Investigation and Elimination of Aerodynamically Induced Torsional Vibrations on an Integrally-Geared Centrifugal Compressor

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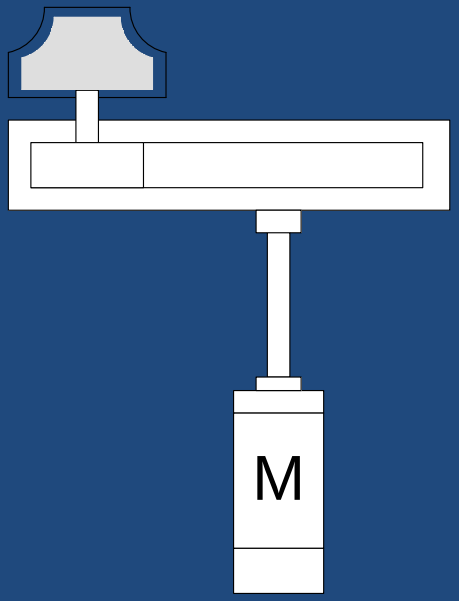
Compressor Description

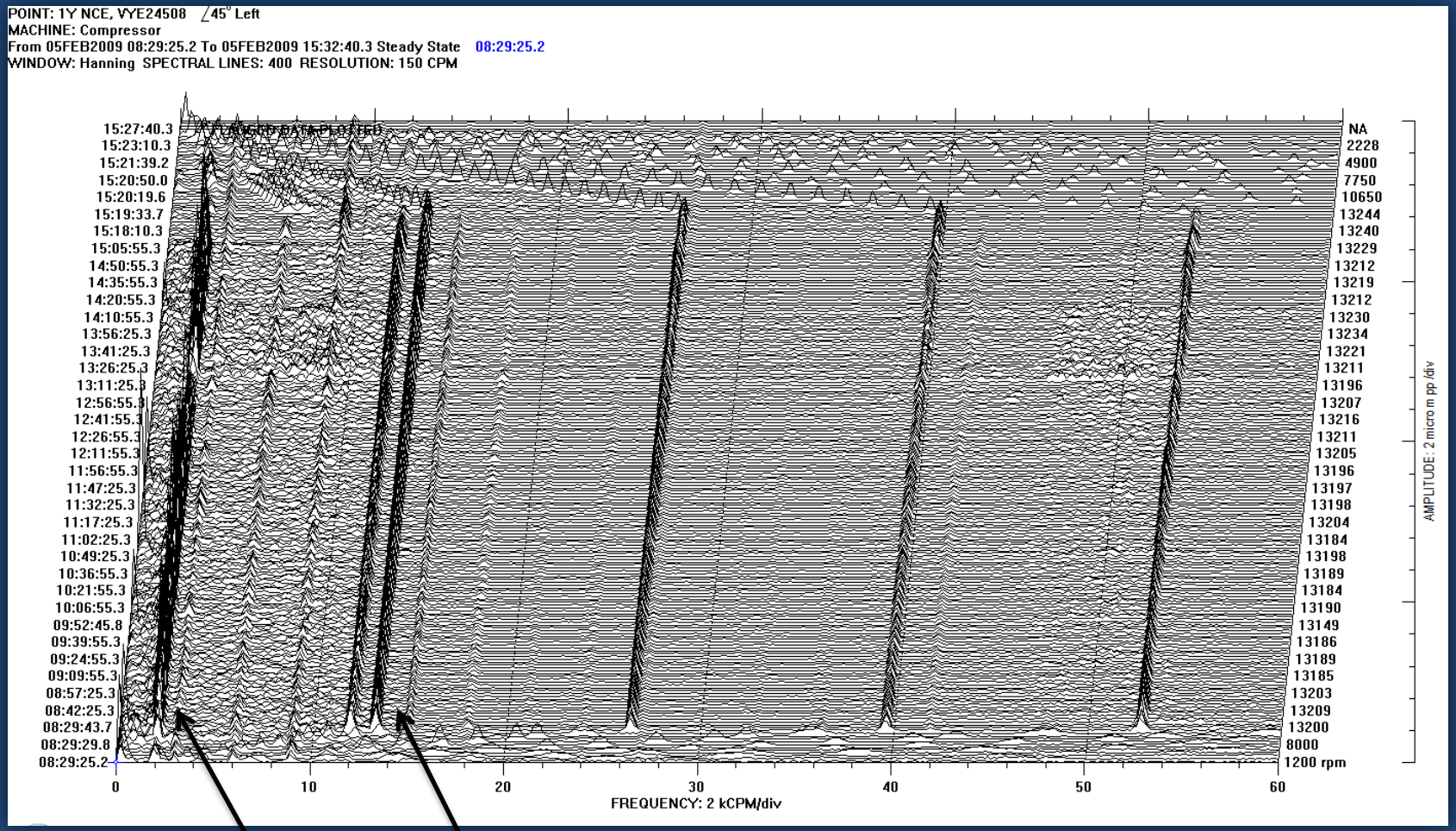
- Single stage integrally-geared, API 617
- Capacity control: Variable Diffuser Guide Vanes (DGVs) – Used due to the requirement of large turndown at relatively constant discharge pressure in this application.
- Driver: 2 pole, 50 Hz Induction motor, IEC 60034
- Coupling: Flexible Disc pack



Test Description and Setup

- Mechanical Run Test
  - Test Gas: CO_2
  - Load (bhp): ~ 100% nominal
- Performance Test (ASME PTC 10 Type II)
  - Test Gas: CO_2
  - Test Speed: 94% nominal
  - Test Load (%bhp): 85% nominal
- Job/Contract components used:
  - Compressor core unit
  - Variable Diffuser Guide Vanes
  - Coupling spacer, driven side coupling hub

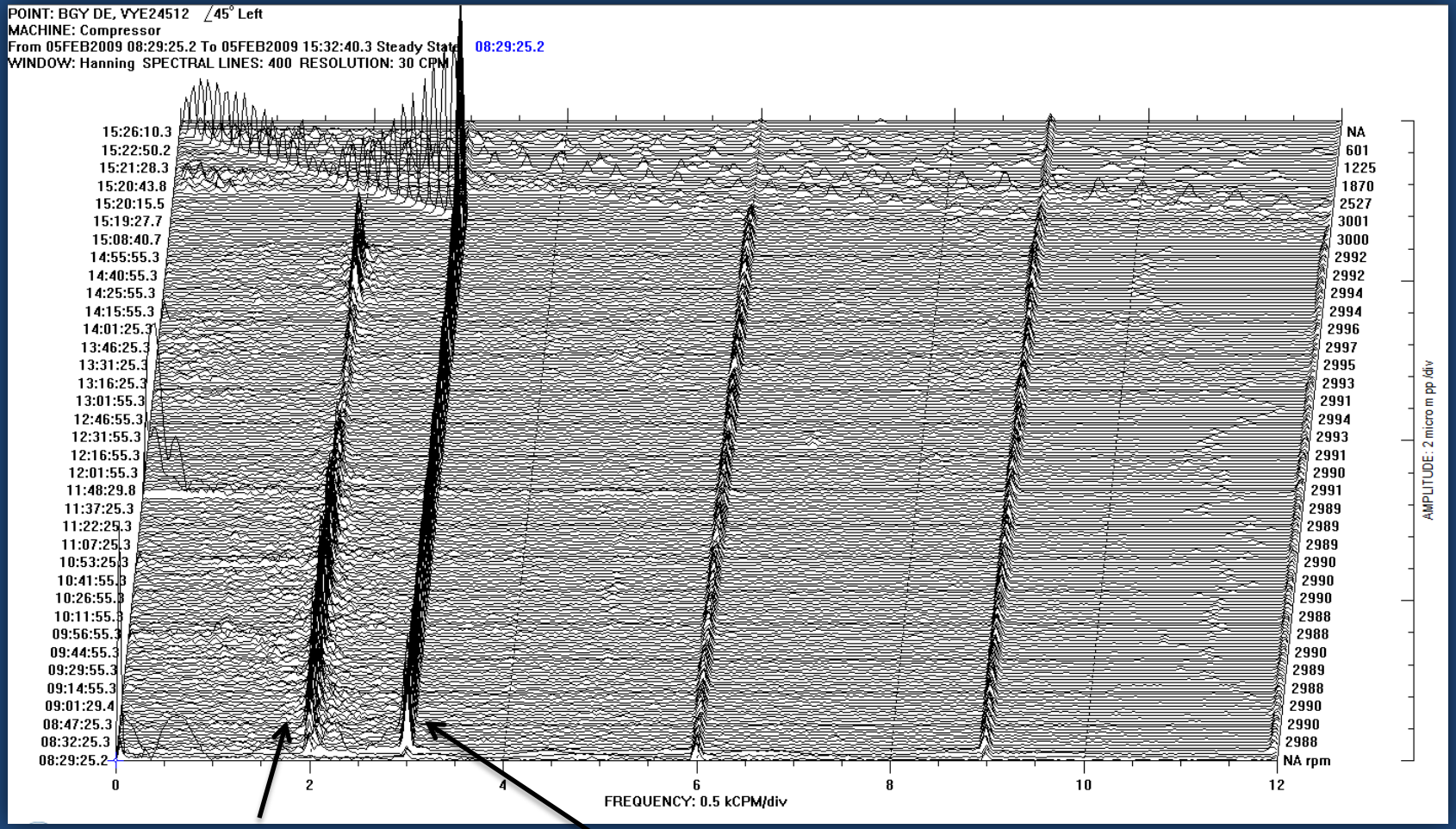
Half Spectrum Waterfall (Pinion)



Sub-synchronous vibrations (.147X)

1X (13200 rpm)

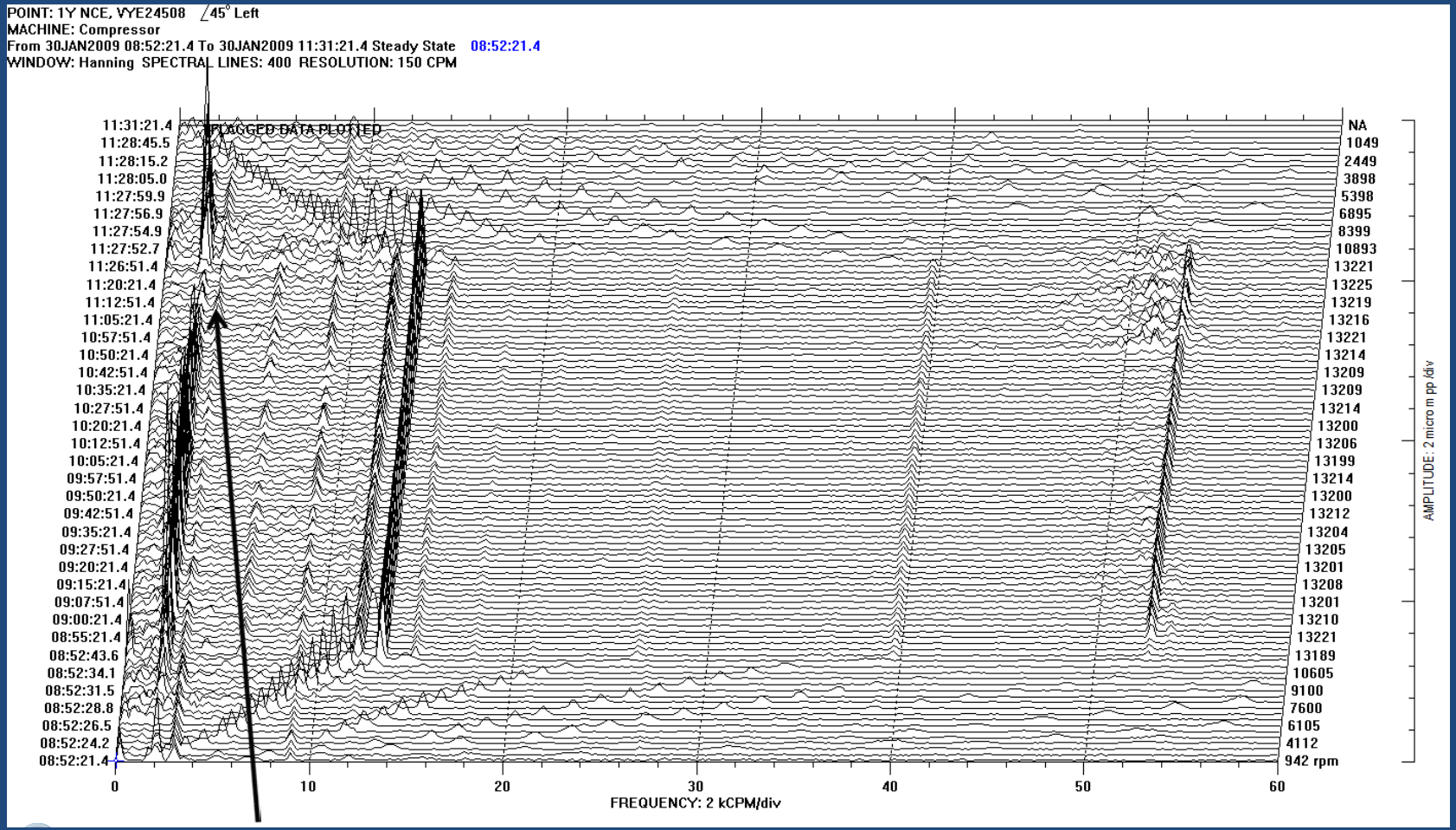
Half Spectrum Waterfall (Bull Gear)



Sub-synchronous vibrations (.147X Pinion)

1X (2990 rpm)

Half Spectrum Waterfall (Pinion – Varying DGV Angle)



Sub-synchronous vibrations disappeared at closed DGV

NOTE: Data for spare rotor. Same phenomena observed.

Key Test Stand Observations

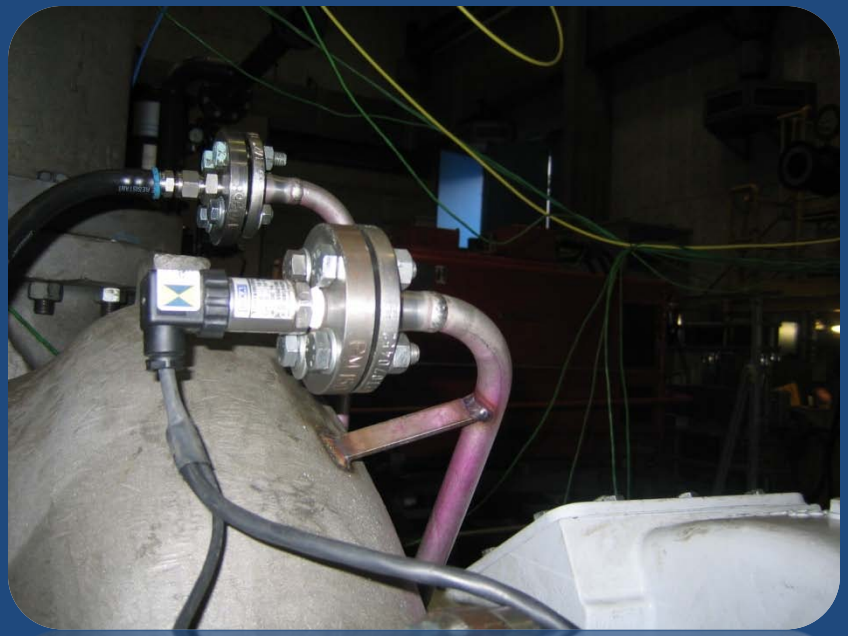
- Sub-synchronous vibrations with peak-peak amplitude between 5 – 10 µm (.2 - .4 mils) on both pinion and bull gear (at the same frequency – 32.5 Hz)
- Source of excitation appeared to be aerodynamic in nature
  - Sub-synchronous vibrations disappeared at closed DGV angles
  - Sub-synchronous vibrations disappeared on drawing a vacuum at normal (open) DGV angle
- Sub-synchronous vibration frequency in proximity of the first torsional natural frequency (TNF)
- Frequency of sub-synchronous vibrations changed by changing driver motor

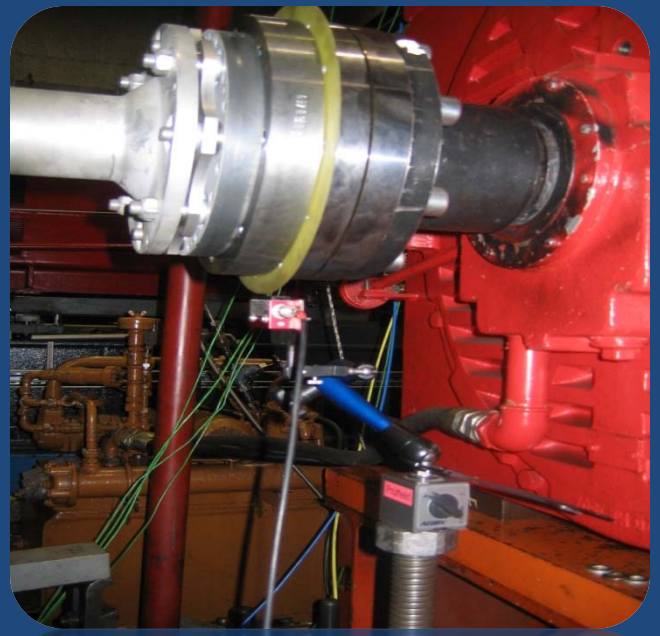
  (2nd test on same machine with lower HP, polar moment of inertia and torsional stiffness motor –> frequency of sub-synchronous vibrations followed direction of 1st TNF)

Additional Internal Testing

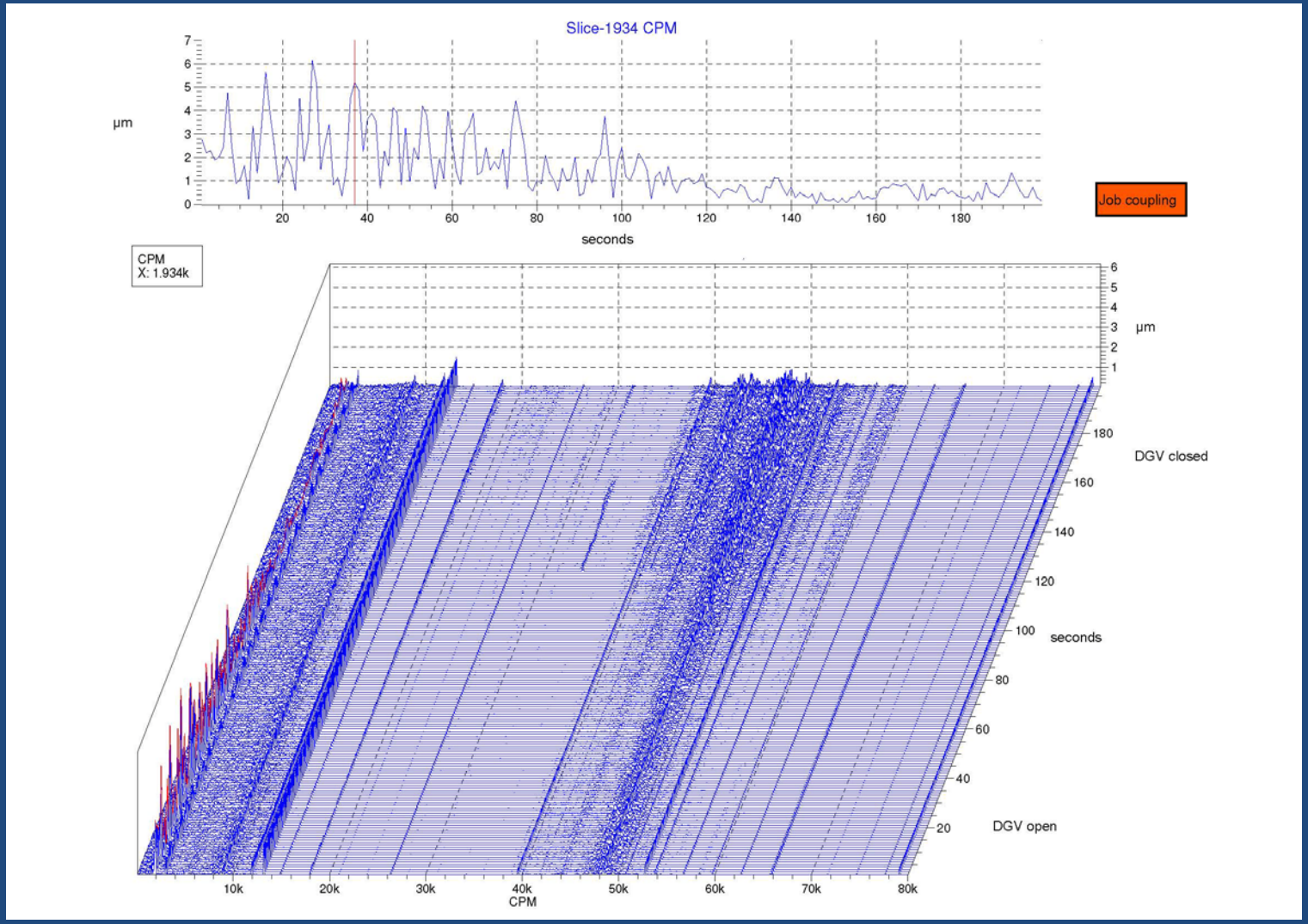
Test Setup and Instrumentation

- Transient impeller gap pressure between DGV and impeller measured with piezo transducer - range 1 kHz
- Transient drive torque measured with strain gage-torque meter disk between coupling spacer and the shop motor

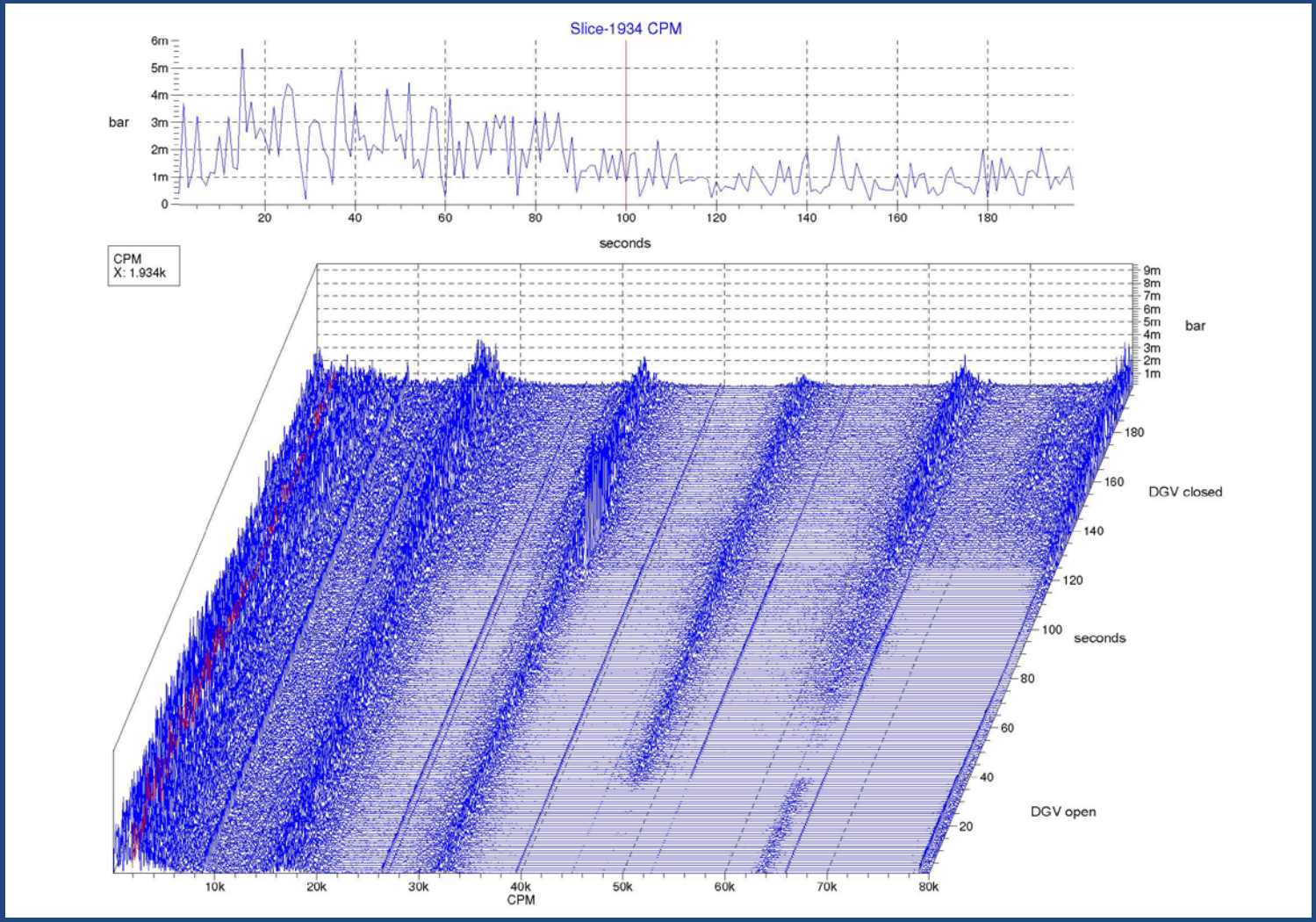




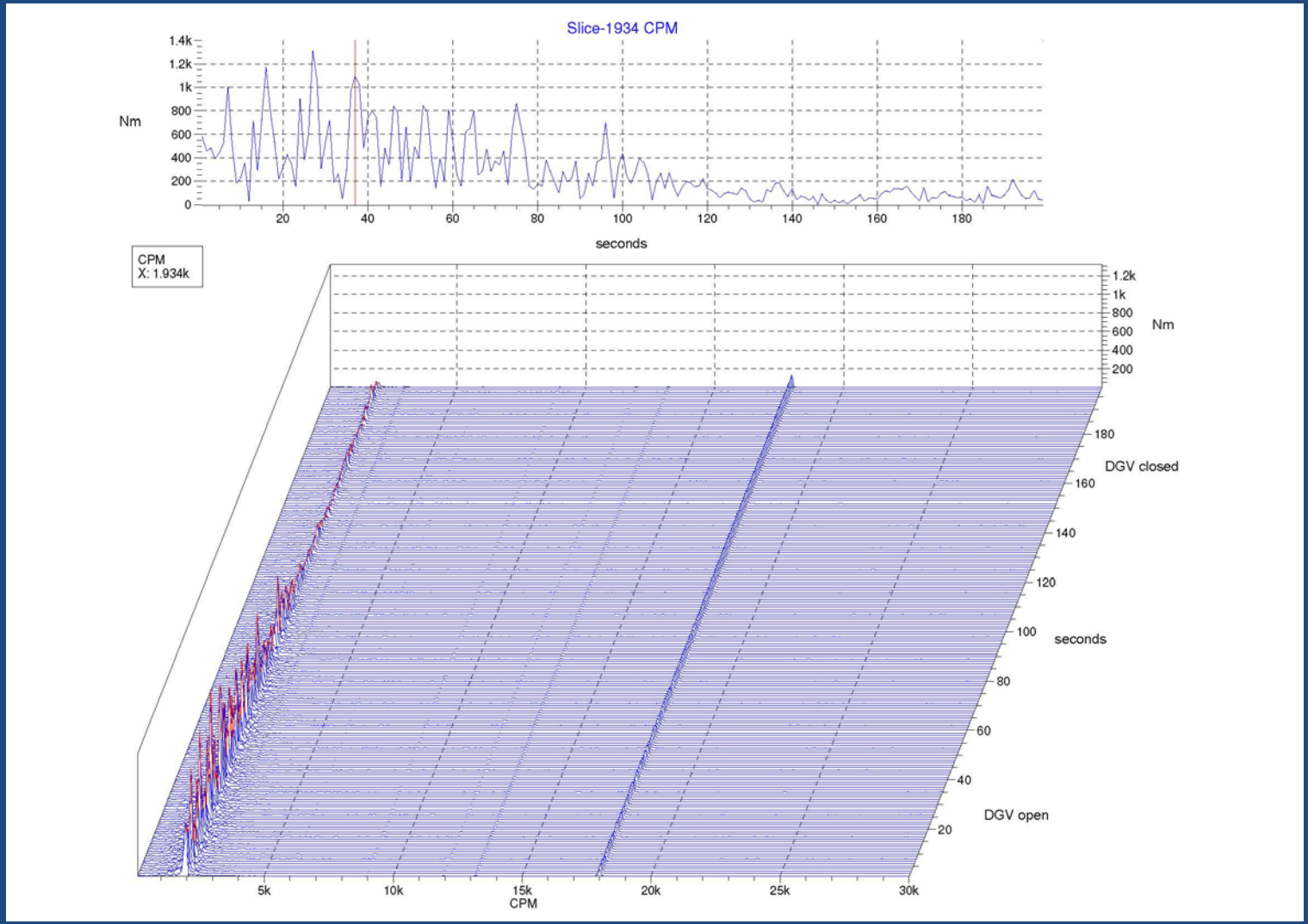
Vibration Measurements



Transient Impeller Gap Pressure Measurements



Transient Coupling Torque Measurements



Key Results

- Source of excitation is the gas flow. Amplitude of torque pulsations dependent on DGV angle.
- The response of the excitation is torque pulsations with a frequency in proximity of the first torsional natural frequency (TNF)
- Magnitude of torque pulsations dependent on DGV angle
- The gear couples the lateral-torsional resulting in lateral vibrations on both the pinion and bull gear side at the first TNF

Proposed Solution and Testing

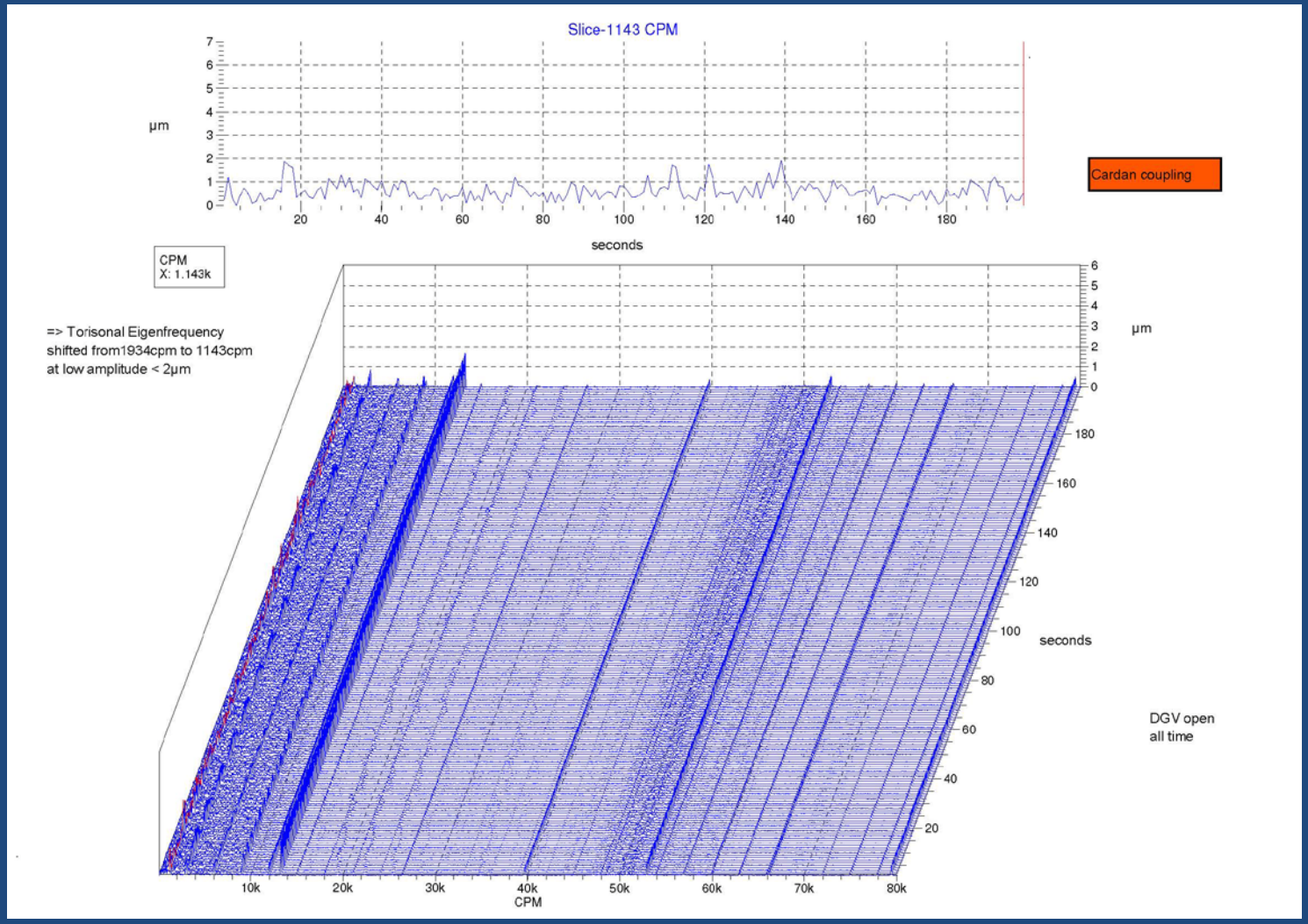
Proposed Solution

- Change the stiffness of the coupling to shift the first torsional natural frequency out of the flow excitation range (or to a lower excitation to minimize response)

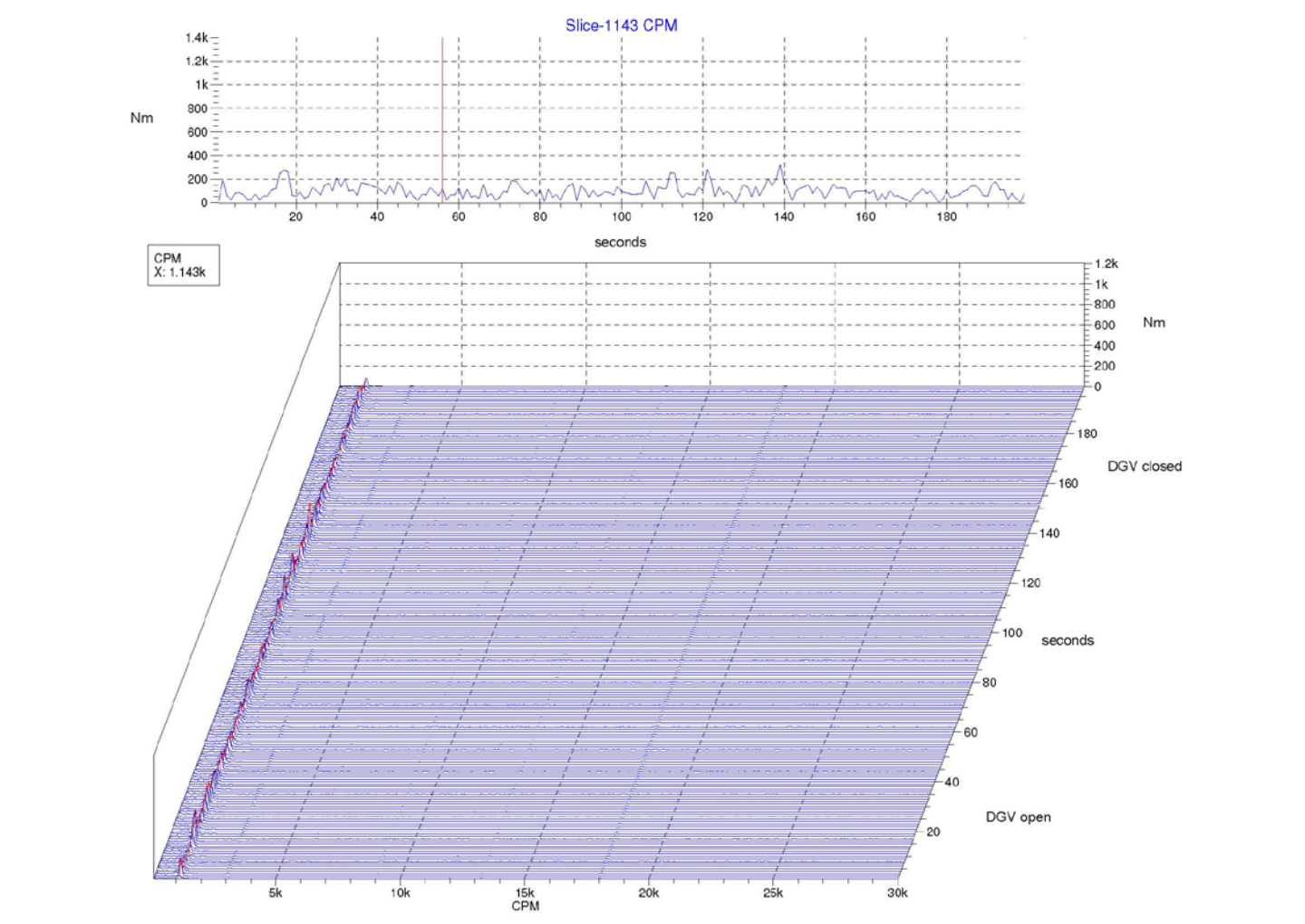
New Test Setup

- Job coupling replaced with a shop cardan coupling with a lower torsional stiffness

Vibration Measurements (Cardan Coupling)



Transient Coupling Torque Measurements (Cardan Coupling)



Test Results and Path Forward

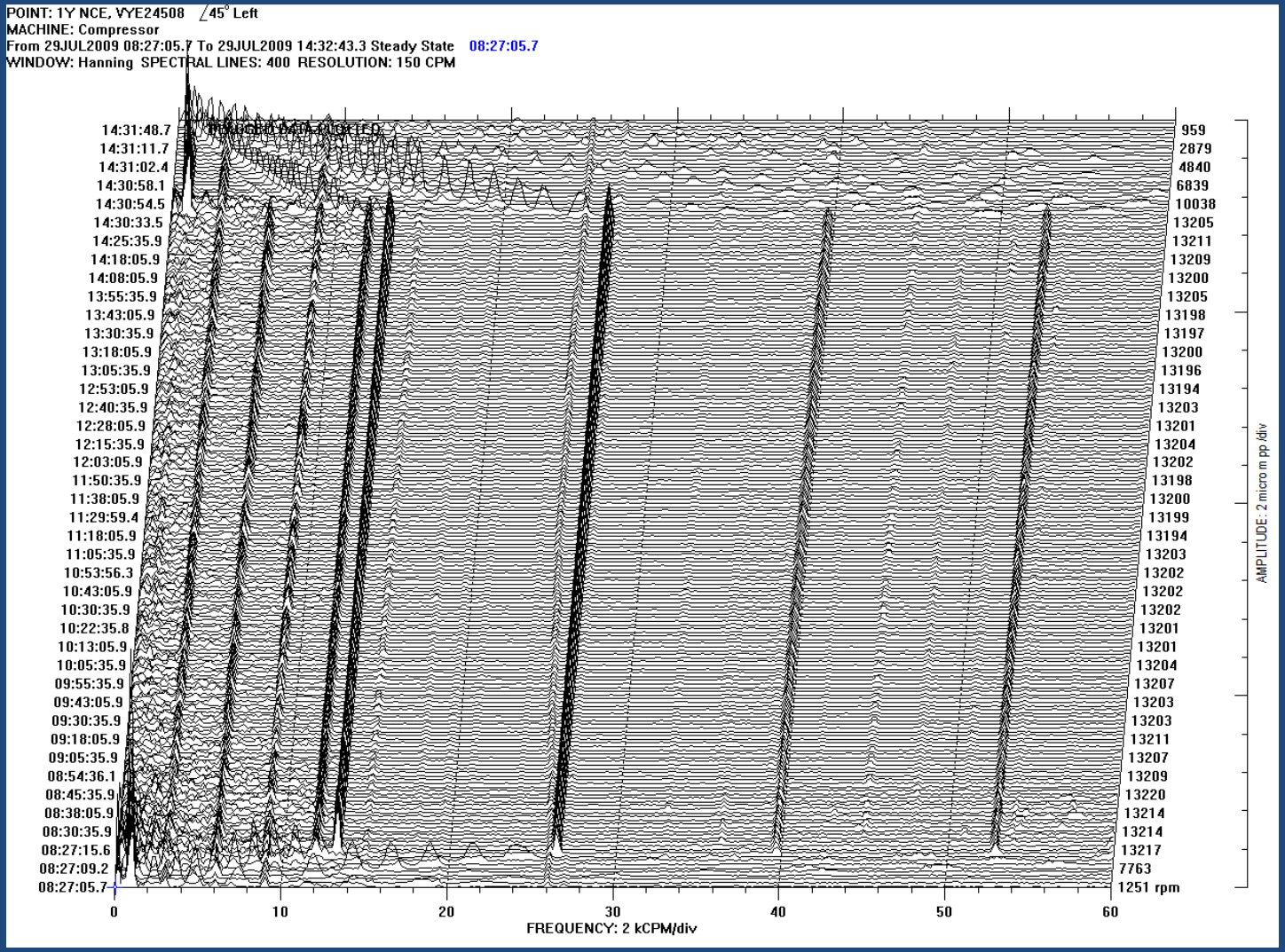
Results of Testing:

- Low amplitude (< 2µm) sub-synchronous vibrations present
- Frequency of sub-synchronous vibrations shifted to the predicted new 1st TNF
- Magnitude of torque pulsations significantly reduced

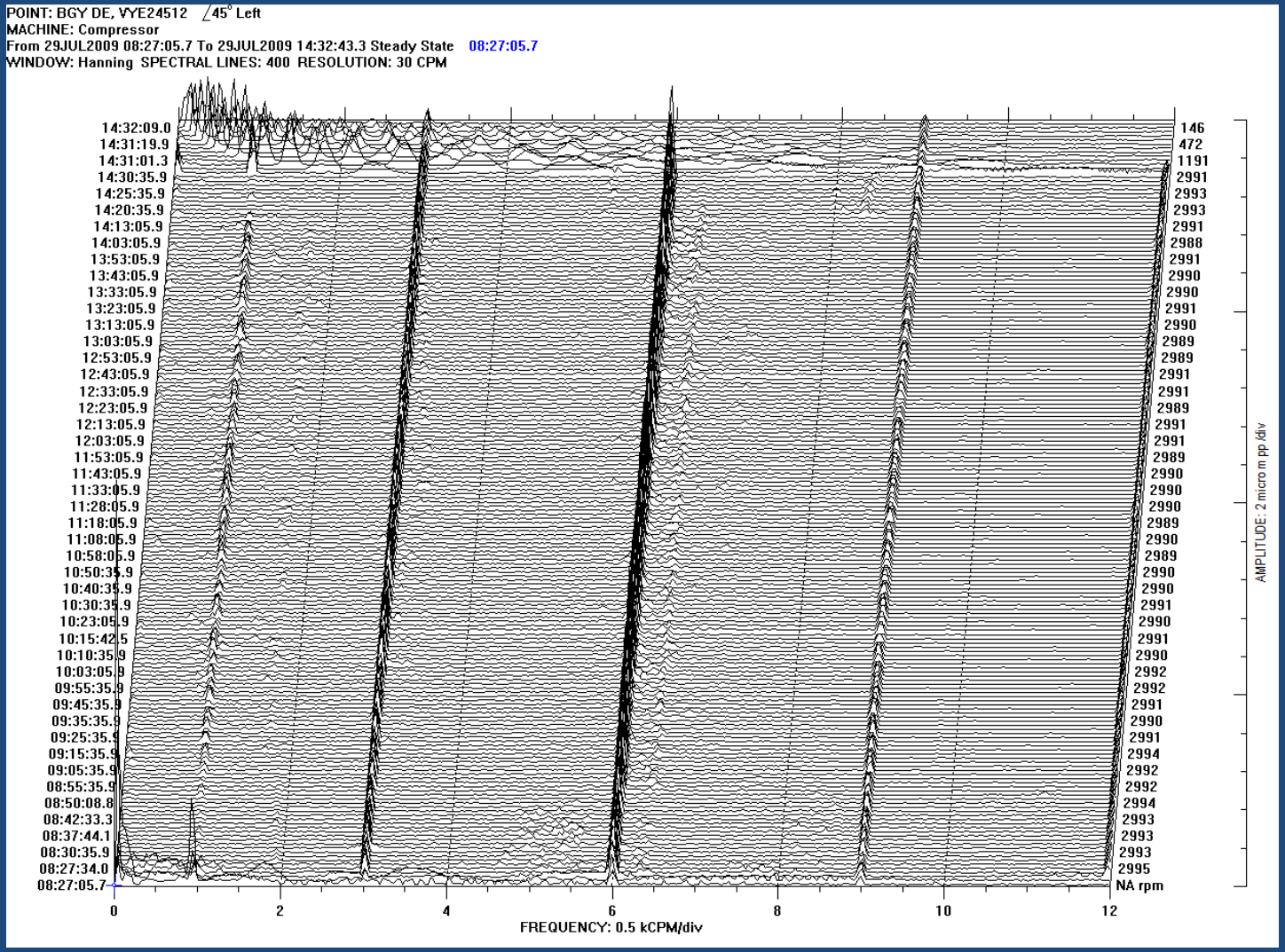
Modifications to the Compressor Package:

- Coupling replaced with a lower torsional stiffness disc pack coupling

Half Spectrum Waterfall (Pinion)



Half Spectrum Waterfall (Bull Gear)



Final Results and Conclusions

- Aerodynamic flow excitation can pass from impeller over integral gearing to drive train
- 1st TNF can be excited through aerodynamic phenomena
- Amplitude of vibrations were reduced by shifting the 1st TNF by selecting a Coupling with a lower torsional stiffness