Opportunities and Challenges for Application of Digital Twins for Condition Monitoring

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Digital Twin Motivation and Objective

- Digital Twin to be used to implement predictive maintenance
- User creates a model of an asset to monitor it more efficiently.
- The data is analyzed in cloud/locally, combine with history and other relevant information.
- Reliability engineering personnel can take appropriate action to prevent machine failure.
- The covid pandemic has accelerated remote monitoring
- Using cloud expert can be anywhere and provide much more accurate predicition

What is a Digital Twin?

a. A CAD Model?

b. Augmented Reality

c. A software model with real-time data and documentation references

d. A smart machine

e. All the above?

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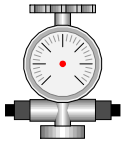
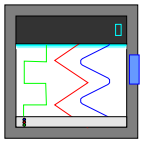
Typical Rotating Machinery Failure Modes

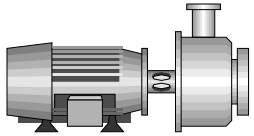
What Sensors are used to detect faults?

- Hydraulic Failure Modes
  - Cavitation
  - Pressure Pulsation
  - Pump Recirculation
  - Radial and Axial Thrust



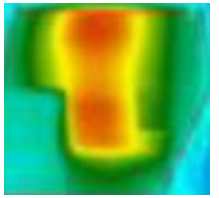


- Mechanical Failure Modes
  - Shaft Seizure or Break
  - Bearing Failure
  - Seal Failure
  - Vibrations
  - Fatigue
  - Misalignment



- Lubrication
  - Viscosity
  - Water
  - Wear Particles

- Motor
  - Rotor Bar Damage
  - Shorted Turns
  - Eccentricity
  - Mechanical Looseness
  - Power Quality
  - Power Circuit
  - Insulation



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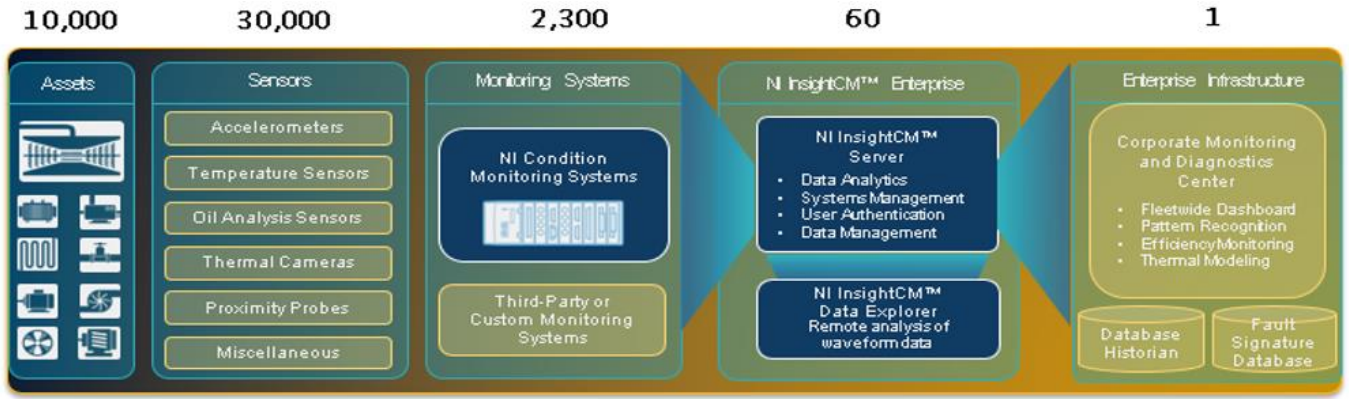
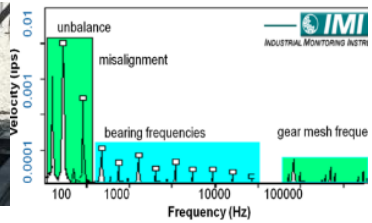
Power Generation





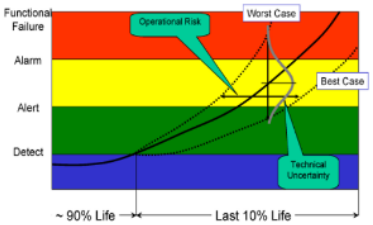


Figure 15. PlantView® health report mat
of Power Vision, Inc.

Credit: NI

Subject Matter Expertise Data Acquisition and Analysis Condition Indicators Alarming Predictive Analytics

Key to Success: Quality Data and Expertise

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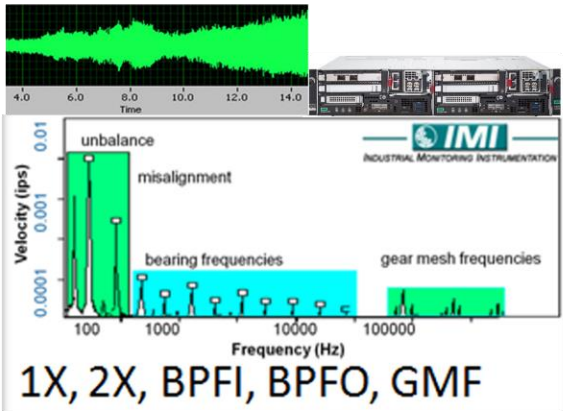
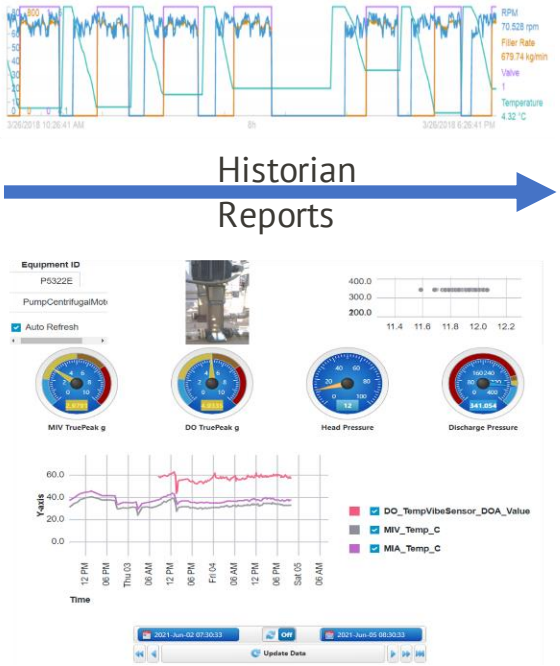
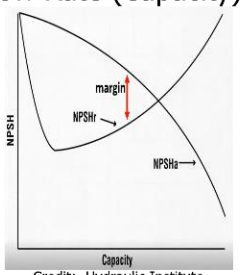
Data Flow and Collection

Edge Processing





Flow Rate (Capacity)



Credit: Hydraulic Institute

Streaming Edge Analytics are a Necessity

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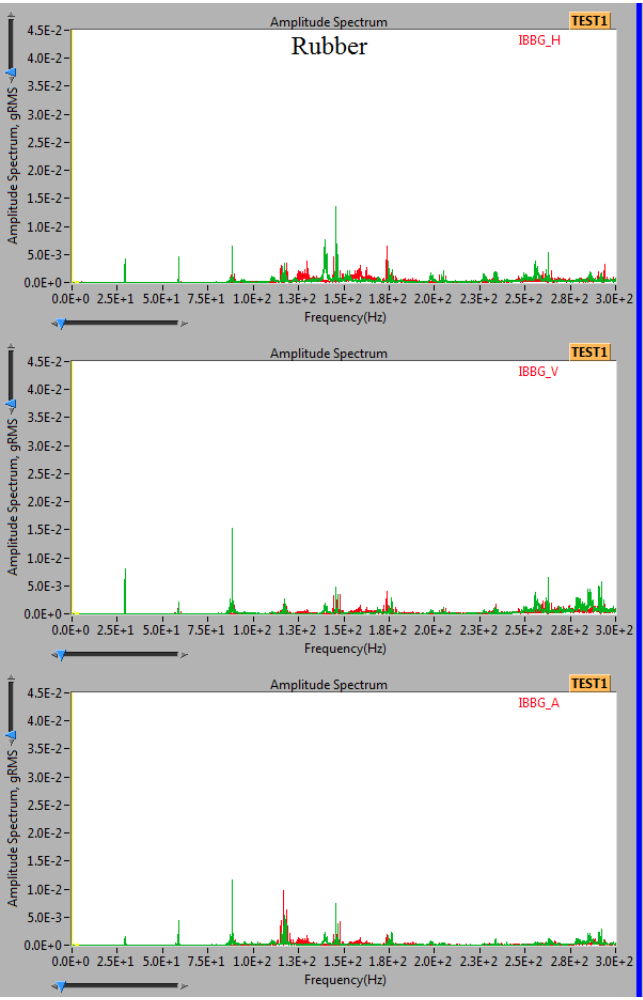
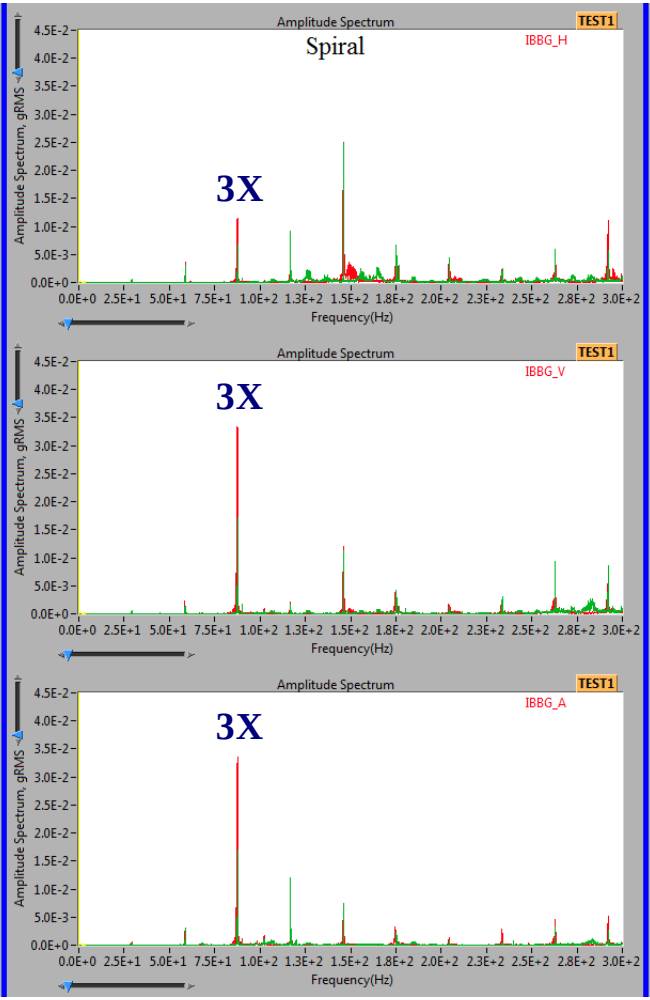
Complexities and Challenges

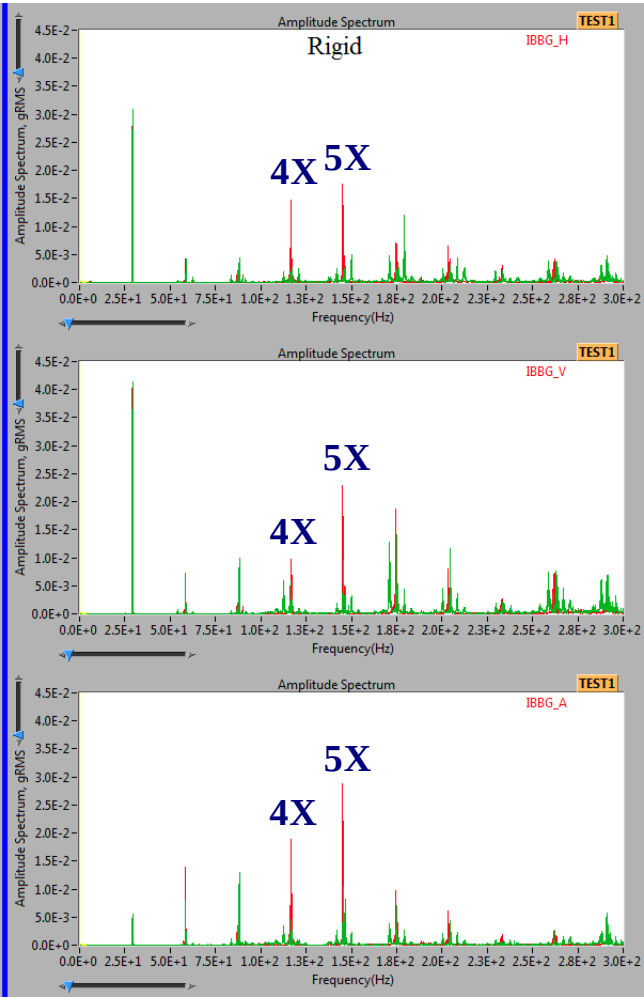
- Illustration of the scatter in misalignment induced vibration spectra
- Interesting observation due to misalignment
- Vibration generation model of misalignment
- Physical model based approach

Simulators (Rotors) Used in Studies

Results: Coupling Type

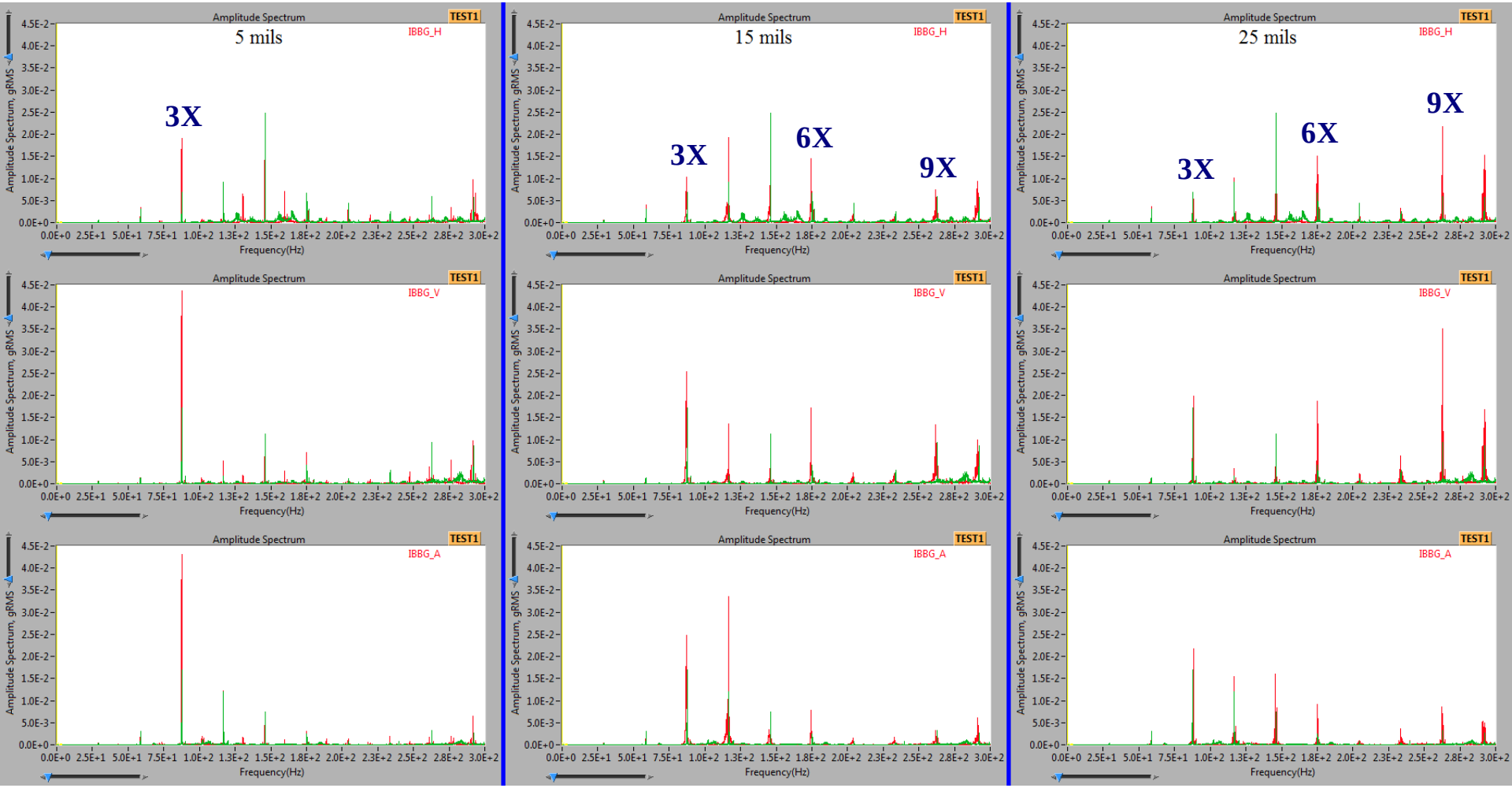






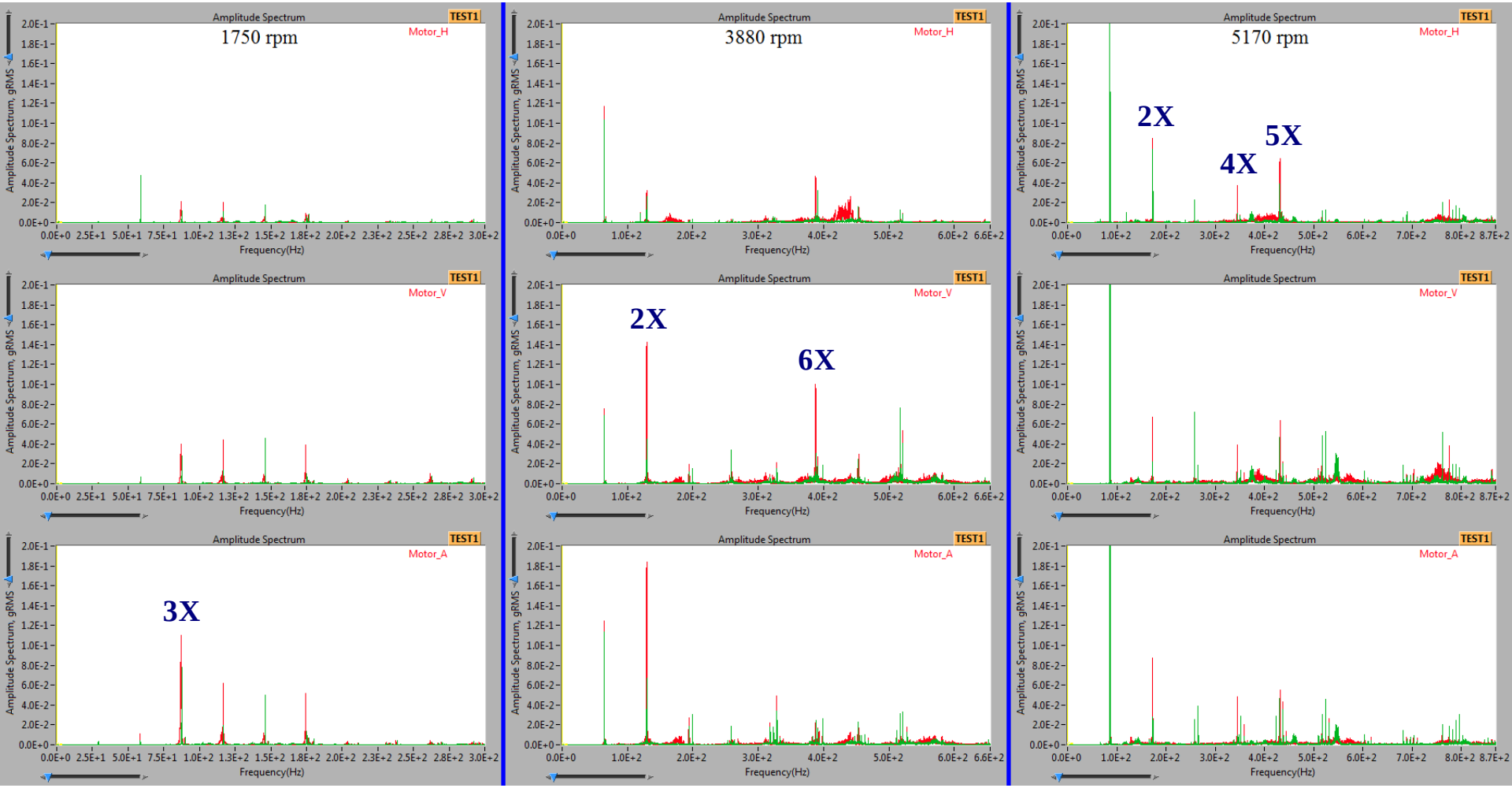
Angular – 0.10° , 1750 rpm, ¾” shaft

Results: Misalignment level



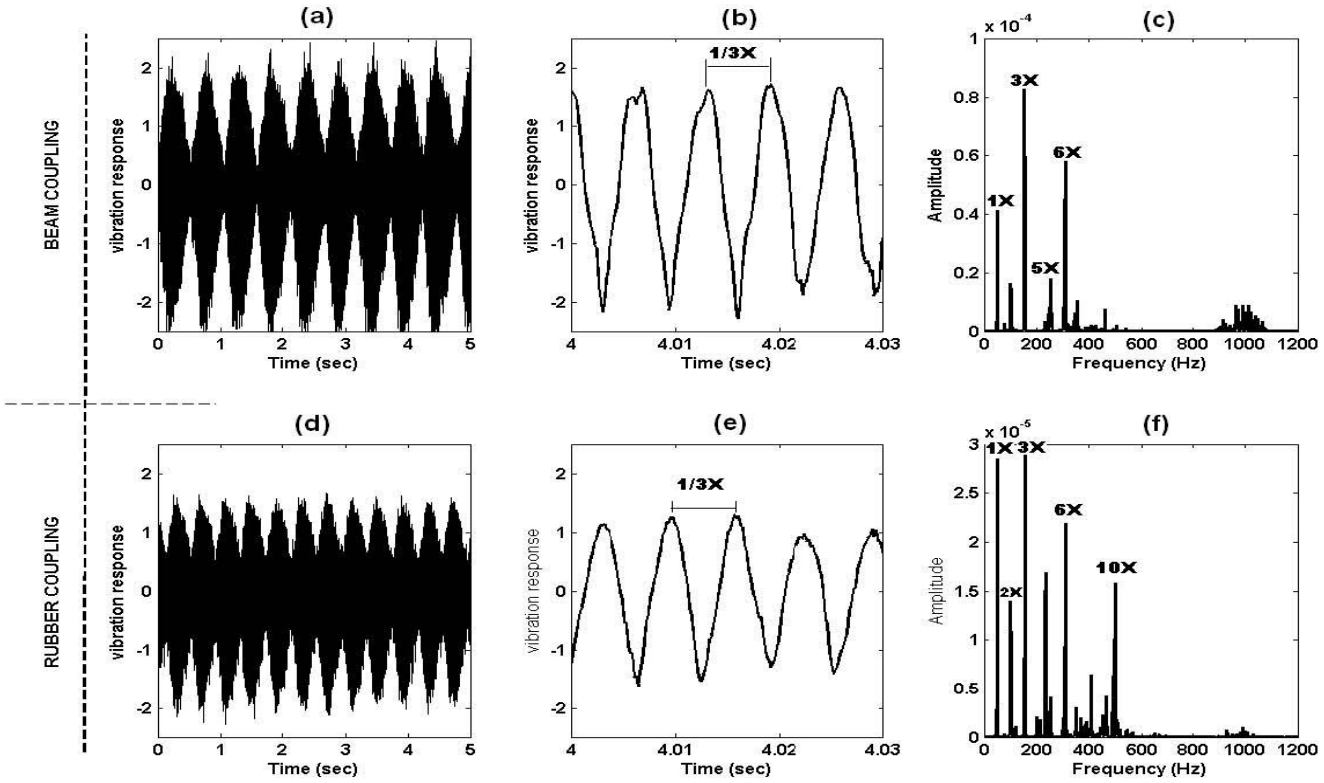
Spiral coupling, 1750 rpm, ¾” shaft

Results: Shaft speed



Parallel – 15 mils, rigid coupling, ¾” shaft

Mysterious Vibration Signature

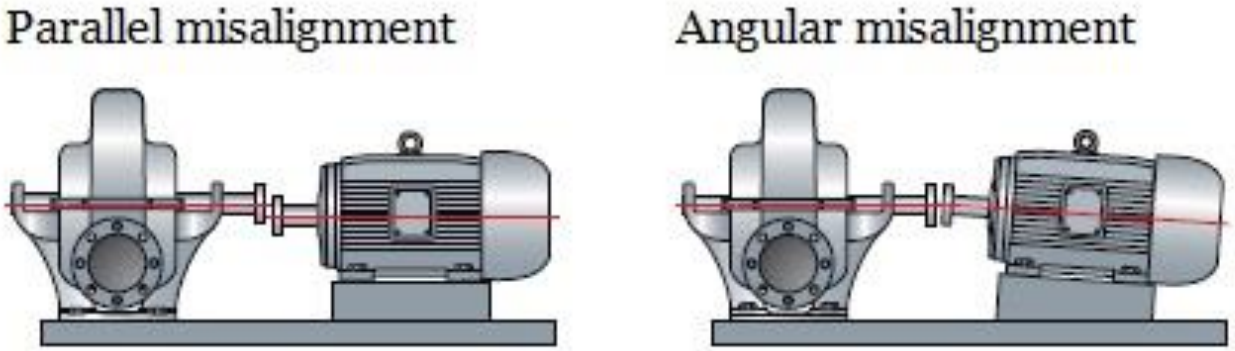


Low frequency/level modulation

What cause this?

What is Misalignment?

- The center lines of two shafts do no coincide.



Strain → Stress → Force ⇒ Vibration

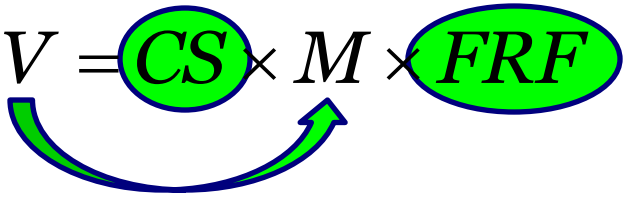
varying

Misalignment Vibration Model

$$V = FF \times FRF$$

$$FF = CS \times M$$

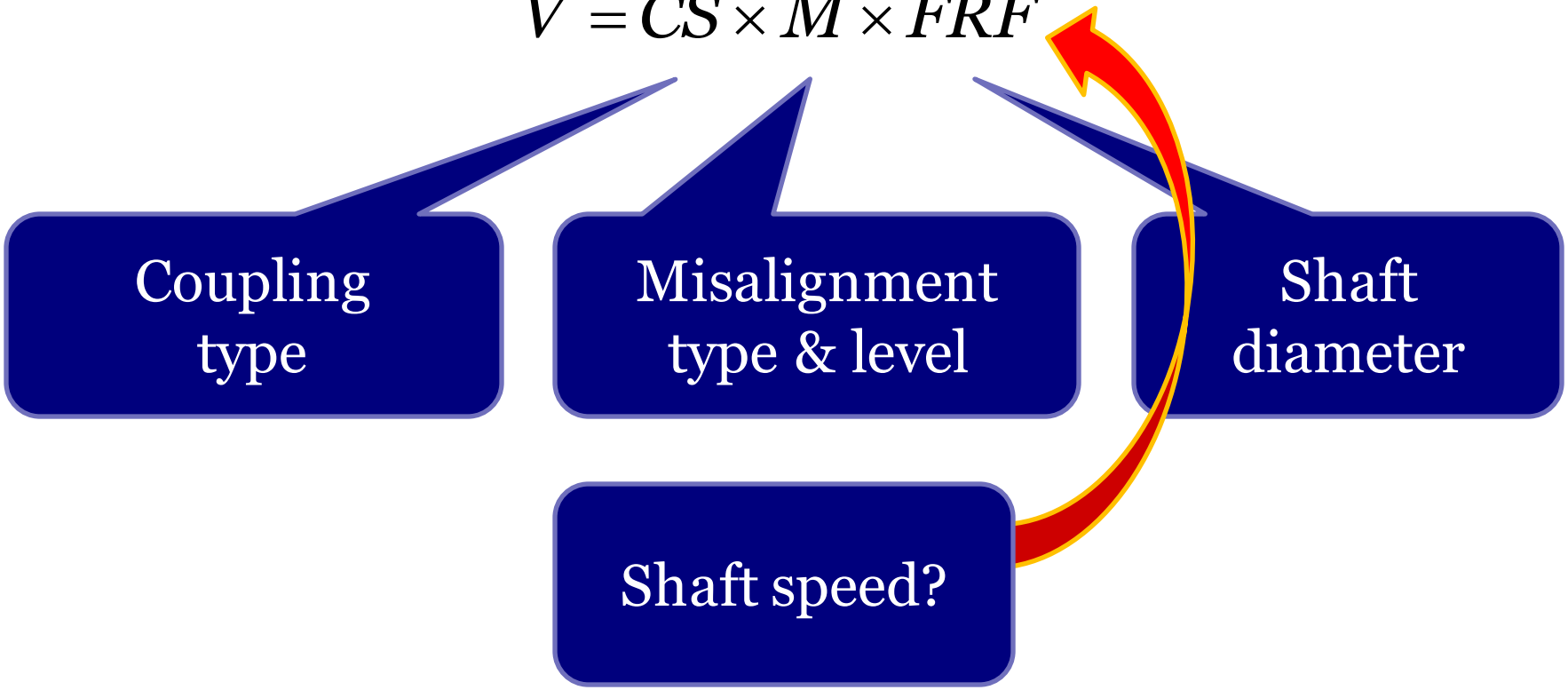
$$V = CS \times M \times FRF$$



- V : Vibration
- FF : Forcing Function
- FRF : Frequency Response Function
- CS : Coupling Stiffness
- M : Misalignment

Vibration Generation Model

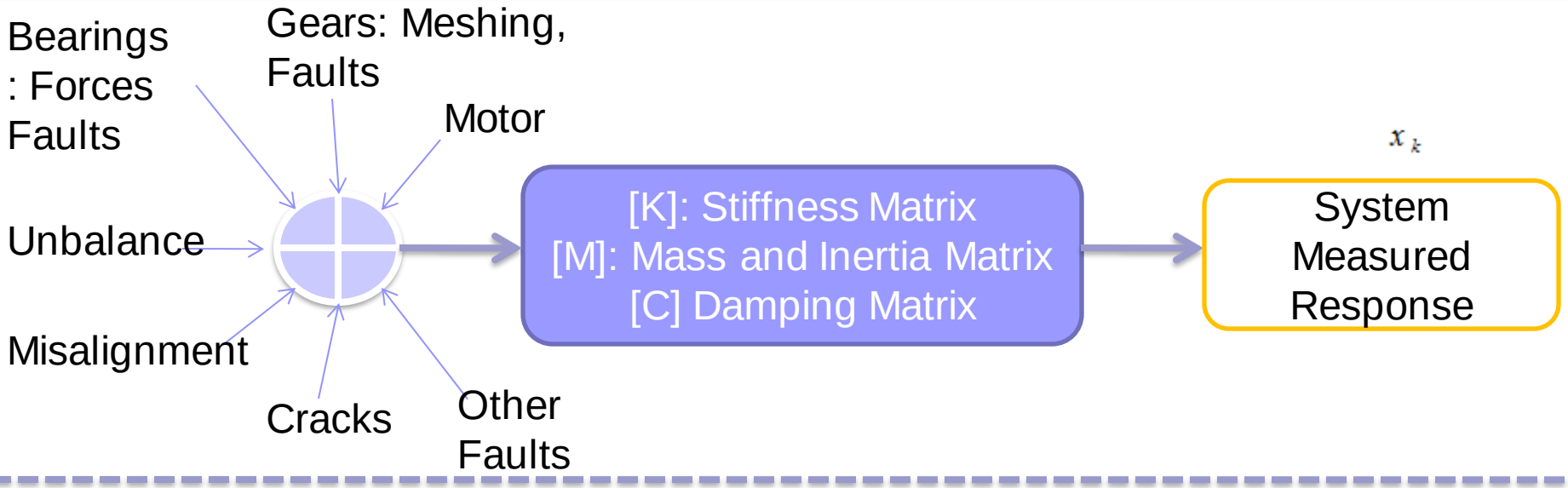
$$V = CS \times M \times FRF$$

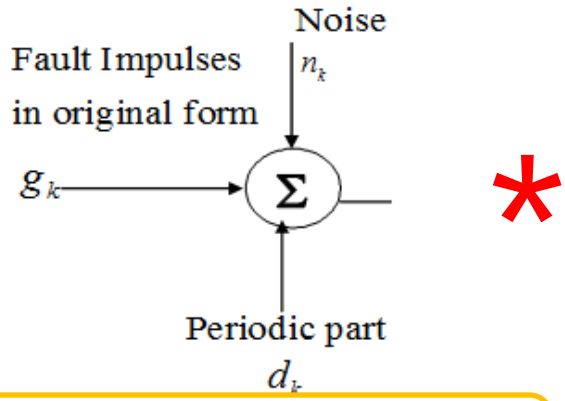


$$V = FF \times FRF$$

The shaft speed samples the FRF.

Measured Vibration Model





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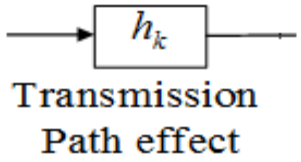


Vibration signal components

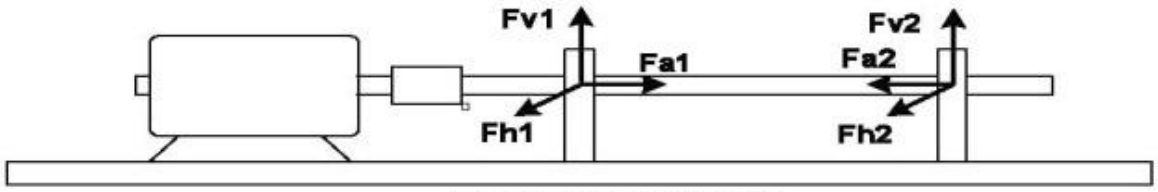
$$x_k = (g_k + n_k + d_k) * h_k$$

Exciting forces: Non linear time variant

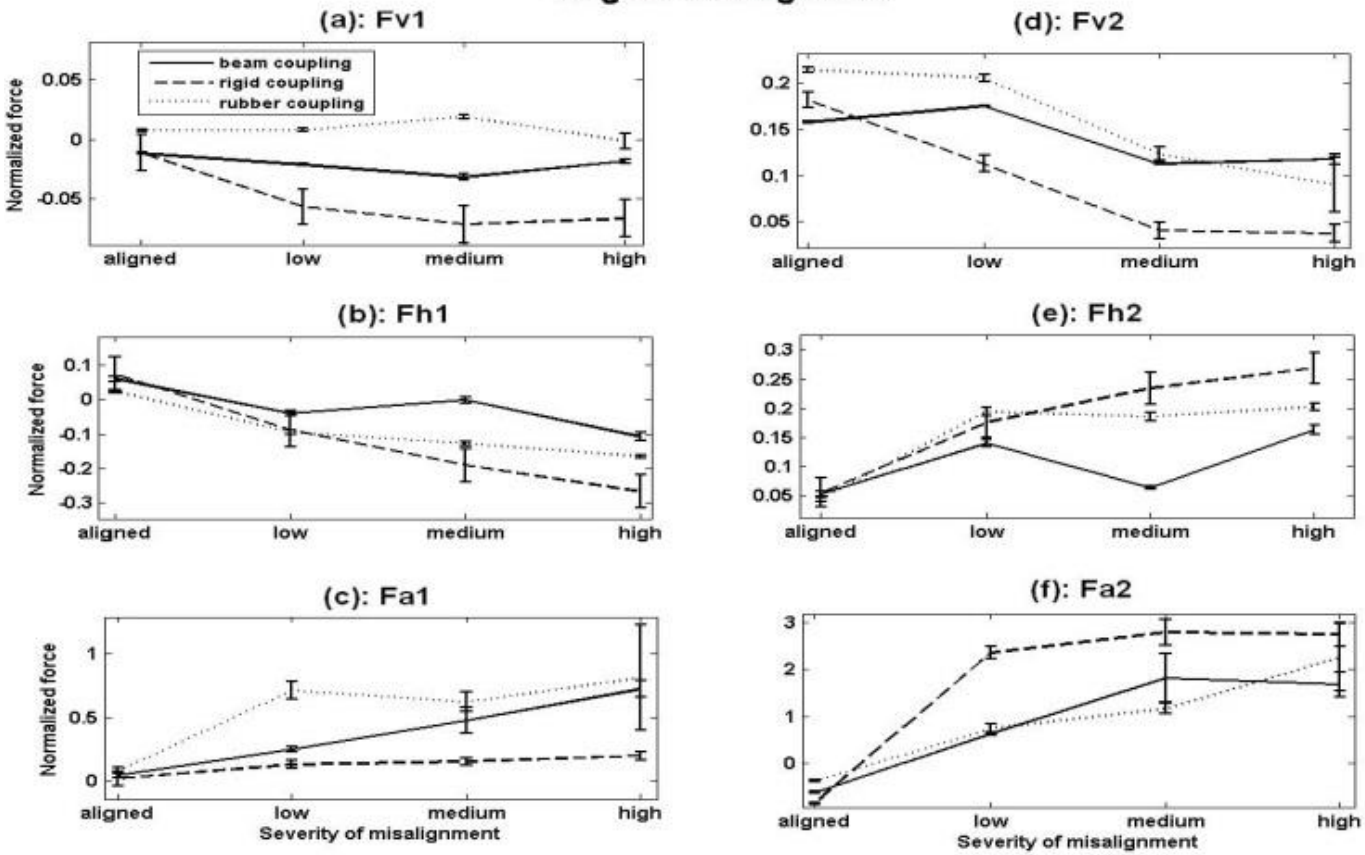
Mechanical System Transfer Function

System Measured Response

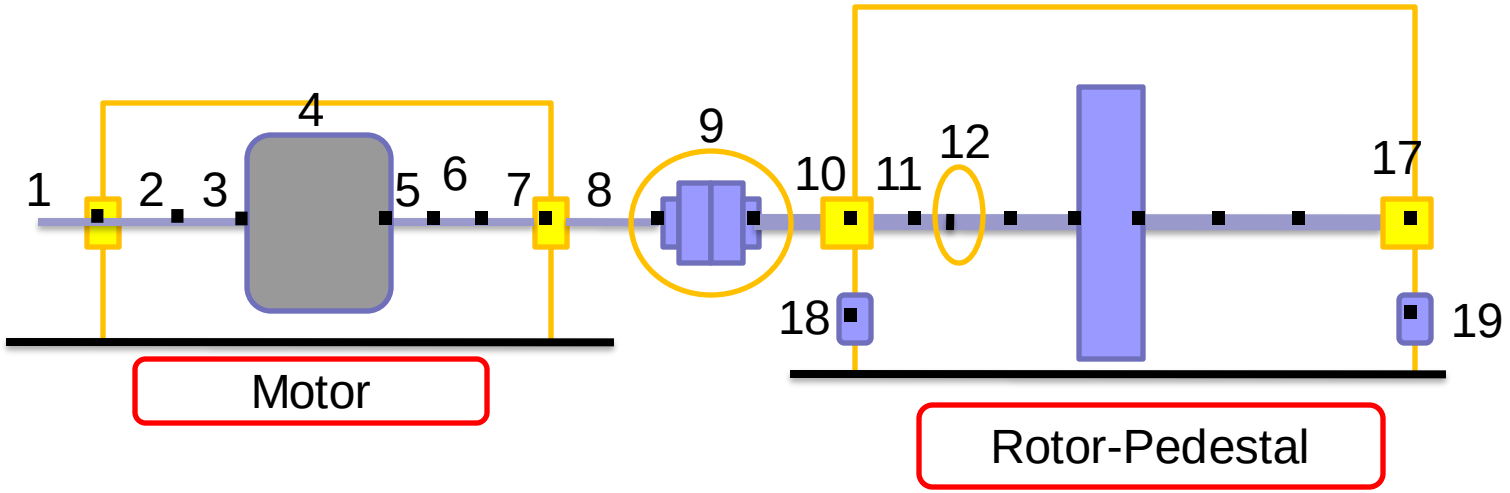
Misalignment Forces (Preload)



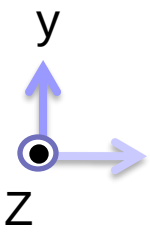
Angular Misalignment



Physics-Based Model Building



1. System divided into stations
2. Each station is composed of one or more beam elements
3. Each beam is identified by a length, inner and outer diameter, material density, modulus of elasticity and modulus of rigidity.
4. Mass and stiffness matrix for each station is written (5 Dofs : 2 translational, 2 rotational, torsional). Shear effect is added to the model. Gyroscopic effect of disk elements included.
5. Stations' mass and stiffness matrices are assembled through the nodes (black dots) to form a global mass-stiffness matrix of the whole system



Vibration Generation Process

- Effect of **coupling type**
  - Defines the shape of the forcing function.
- Effect of **misalignment type & level**
  - Type: Selects the direction of the coupling stiffness.
  - Level: Defines the magnitude of the forcing function.

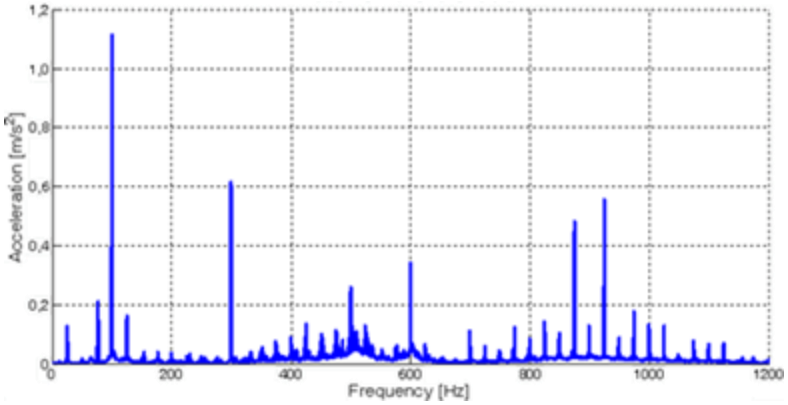
ORIGIN

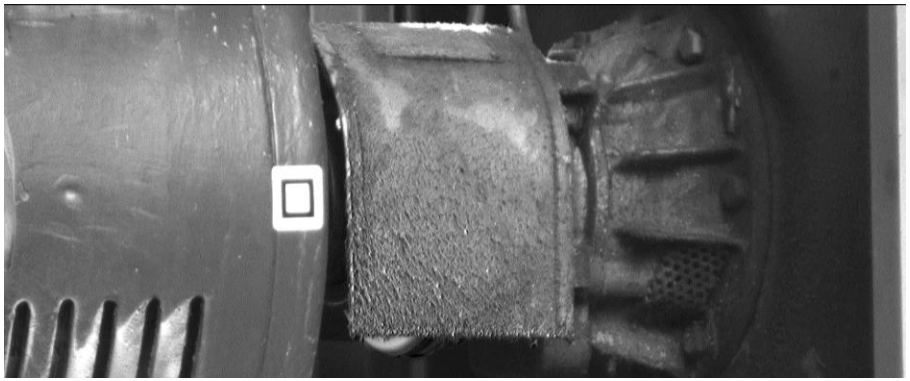
- Effect of **shaft speed**
  - Amplifies and attenuates harmonic peaks.
- Effect of **shaft diameter**
  - Changes the FRF → amplifies and attenuates harmonic peaks even at the same shaft speed.

TRANSFER

Motion Amplification using High Speed Camera to Visualize Component Motion

- Camera acts as sensor – Displacements less than 100 microns not perceptible to the human eye
- Technology turns every pixel in the camera's view into a sensor
- Amplification of the motion facilitates visualization of the actual movement of the asset
- Measure and quantify any structure or asset that a camera can see





Provide information to the people who need it
And when they need it

Data Collection

Plan and Schedule Maintenance

Program and Plant Management

Data Analysis

Execute Corrective Actions

Bi-Directional Communication!

Future - 2030's and Beyond

- New wireless sensors, power sources, and communication technology
- Price per point will drop from current $500 to $50
- Cognitive/AI will assist all vibration analysts
- Expert availability via Cloud and bi-directional communication
- Improved prognostics models combining vibration, motor current, and other technologies
- Physics of machines/assets will remain important part of the predictive model
- Proactive maintenance will get upper management respect