

Engine Driven Pumps - Vibration Problem Resolution Using Specialized Testing Techniques

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Outline

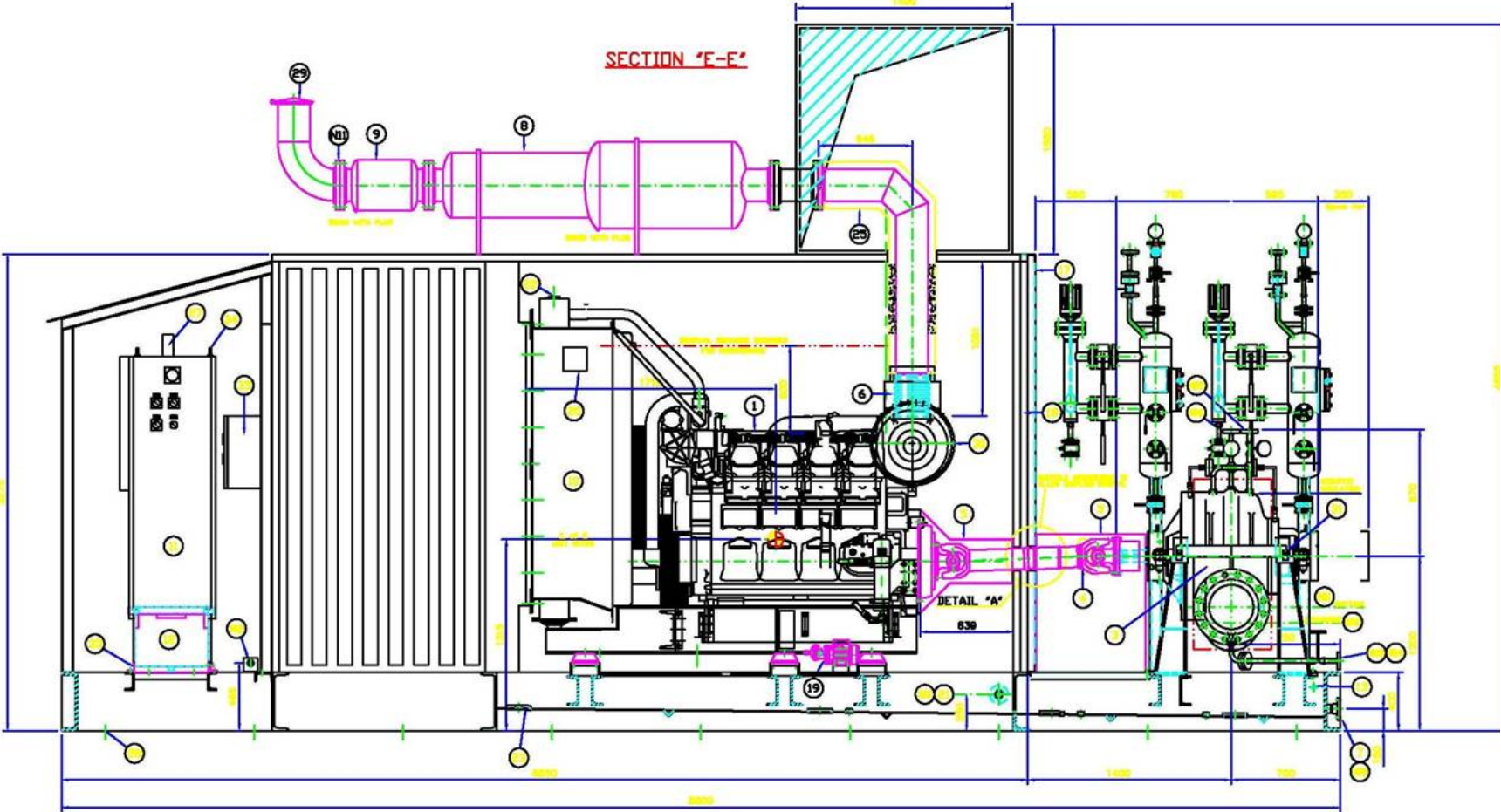
- Problem description and approach overview
- Specialized testing to characterize the problem
- Conclusions and recommendations based on the test results
- Implementing the solution
- Lessons learned

Problem Description - 1

- Two diesel-engine driven radially split diesel and gasoline pumps
- Engine-pumps operated within specified vibration levels during pre-shipment factory tests.
- High vibration levels since start-up – maximum 12.4 mm/s RMS on engine casing of the diesel pump.
- Past fix attempts were not successful and in one case led to higher vibration levels
- Focus of the case history is primarily on the diesel pump P2952X to stay within presentation time-limits.

Problem Description - 2

Engine driven pump layout drawing



Problem Description - 3

Discrete and overall vibration on each bearing housing of unit P2952X (diesel) at 1,760 rpm. Amplitude in mm/s RMS. Levels over 5 mm/s are shown in red.

| Location | Direction | 1x | 2x | 3x | Overall |
|----------------------------------|------------|-----|-----|-----|---------|
| Engine Inboard Casing | Axial | 2.2 | 0.7 | 0.4 | 4.6 |
| | Horizontal | 1.7 | 0.7 | 1.0 | 5.4 |
| | Vertical | 9.4 | 0.5 | 2.1 | 12.4 |
| Engine side Intermediate Bearing | Axial | 0.3 | 1.1 | 5.2 | 6.7 |
| | Horizontal | 0.9 | 1.0 | 2.1 | 9.0 |
| | Vertical | 0.6 | 1.0 | 0.8 | 5.3 |
| Pump side Intermediate Bearing | Axial | 0.2 | 1.2 | 5.2 | 6.7 |
| | Horizontal | 0.1 | 1.0 | 4.6 | 7.0 |
| | Vertical | 0.1 | 1.0 | 1.1 | 5.3 |
| Pump Inboard Bearing | Axial | 0.3 | 0.3 | 0.8 | 2.3 |
| | Horizontal | 0.5 | 1.4 | 1.9 | 3.9 |
| | Vertical | 0.1 | 0.1 | 0.3 | 2.9 |
| Pump Outboard Bearing | Axial | 0.3 | 0.3 | 0.6 | 2.4 |
| | Horizontal | 0.4 | 1.3 | 2.5 | 4.3 |
| | Vertical | 0.2 | 0.2 | 0.7 | 2.8 |

Problem Description - 4

Discrete and overall vibration on each bearing housing of unit P2956X (petrol) at 1,760 rpm. Amplitude in mm/s RMS. Levels over 5 mm/s are shown in red.

| Location | Direction | 1x | 2x | 3x | Overall |
|-----------------------|------------|-----|-----|-----|---------|
| Engine Inboard Casing | Axial | 0.7 | 1.3 | 0.9 | 5.5 |
| | Horizontal | 2.2 | 3.9 | 2.7 | 10.4 |
| | Vertical | 1.1 | 0.6 | 0.9 | 7.8 |
| Pump Inboard Bearing | Axial | 0.6 | 2.1 | 0.2 | 5.1 |
| | Horizontal | 0.1 | 2.6 | 0.6 | 3.3 |
| | Vertical | 0.2 | 1.8 | 0.1 | 2.8 |
| Pump Outboard Bearing | Axial | 0.6 | 2.0 | 0.2 | 5.3 |
| | Horizontal | 0.2 | 2.6 | 0.7 | 4.3 |
| | Vertical | 0.1 | 1.9 | 0.2 | 3.3 |

Approach Overview

- Characterize and understand problem using specialized testing:

Monitoring test during transient and steady operation to monitor the vibration amplitude, natural frequencies, and phase angle.

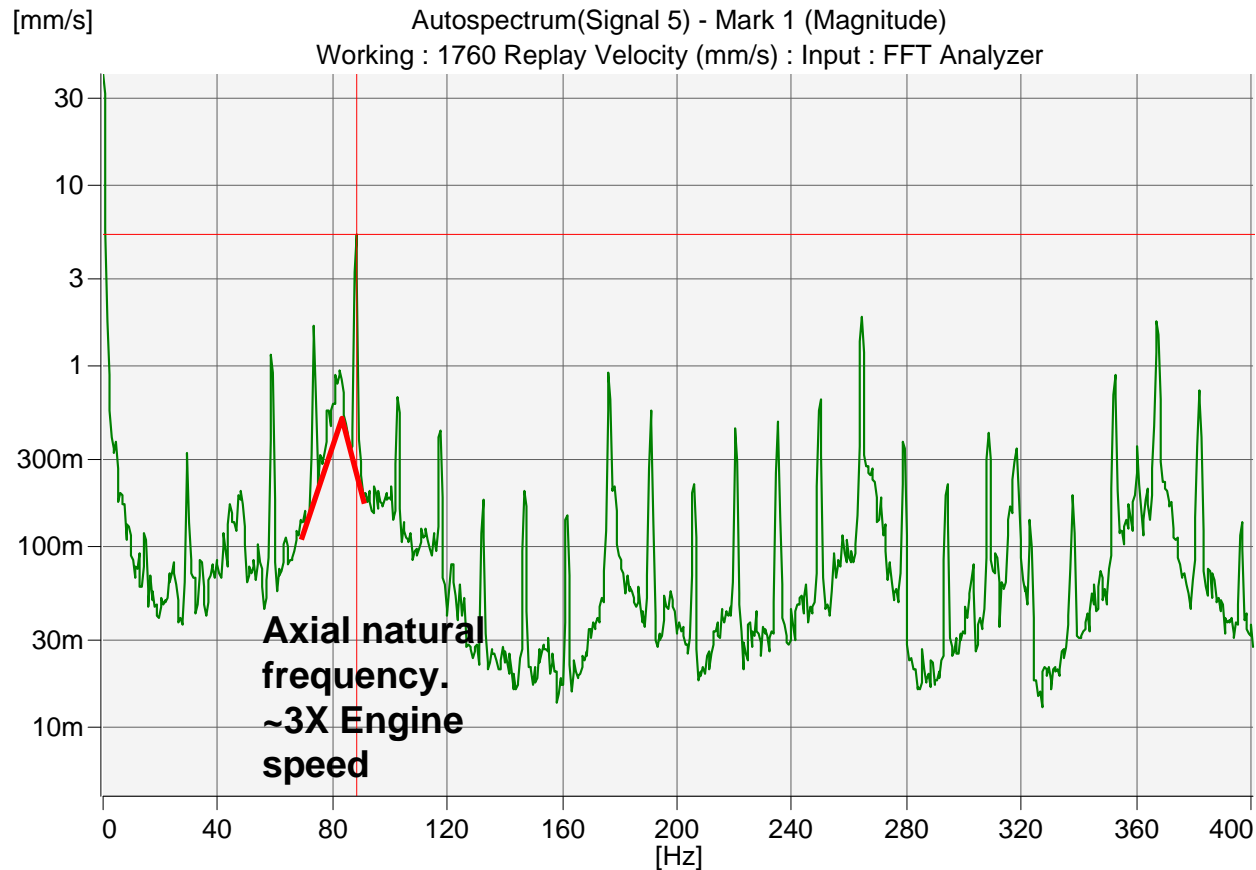
Experimental Modal Analysis (EMA) test to confirm the natural frequencies of the pump-engine structure.

Operating Deflection Shape (ODS) testing during operation.

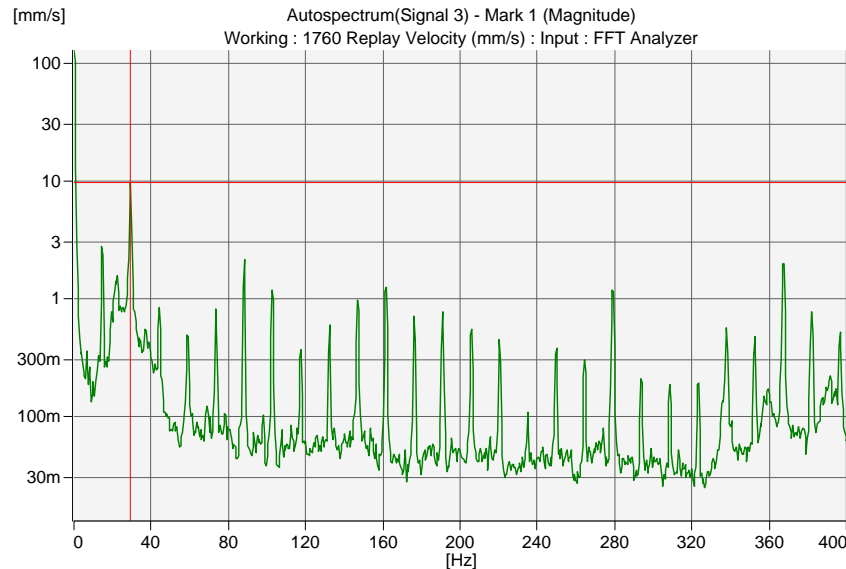
- Process ODS data into animations to visualize system response at various frequencies
- Analyze results and recommend a solution(s)
- Implement the correct solution

Initial vibration testing - 1

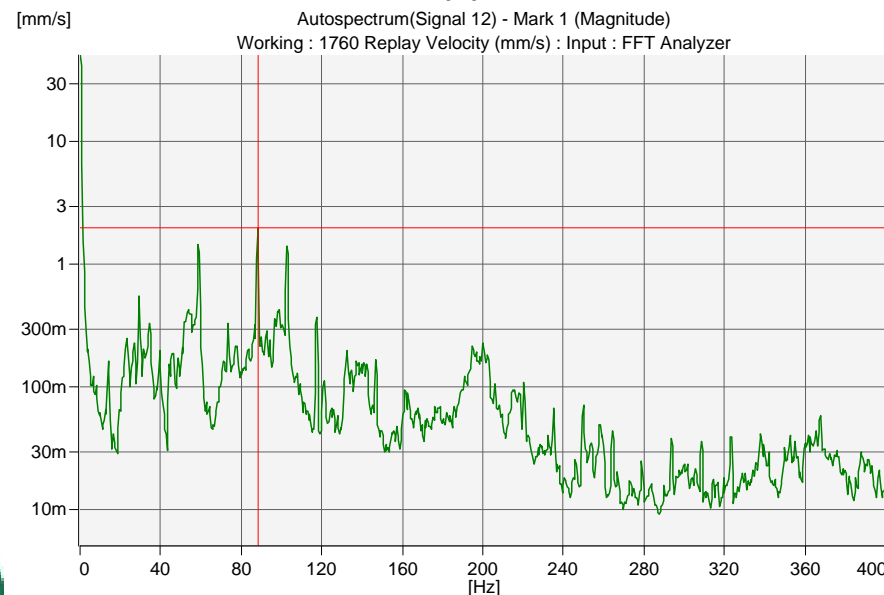
- Initial vibration testing used to identify potential issues to allow focusing on more specialized testing.
- Below: Typical vibration spectra of the P2952X engine inboard casing. Measurement in the axial direction. Note by plotting amplitude in the log scale a potential natural frequency is indicated.



Initial vibration testing - 2



Left: Measured on the engine inboard casing in the vertical direction. Note the “picket fence” type response. Harmonics are $\frac{1}{2}$ engine speed.



Below-left: Horizontal direction – Side to side mode near 96Hz (3.5Xengine speed).

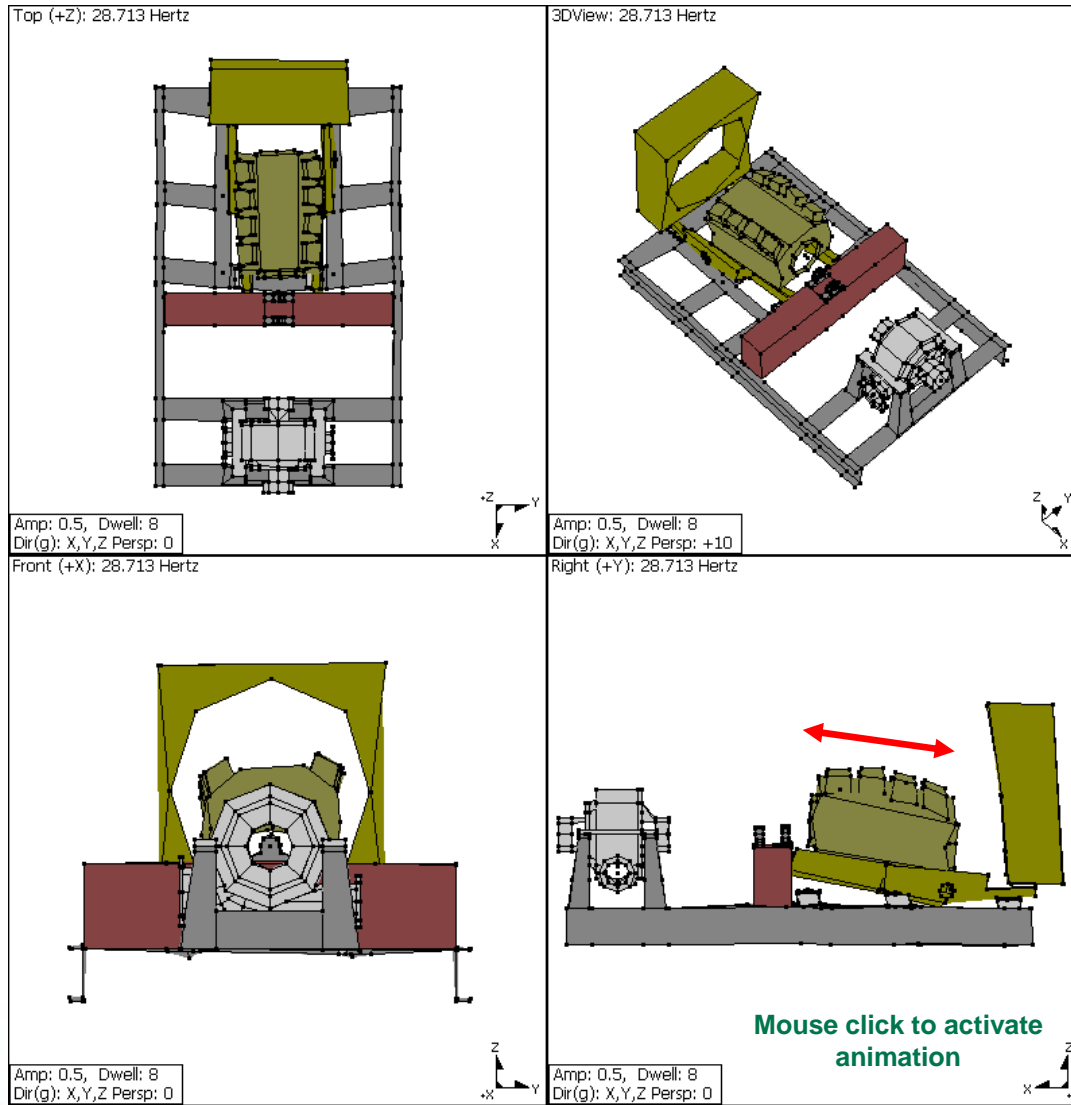
Initial conclusion: Engine harmonics are exciting system natural frequencies.

Need ODS testing to provide details to identify potential solutions.

ODS testing - 1

- Natural excitation signature of the pump and engine system.
- Over 850 vibration measurements using triaxial accelerometers which measure vibration in three orthogonal directions.
- Data base of amplitude vs. frequency and phase angle.
- 3-D CAD model assigning motion to each individual vibration data point.
- Create animations of the pump-engine-foundation system.
- Animations are exaggerated but to scale.
- Animations help guide the troubleshooter to the problem and solutions.

ODS testing - 2

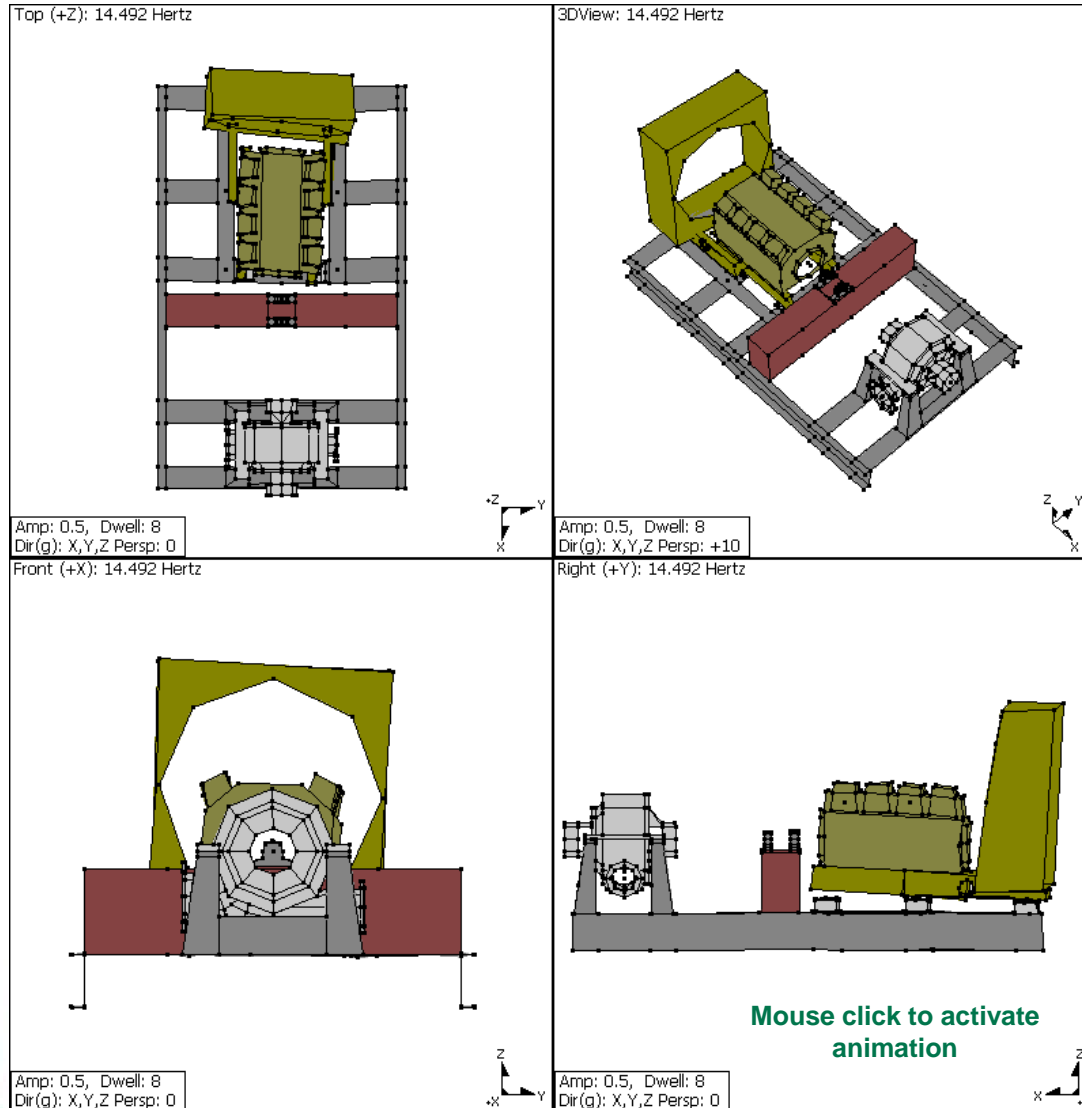


1x rpm (1722 cpm).

The animation shows flexibility of the diesel engine supports.

Pump remains stationary.

ODS testing - 3

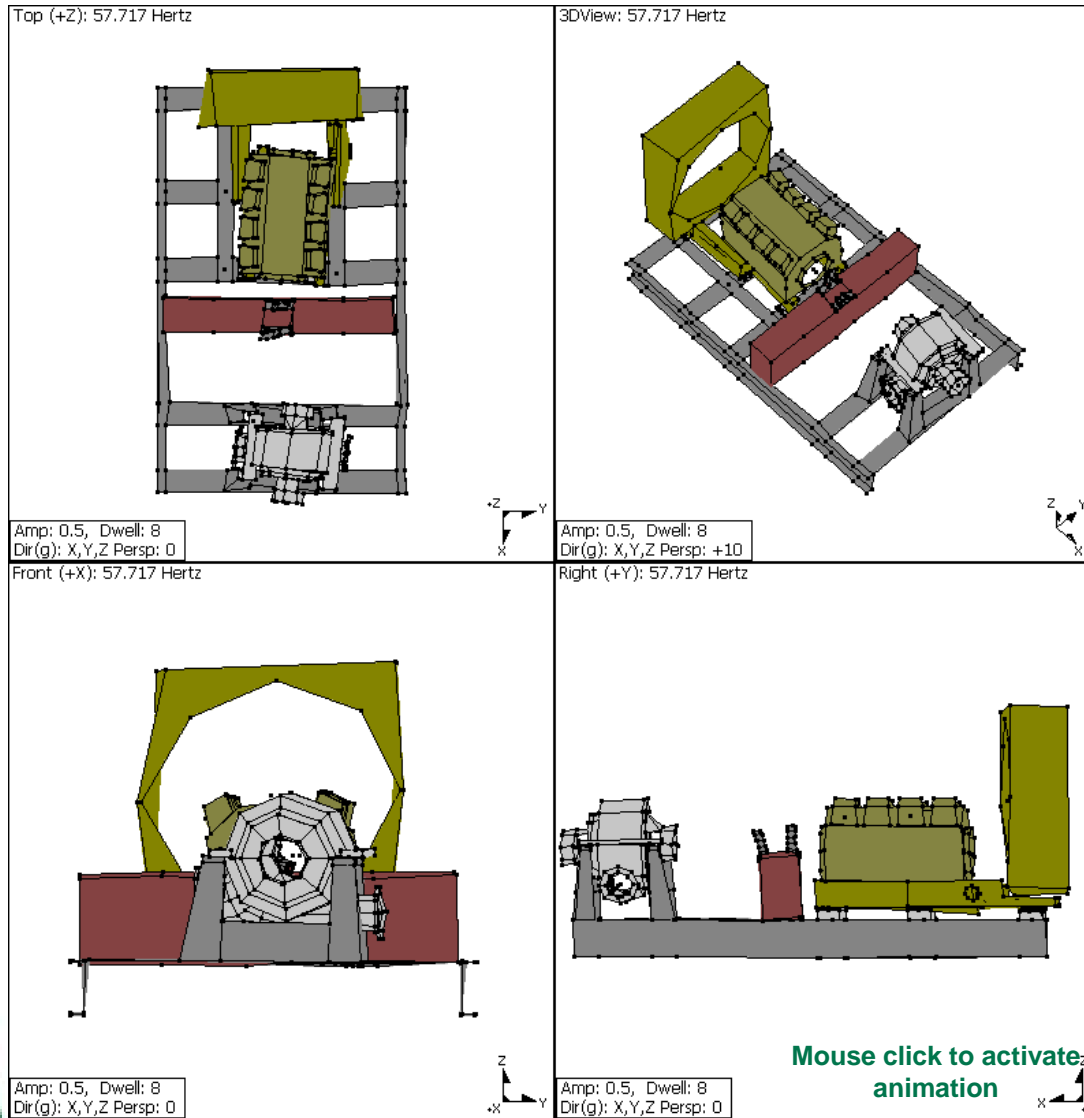


$\frac{1}{2}x$ rpm (890 cpm).

The animation shows the “swinging” of the engine supports

Pump remains stationary.

ODS testing - 4

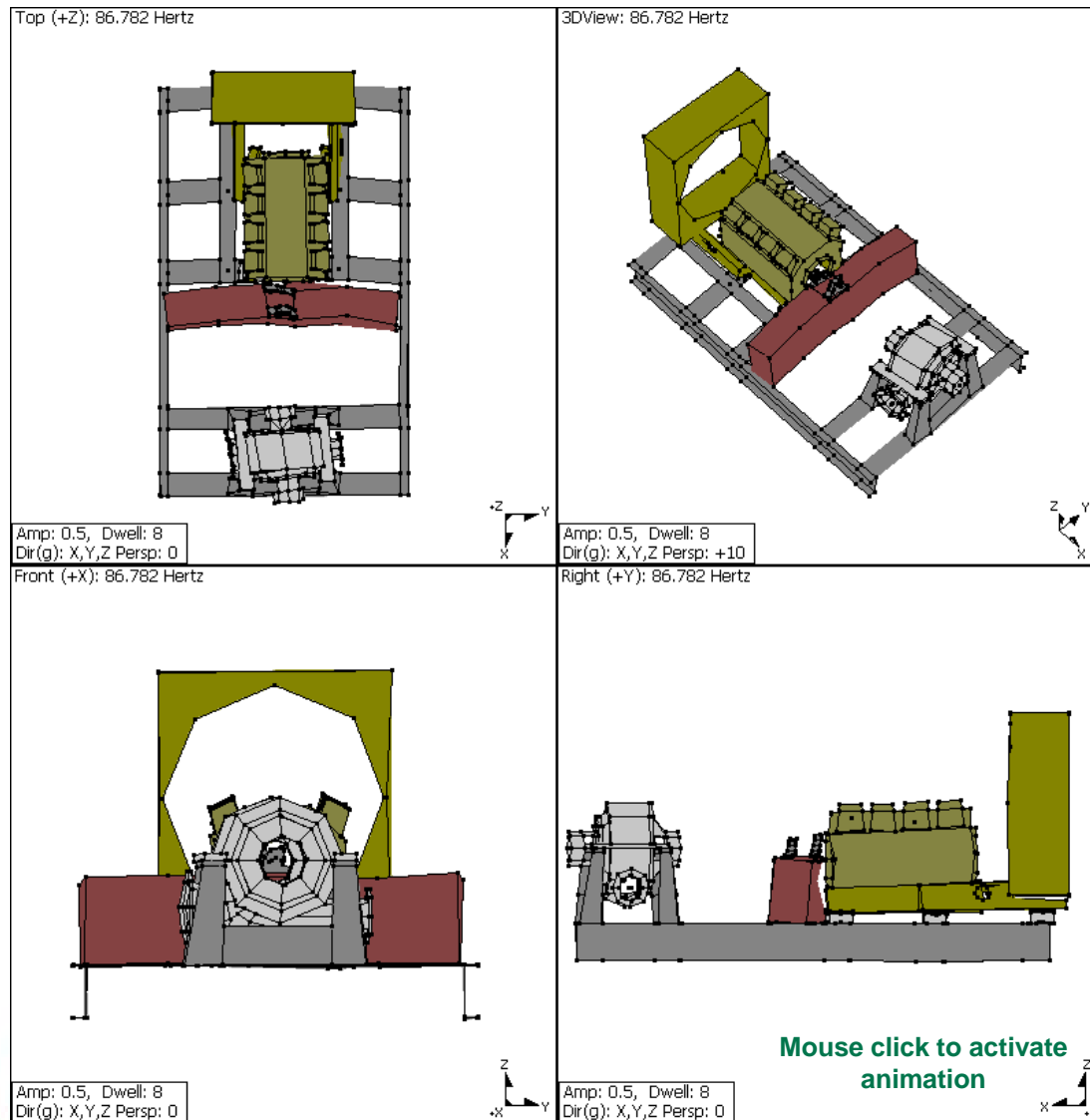


2x rpm

The animation shows horizontal side-to-side mode.

Pump and engine are out of phase.

ODS testing - 5



3x rpm (86.8Hz or 5,208 rpm)

The animation shows the intermediate pedestal rocking axially, and

A pump twist mode.

ODS “representation” of the FFT spectra shown earlier on slides 8 and 9.

General conclusions

- Engines are moving considerably relative to the pumps due to flexible mounting pad support of engine feet.
- Transmitted motion through shaft to other system components including the P2952X steady bearings and their support beam, and the pump/pedestal.
- Vibration greatly amplified at select operating speeds leading to strong engine-driven harmonic response at multiples of $\frac{1}{2}$ x engine rpm.
- Engine mis-firing caused $\frac{1}{2}$ x rpm force response excitation (“picket fence”).
- Engine soft-mounting amplified the response levels.

Specific conclusions – P2952X

- Highest vibration at intermediate bearing due to excitation of the pedestal mode in the axial direction (3x rpm, 84.5Hz) and side-to-side (3.5x rpm, 96Hz).
- The modes were being excited by the 3x and 3.5x rpm harmonics of 1/2 x rpm sourced engine excitation when the system was running at 1,722 rpm (28.7 Hz).

Recommendations – P2952X

Initial:

- Replace flexible mounts with single or two-piece shim pack of equal height (no stacking of thin multiple thin shims). Retune engines to minimize mis-fire ($1/2 \times \text{rpm}$) excitation.

If the above is not effective, then also:

- Grout the baseplate for added stiffening and damping – may not be practical.
- Add piping shock absorbers/vibration dampeners to critically damp the 84.5Hz and 96Hz modes.

OR

Lowering engine operating speed will reduce vibration by shifting the excitation frequency away from these natural frequencies. Lower engine rpm may require a larger impeller diameter to meet specified flow and head requirements.

Implement solutions – P2952X

- Flexible rubber mounting pads replaced with appropriate metal shims.
- Engine tuning verified.
- Grout added under the engine.
- Engine rpm reduced.
- Impeller diameter increased to meet flow and head requirements at lower engine rpm

Result: System vibration levels reduced to acceptable levels.

Lessons Learned

- Be aware that factory vibration test results and field test results will differ due to variances in the foundation, piping, and other issues that impact structural natural frequencies.
- Carefully consider the use of flexible pads versus rigid mounting.
- Successful troubleshooting of more complex problems requires collaboration between the OEM, the plant, and 3rd party specialists.
- Specialized testing including the use of Operating Deflection Shape (ODS) and experimental modal analysis is a powerful troubleshooting tool to facilitate and visually understand vibration problems in any turbomachinery system.
- A pre-construction “design audit” of the system – pump, driver, base, foundation, and piping – performed by an experienced analyst using modern FEA tools can help avoid these types of problems.



Questions?