Abstract

37th Turbomachinery Symposium

Case Study:

VFD Induced Coupling Failure

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A catastrophic failure of a high performance disc coupling connecting the speed increaser and LP compressor in a VFD controlled 18,300 HP motor/speed increaser/LP compressor/HP compressor train, led to months of reduced plant operation while the root cause of the failure, and corrective action, both outlined in this Case Study, were determined.

VFD Induced Coupling Failure

John A. Kocur, Jr.
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Turbomachinery Symposium 2008 – Case History

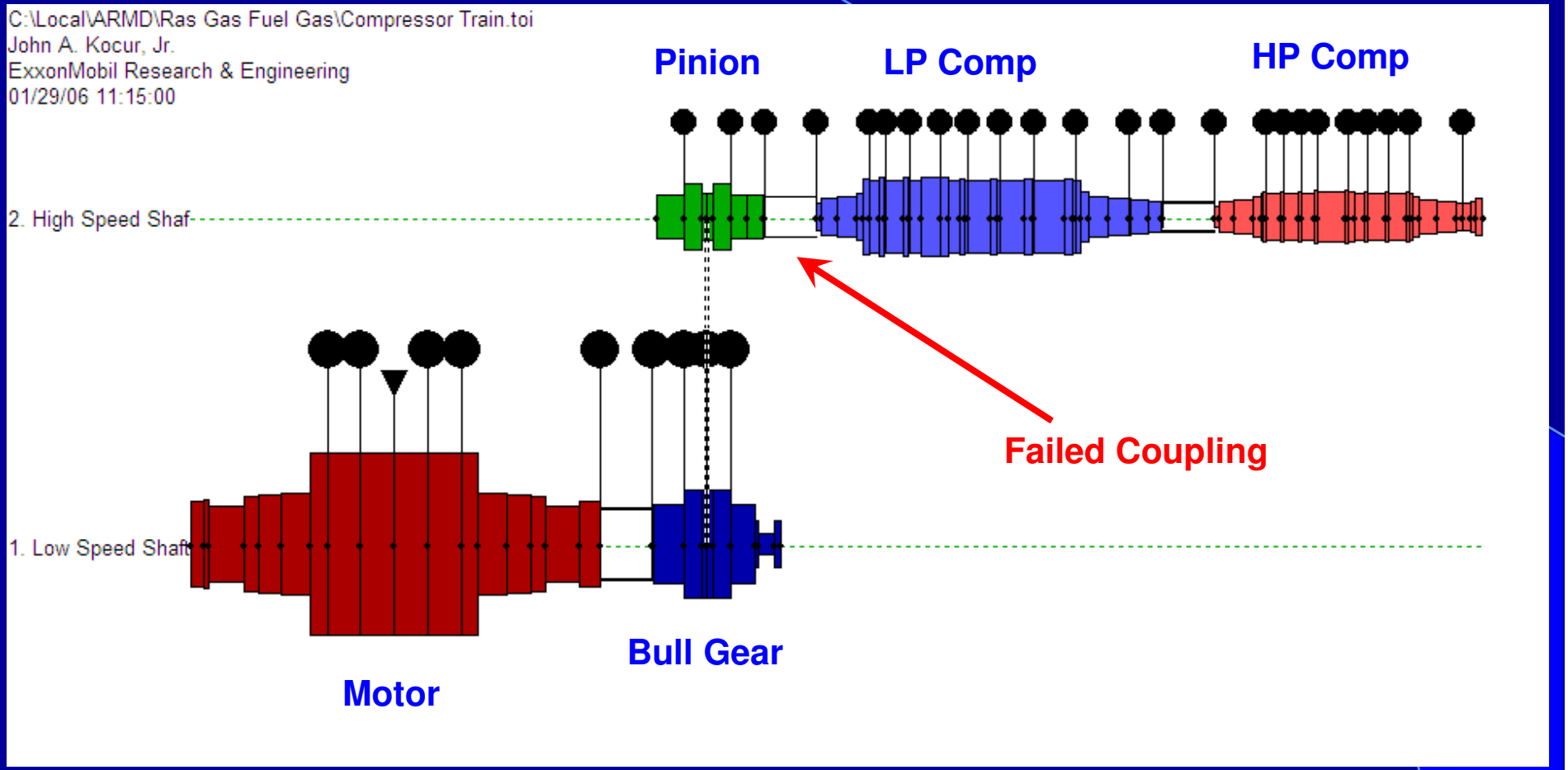
Introduction

- Background Information
- Failure Description
- Details of the RCFA
- Measurement Activities
- Controller Operation
- Torque Estimation
- Correction Activities
- Conclusions

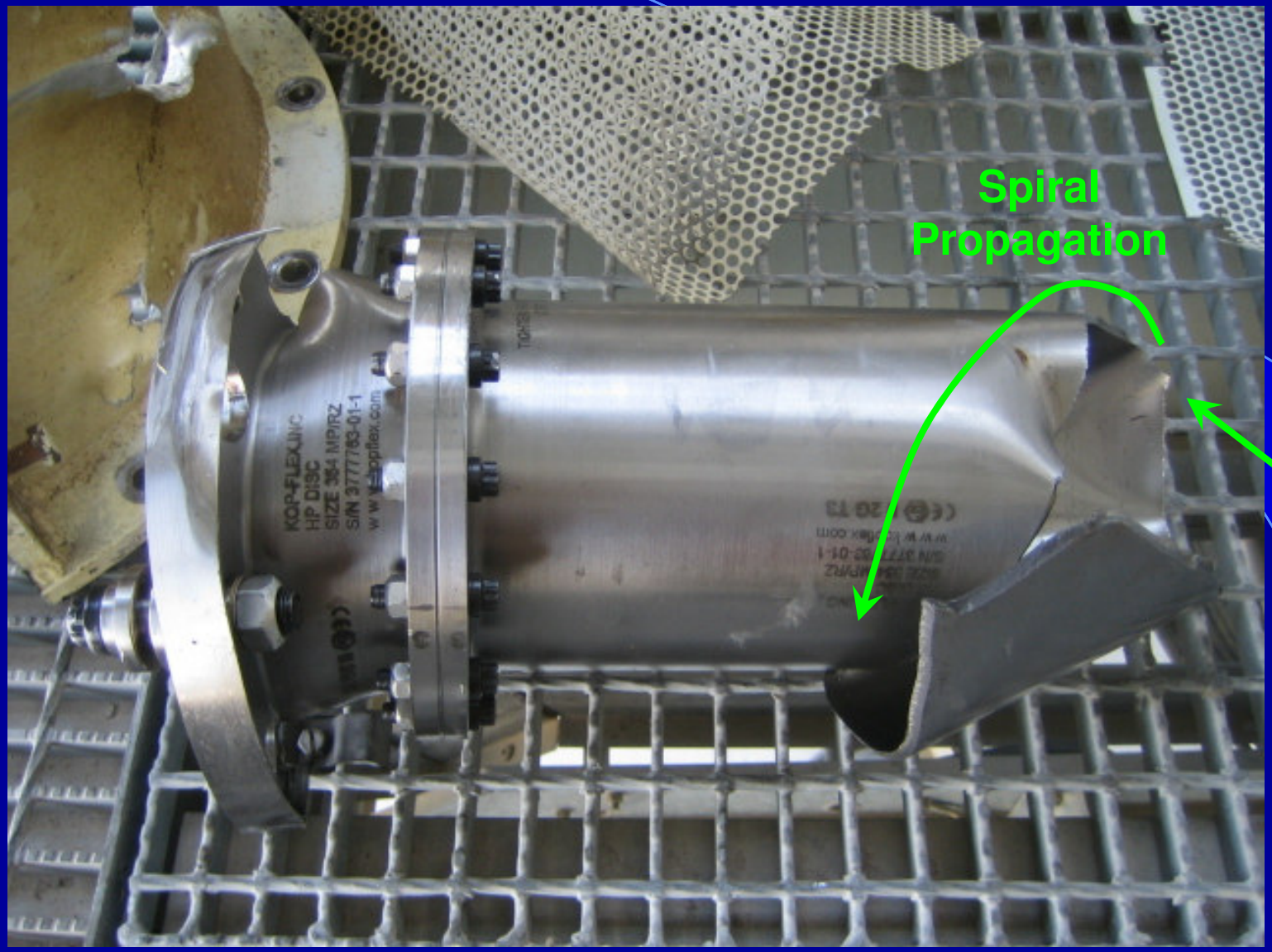
Background Information

- **VFD Induction Motor Driven Train**
  - Motor: 18305 HP @ 1575 RPM
  - Speed Increaser
  - LP & HP Compressors @6000 RPM
- **High Speed Coupling Failure**
  - After 2000 hrs of operation
    - → ≈190,000,000 cycles
  - Pinion – LP compressor coupling
  - Safety issue due to released parts

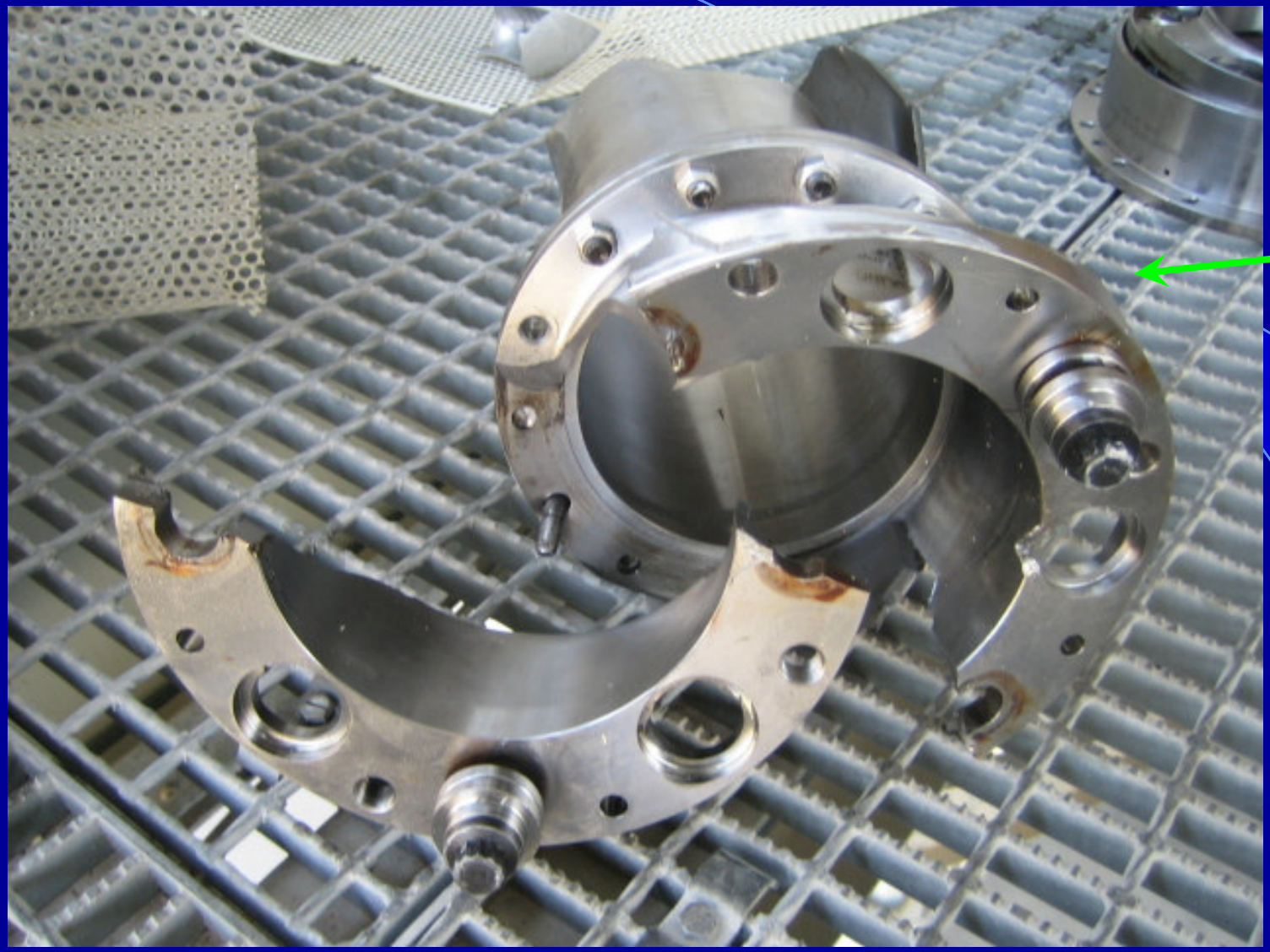
Train Diagram



Torsion Induced Failure

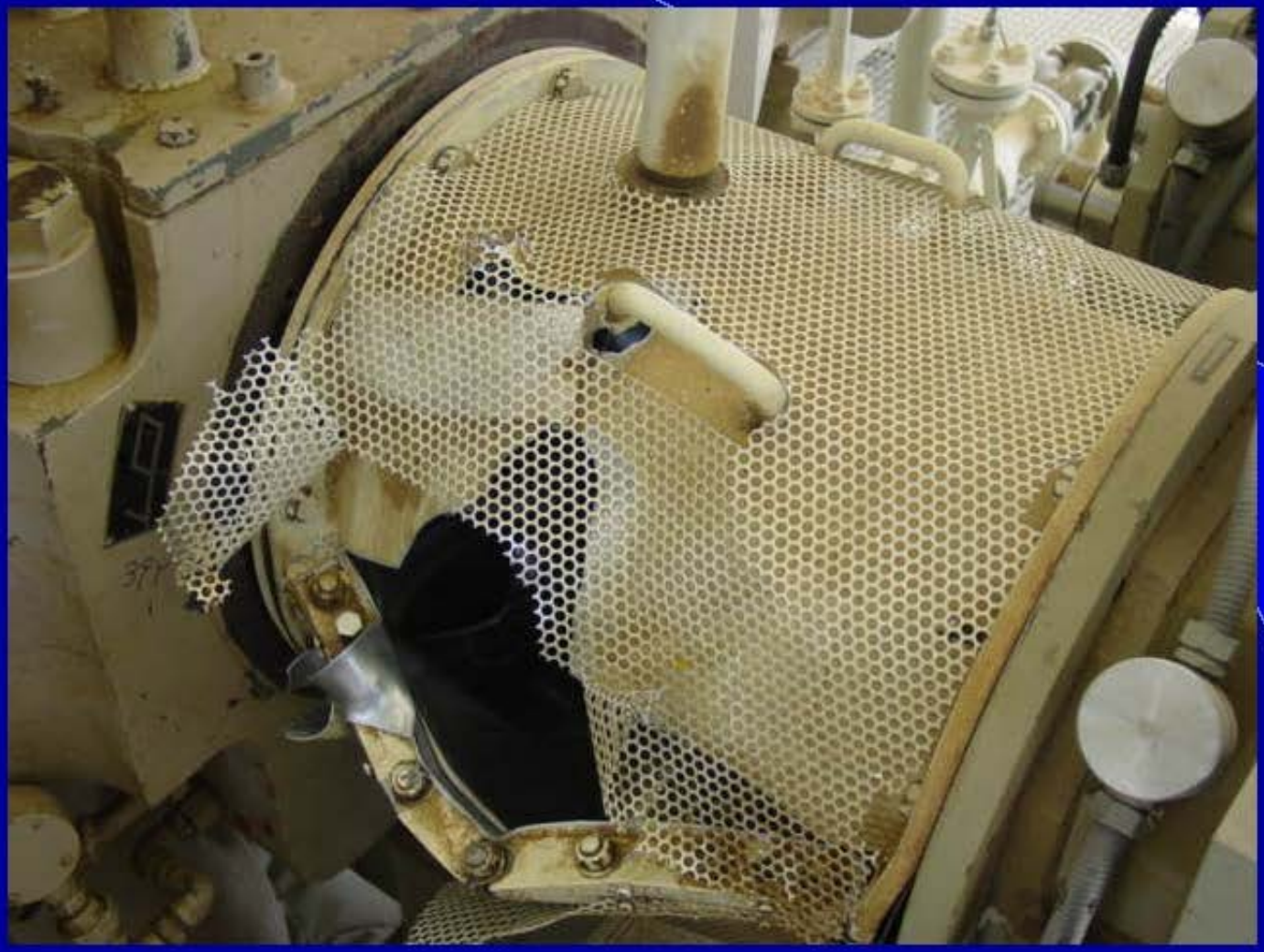


Secondary Damage



Flailing split retained hub releasing piece

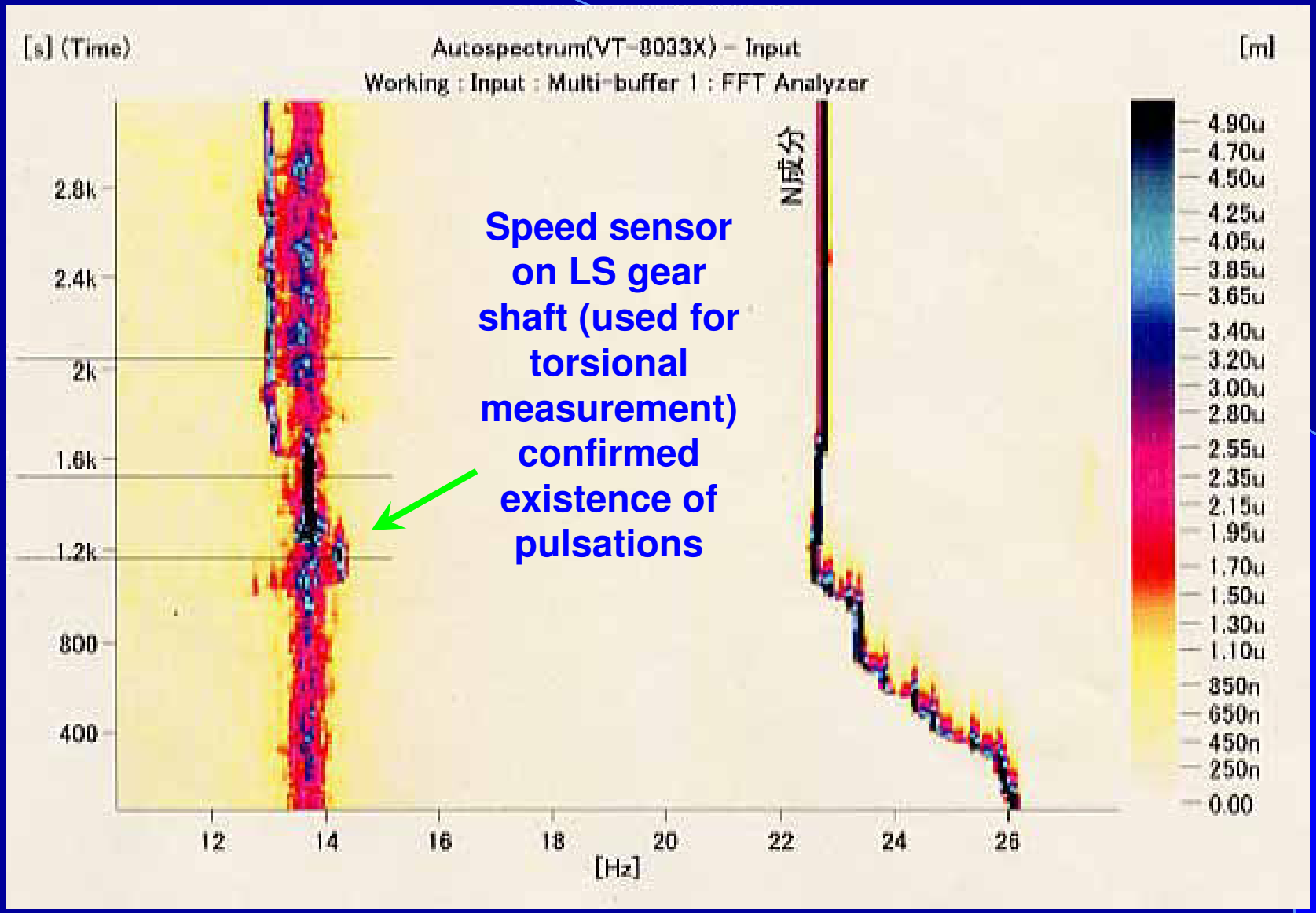
Guard Penetrated



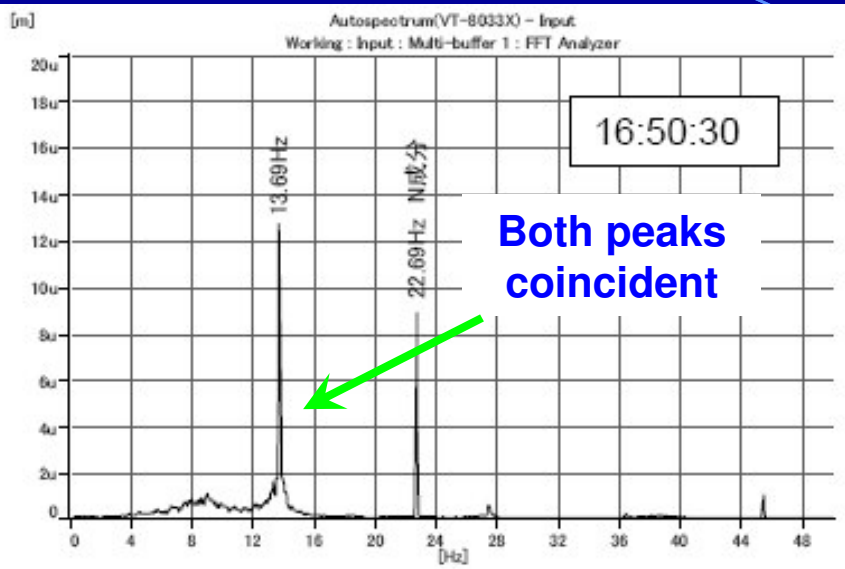
RCFA

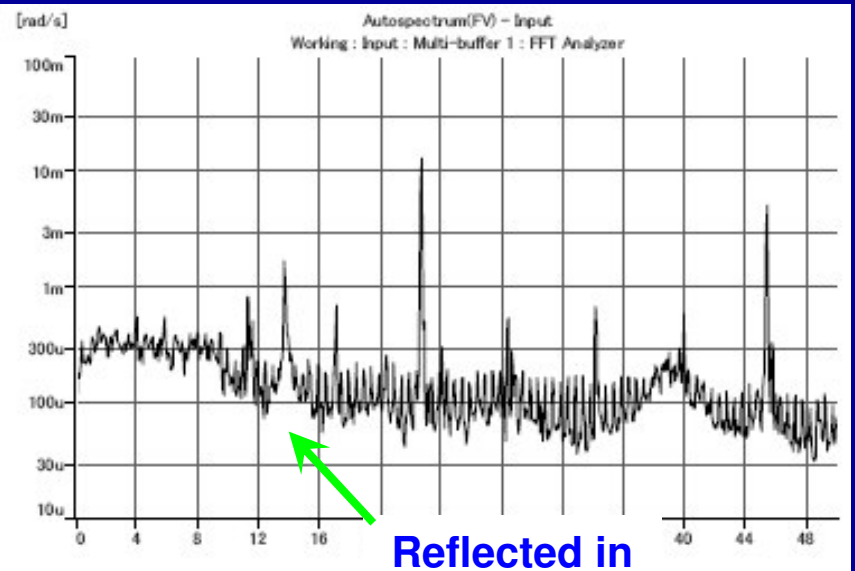
- **Vibration signatures prior to failure**
  - Gear radial subsynchronous vibration at 13.7 Hz
  - Coincident with 1st torsional natural frequency
- **Instrumented LS coupling for torsional measurements**
  - Torsional pulsations were identified
  - Two distinct factors involved

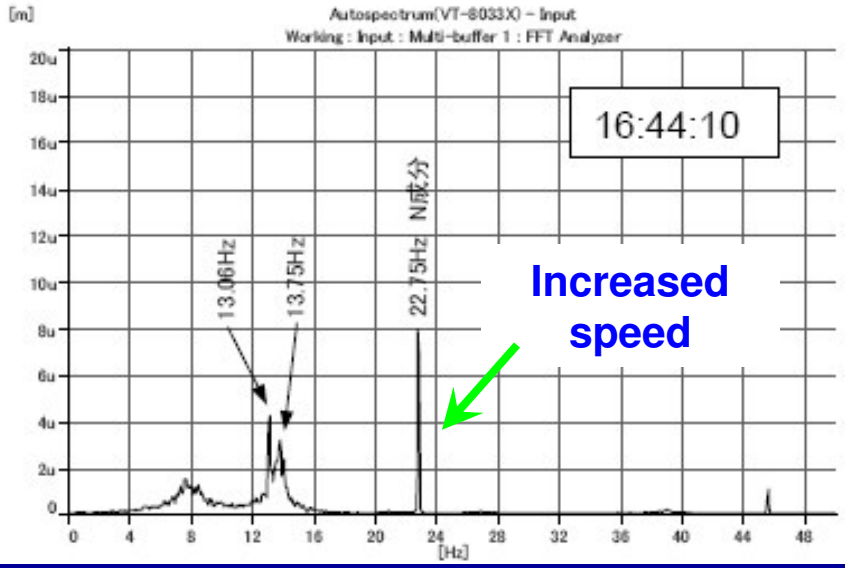
Torsional Measurements

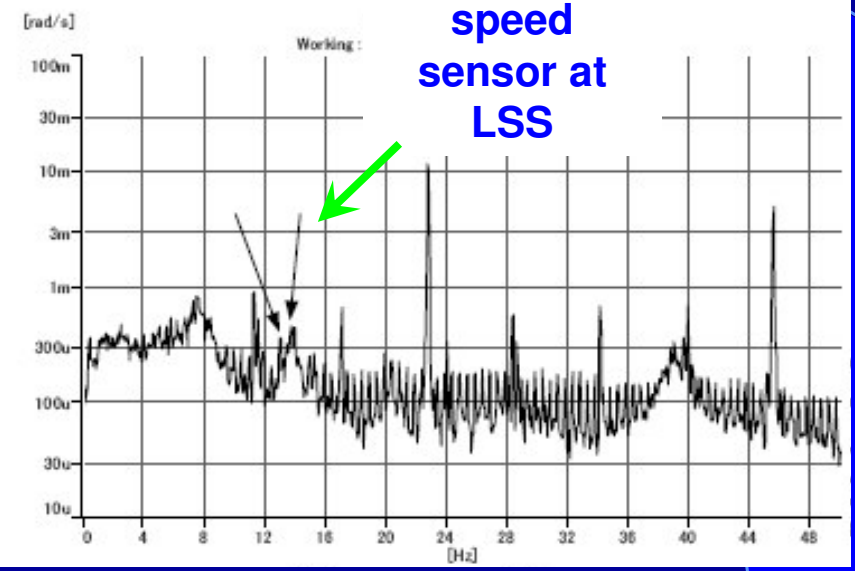


Vibration Measurements

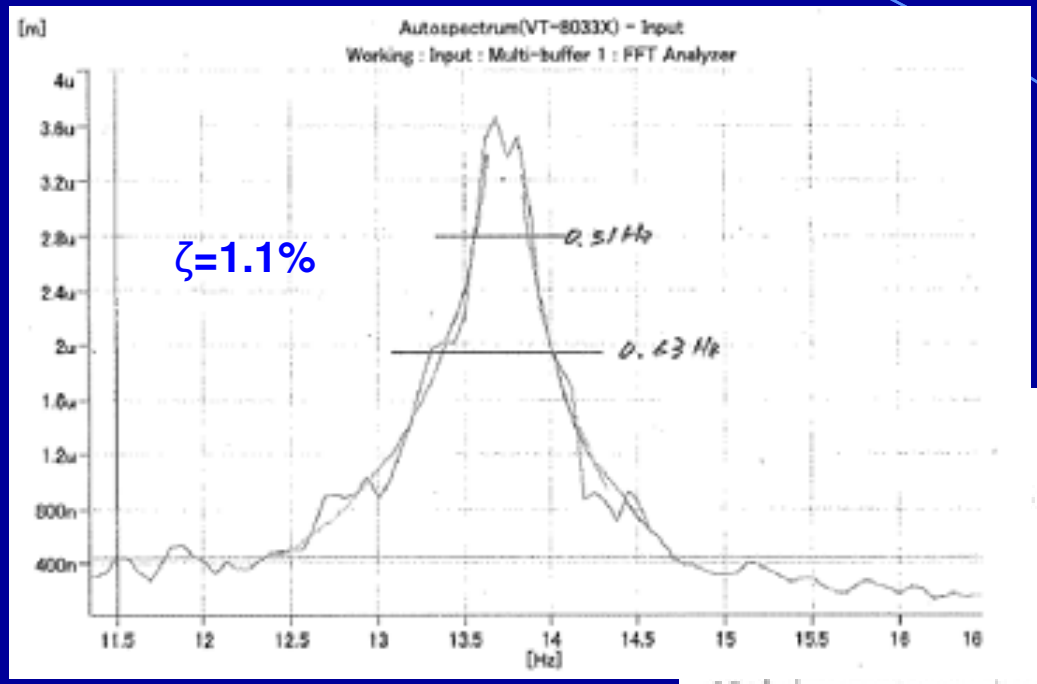




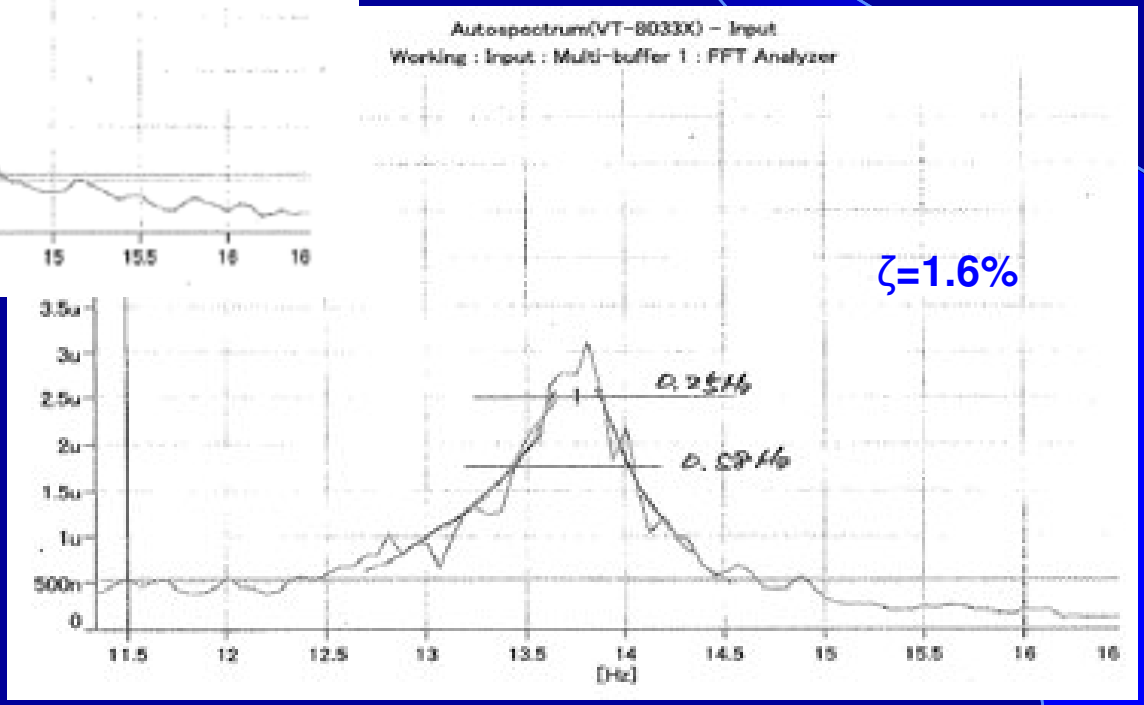




Damping Estimation



Damping estimation from the response around the natural frequency



Seems to confirm the popular assumption that trains w/ disk/diaphragm couplings have 1.6% of critical damping

VFD Sidebands

- **Sharp peak represents sidebands of the PWM frequency**

$$f_{sb} = \left| f_{pwm} - I_{odd} * f_o \right|$$

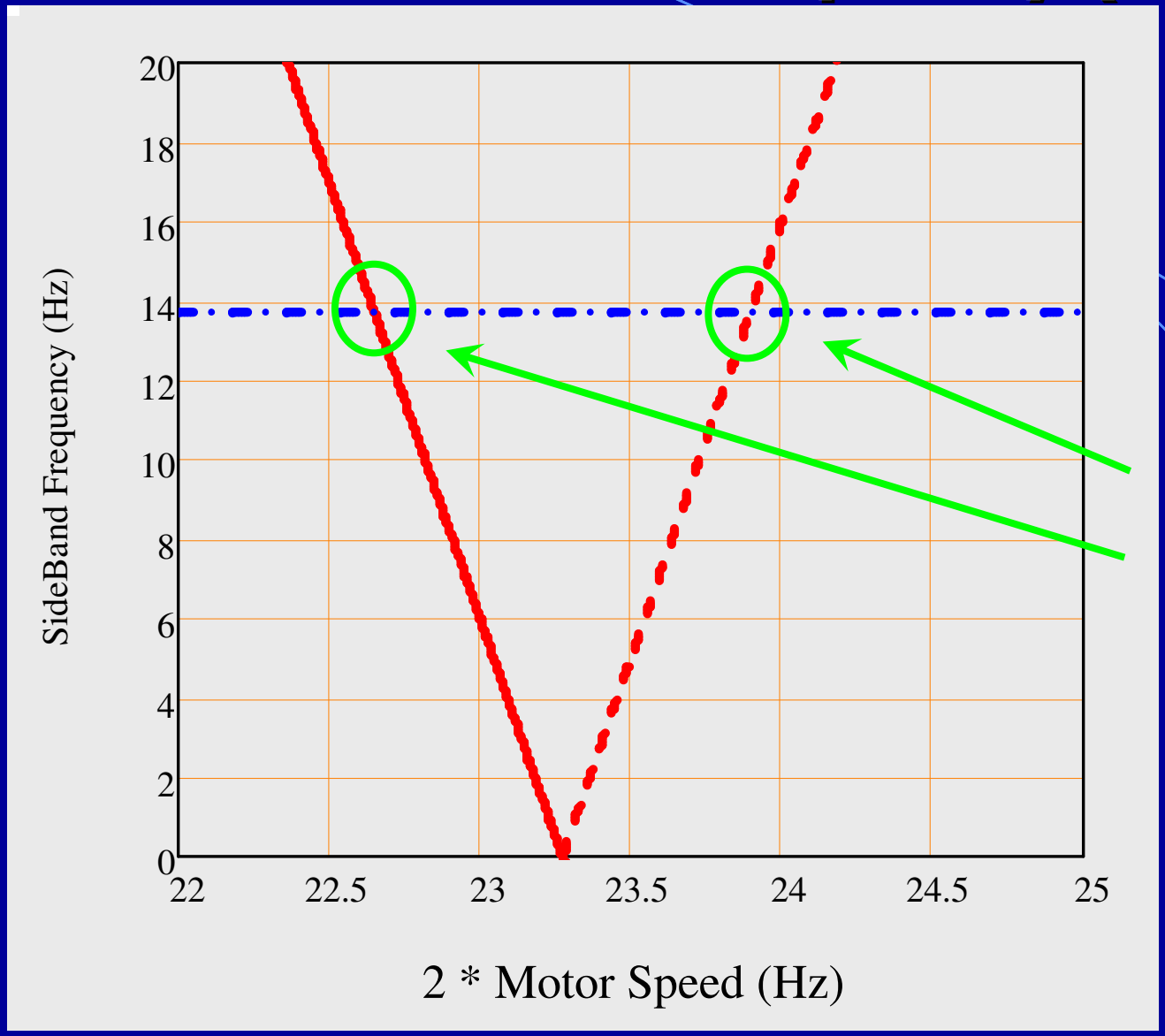
I_{odd} = Odd Integer

f_o = 2*Motor Speed

f_{sb} = Sideband Frequency

$f_{pwm} = 512$ Hz

Sideband Frequency (11x)



Coincident with 1st torsional natural frequency

Re-excitation of 1st Torsional NF

- **Broad peak associated with re-excitation of 1st mode**
- **Re-excitation magnitude limited by VFD controller setting**
  - **Torque restrictions in place to control speed ramp and restoration rates**

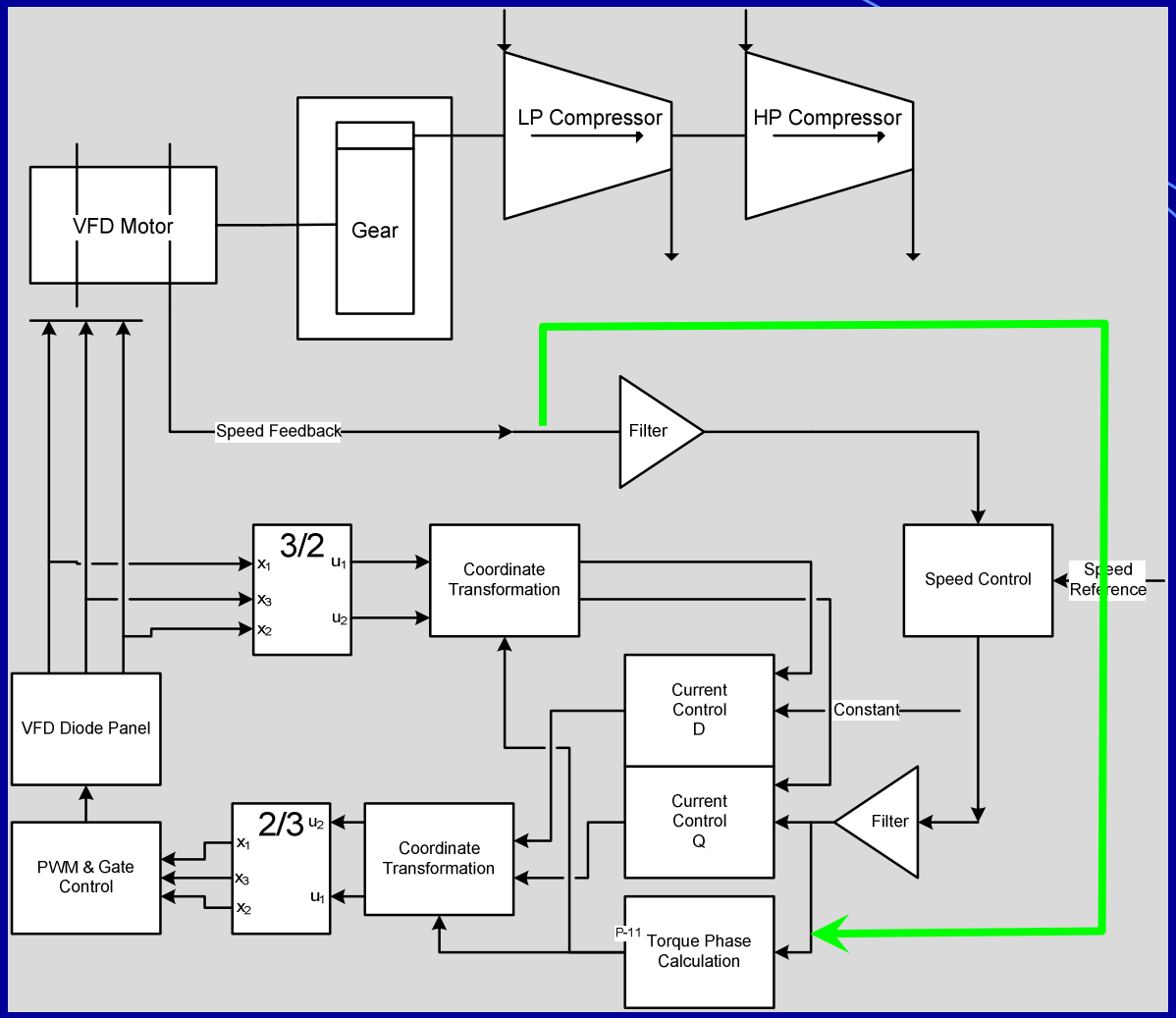
$$T_l = \frac{I_t * (f_d - f_a)}{t_r}$$

Where:

t_r = response time
I_t = train inertia
f_d = desired speed
f_a = actual speed
T_l = limit torque

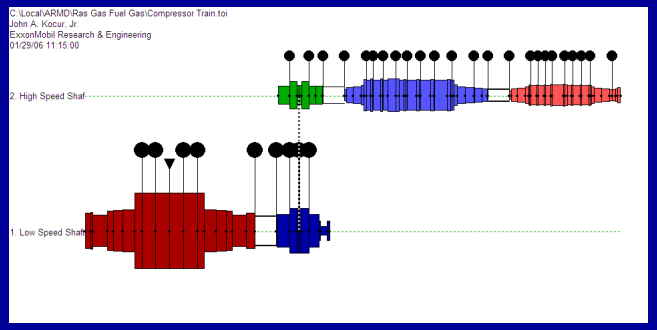
- **Unfiltered speed signal introduced 13Hz component into controller algorithm**

VFD Model Behavior

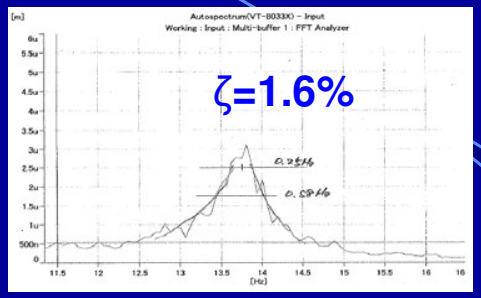


- Initial discussions w/ vendor showed speed feedback signal to be filtered
- Further investigations revealed the existence of an unfiltered branch

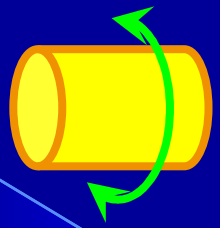
Estimate of Motor Pulsating Torque



Torsional Model



Damping Estimation

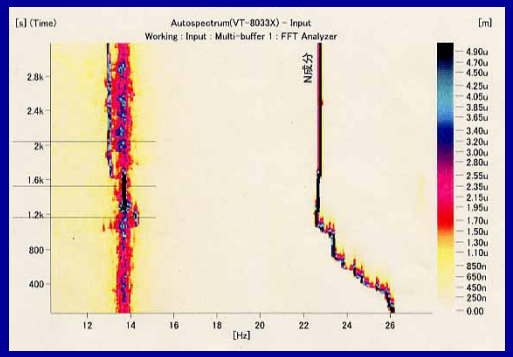


Alternating Torque

+

+

=



Torsional Response @ Gear Shaft

Fatigue Analysis

- **Coupling Vendor**
  - Constructed test rig to measure strain/stress vs. coupling torque
  - Determined that pulsating torque needs to exceed 60% of rated to cause HCF
- **Predicted Torque**
  - Analysis predicted that pulsating torque reached 20% of rated for measured displacement when peaks not coincident
  - Response increased by 4X during speeds when sideband is coincident with 1st TNF

Conclusions

- **Re-excitation of 1st TNF not sufficient to cause failure**
  - Testing and analysis revealed this causes pulsating torque at 20% of rated
- **During coincidence with sidebands pulsating torque can reach 80% of rated**
  - Several sidebands present
  - Coincident during specific speeds
  - Can explain the time to failure

$$f_{sb} = \left| f_{pwm} - I_{odd} * f_o \right|$$

$$f_{sb} = 150 - 3 * f_o$$

Corrective Actions

- **VFD Controller**
  - Vendor unable to "tune" parameters of the vector control algorithm to minimize 1st TNF excitation and sidebands to acceptable levels
  - Vendor implemented volts/Hz algorithm
    - → No speed feedback
  - Gear vibrations less than 4 μm acceptable
  - Some tuning at site to get acceptable startup vibration levels
- **New controller successful with 2 years operation**

Gear Vibrations