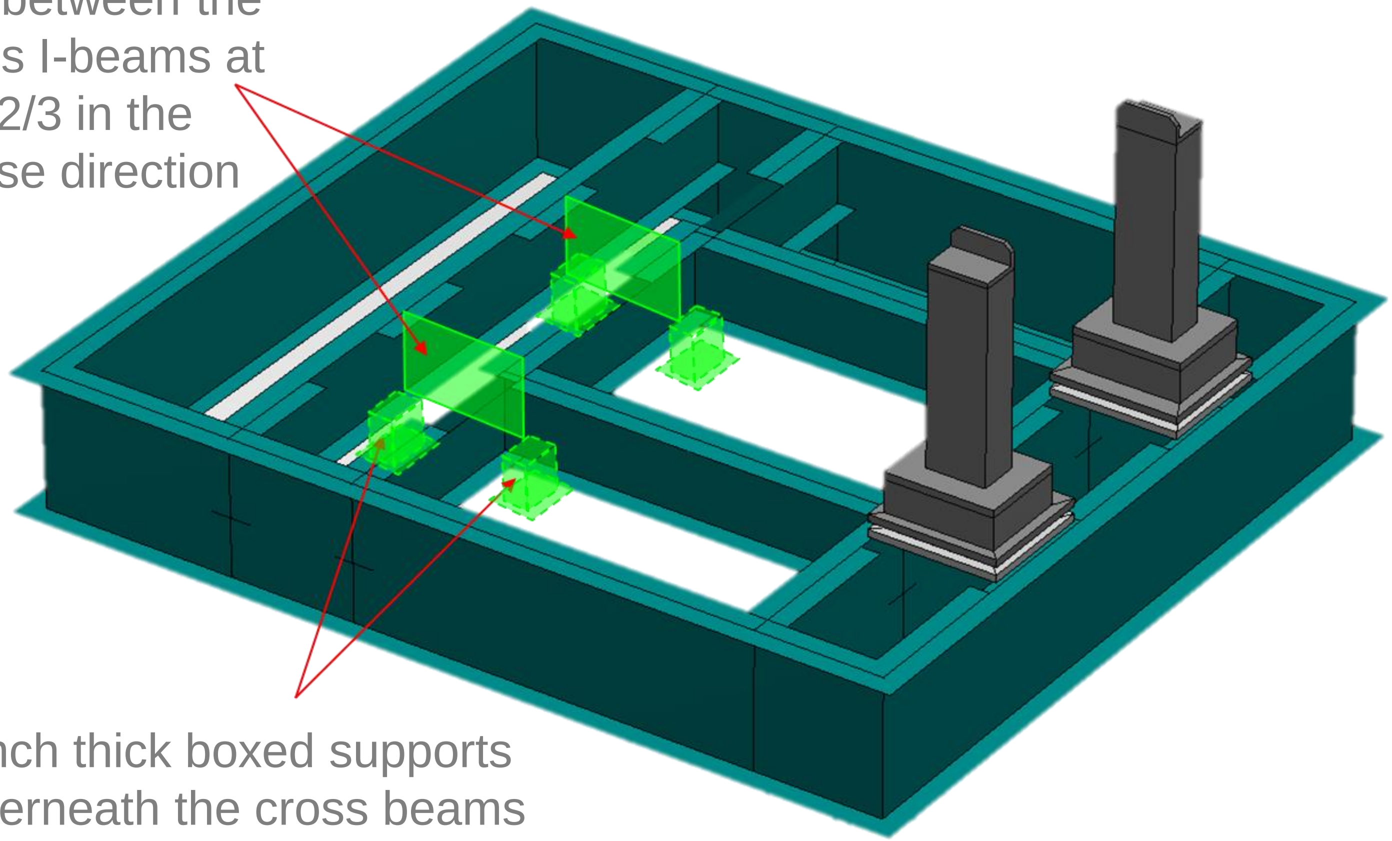
5. As load was increased to 5 MW, this natural frequency shifted downwards to 61 Hz. At 7.8 MW, when maximum amplification was reached, this mode shifted to 60.5 Hz (LP rotor speed). After 14 MW, mode is slightly below LP rotor speed (~60 Hz), and at full load (33 MW) finally drifted down to ~55 Hz (9% separation margin from LP speed).
6. Based on Operating Deflection Shape (ODS) testing, excessive flexibility was detected at baseplate underneath TRF Aft section, where Aft mounts are located – appears that cross I-beams, in cantilever attachment, are allowing excess vertical bending.

Recommendations

1. Shift offending structural natural frequency away from LP rotor speed.
2. Eliminate looseness at bearing/ bushing of Aft mount supports by replacing bushing/ bearings and torque bar supports (restoring original tight clearances).
3. Additional gussets (1/2 inch thick) between two cross I-beams that support torque bar and Aft mounts. Ideally, cross I-beams should be same size as main I-beams (main baseplate frame) to avoid bending. Therefore, cross-I-beams can also be supported with concrete floor (to eliminate gap between lower flange of cross I-beams and concrete floor). New supports must be anchored to concrete floor.

Recommendations

½ inch thick additional gussets between the two cross I-beams at 1/3 and 2/3 in the transverse direction



½ inch thick boxed supports underneath the cross beams at 1/3 and 2/3 of the cross beams anchored to the concrete floor

What If

Motion Magnified Video (MMV) Testing

Had Been Available???

What is Motion Magnified Video?

High-Speed, High Resolution Video → **Vibration Analysis** → **Motion Magnification** → **Problem Diagnosis**

High-Speed, High Resolution Video

- Equivalent of millions of accelerometers, 1 per pixel
- Non-contact
- Communication tool

Vibration Analysis

- Analyzes & quantifies motion in minutes
- Frequencies
- Displacement
  - 2-dimensional
- Phase

Motion Magnification

- Algorithms magnify motion to human visual threshold, up to 1000x
- A couple different technologies
- Frequency and time domain

Problem Diagnosis

- Understand what is happening
- Effectively communicate information

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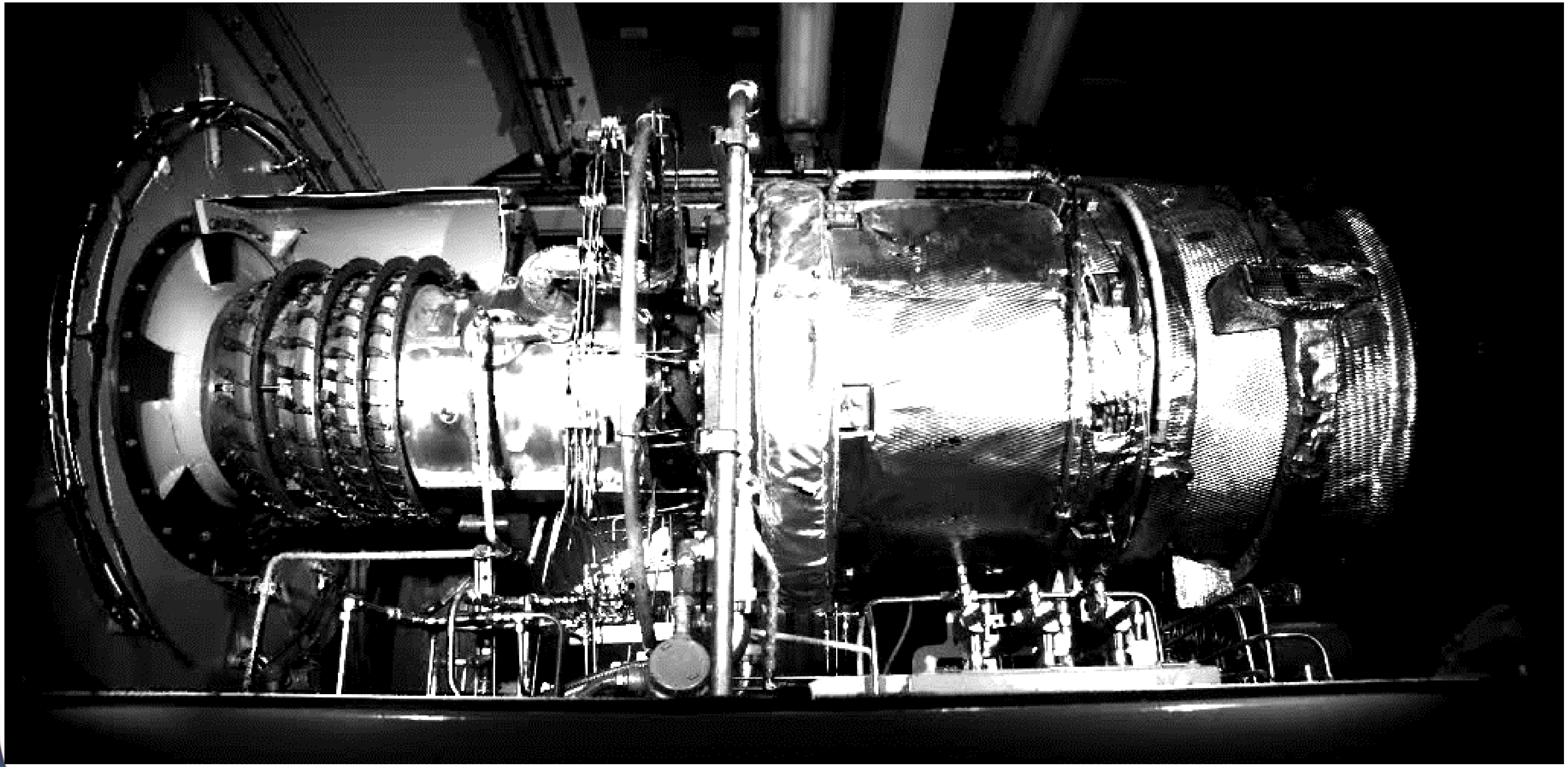
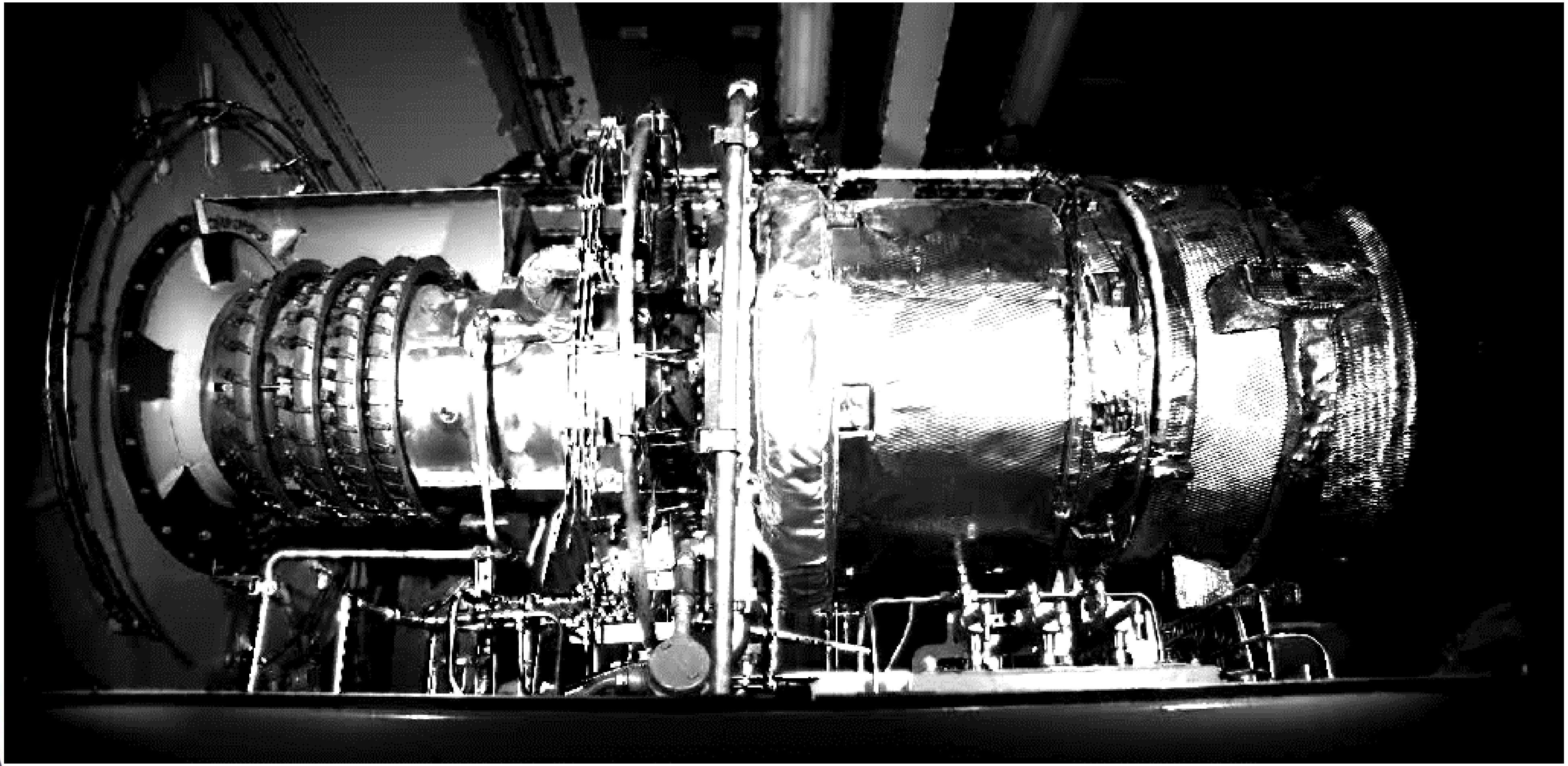
Examples of Motion Magnified Videos



HP Rotor 1x rpm (252 Hz)

Examples of Motion Magnified Videos



LP Rotor 1x rpm (30 Hz)

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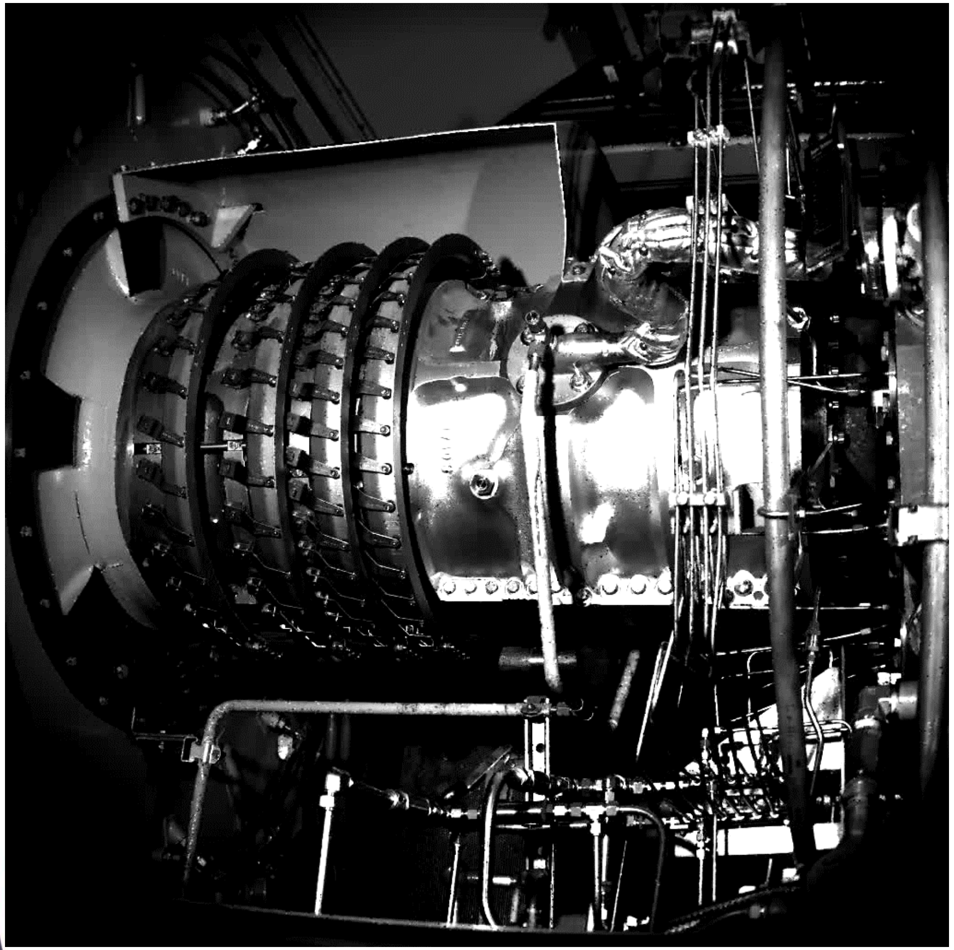
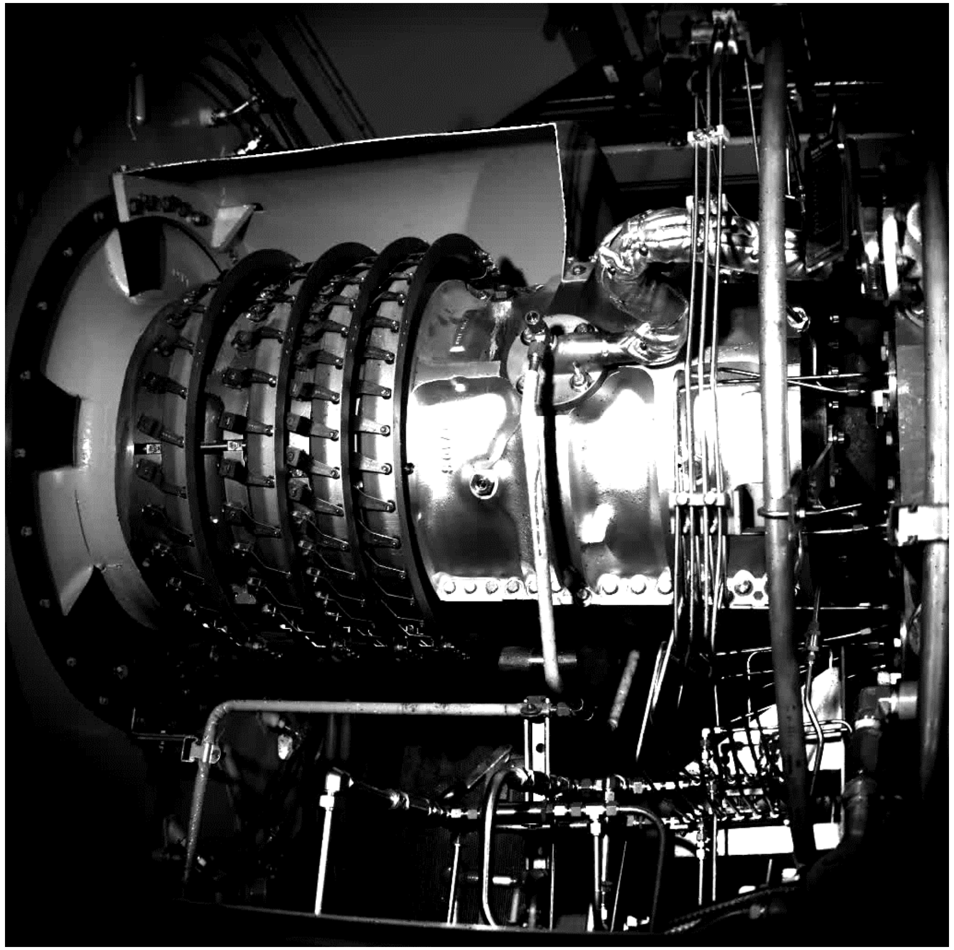
Examples of Motion Magnified Videos



235 Hz



344 Hz

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Benefits

SIMILAR TO ODS

- Visual
  - Realistically demonstrates mode shapes and frequencies of vibration
  - Easy for non-experts to understand
- Large variety of applications
  - Rotating equipment – Safe (without contact)
  - Stationary balance of plant
- Comprehensive
  - Show context of the problem
  - Rule out what isn’t the problem
  - Guide additional testing, like ODS!

DIFFERENT THAN ODS

- Fast
  - Analysis results in minutes, not days/weeks
- Non-contact
  - Not affected by heat, radiation, height, or other hazard/accessibility constraints
  - No “sensor effect” – passive measurement
  - Has to be visible
- Comprehensive without the cost trade-off
  - Millions of data points sampled in seconds

Additional Considerations for Turbine Application

- Supplemental lighting required – required disabling fire suppression during test
- Air movement can affect camera motion – digital stabilization can typically correct
- Floor vibration can affect camera motion – digital stabilization can typically correct, mechanical stabilization preferred
- Creative camera setup may be required – base plate was target in this case

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Questions?

Thank you!