Bently Nevada

The Plant Asset Management Company SM

Gearbox Spectral Components and Monitoring Methods

Presented by:

Timothy S Irwin, P.E.

Machinery Management Engineer

Bently Nevada, Machinery Diagnostics Group

Ph: 803-408-3079

tim.irwin@bently.com

- Odontics

Webster's Dictionary – Pertaining to the teeth

May be used to describe the branch of kinematics that is concerned with the transmission of continuous motion from one body to another by means of projecting teeth.

Gearbox Spectral Components and Monitoring Methods

- Safety First!!!
  - Awareness of equipment surroundings:
    - Temperature extremes.
    - Exposed rotating components.
    - Access to installed equipment.
    - Unusual operating conditions.
    - Local operational equipment.
    - **HEARING PROTECTION!**
  - Keep yourself out of the 'Line of Fire' as much as possible!!
    - Stay along the shaft axis as much as possible.
  - Installed equipment inspections
    - Proper Lock-out/Tag-out process.
    - Do not take unnecessary risks.
    - Get the job done and get out.

Gearbox Spectral Components
and Monitoring Methods

BENTLY® Nevada

- Five Fundamental Gear Frequencies
- Additional Component Frequencies
- Fundamental Frequency Analysis
- Transducer Selection and Monitoring

- The Five Fundamental Frequencies

  - Gear rotational frequency, Hz...................(f_{rg})
  - Pinion rotational frequency, Hz.................(f_{rp})
  - Mesh frequency, HZ................................(f_m)
  - Tooth repeat frequency, Hz.....................(f_{tr})
  - Assembly phase passage frequency, Hz.....(f_a)

Gearbox Spectral Components and Monitoring Methods

- To develop the five fundamental frequencies you need the following information:

  - Number of teeth on the pinion...................(N_p)
  - Pinion speed, rpm..(R_p)
  - Number of teeth on gear............................(N_g)
  - Gear speed, rpm..(R_g)
  - Ratio, N_g/N_p or R_p/R_g..................................(M_g)

Additional helpful information is: rotor arrangement, bearing configuration, shaft rotations, etc. Basically any technical detail you can find.

BENTLY® Nevada

• Calculating the Fundamentals:

- Gear Frequency, $F_{rg} = R_g / 60$ (Hz)
- Pinion Frequency, $F_{rp} = R_p / 60$ (Hz)
- Tooth Mesh Frequency,
  - $F_m = F_{rp} \times N_p$ (Hz) or $F_{rg} \times N_g$ (Hz)
- Assembly Phase Frequency, N_a = Product of the common prime factors:
  - $F_a = F_m / N_a$ (Hz)
- Tooth Repeat Frequency (Hunting tooth),
  - $F_{tr} = (F_m \times N_a) / (N_g \times N_p)$ (Hz)
  - Tooth Repeat & Assembly Phase AVI

• Fundamentals Example

- Gear Frequency (F_{rg}), 18 = 1080 / 60 (Hz)
- Pinion Frequency (F_{rp}), 30 = 1800 / 60 (Hz)
- Tooth Mesh Frequency (F_m),
  - 270 (16,200 cpm) = 30 x 9 (Hz) or 18 x 15 (Hz)
- Assembly Phase Frequency (F_a), N_a =
  Product of the common prime factors:
  - 90 (5,400 cpm) = 270 / 3 (Hz)
- Tooth Repeat Frequency (Hunting tooth) (F_{tr}),
  - 180 (10,800 cpm) = (270 x 90) / (15 x 9) (Hz)

- Gear Frequency Relationships

To Obtain		F_{tr}	F_{rg}	F_{rp}	F_a	F_m
Multiply						
F_{rp}	by	N_a/N_g	$1/M_g$	1	N_p/N_a	N_p
F_{rg}		N_a/N_p	1	M_g	N_g/N_a	N_g
F_m		$N_a/(N_g \times N_p)$	$1/N_g$	$1/N_p$	$1/N_a$	1

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies
  - Tooth Problems
    - Alignment
    - Cracked
    - Broken
    - Wear
  - Bearings
    - Sleeve
    - Rolling Element
  - Resonances
  - Balance
  - Eccentricity/Backlash
  - Pitch Line Runout
  - Apex Runout
  - Rubs
  - Ghost Frequencies

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies
  - Tooth Problems
    - Cracked or Broken
      - Typically should be seen as an increase in ‘1x’ of the running speed of the gear or pinion that has the problem. Can be hard to distinguish from other ‘1x’ problems.
      - Should be seen easier in the Waveform as a spike with a frequency of ‘1x’ of the running speed of the gear or pinion that has the problem.
    - Wear
      - Overall energy levels are increasing.
      - Can be seen as an increase in ‘1x’ of the damaged component.
      - If the wear is severe enough can also be seen to excite a gear’s natural frequency. May see sidebands of damaged gear.

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies
  - Tooth Problems - continued
    - Alignment - Internal
      - Higher amplitudes at multiples of gear mesh frequency.
      - Running speed sidebands around the GMF multiples.
    - Alignment – External
      - Cross coupling phase change.
      - Increased ‘2x’ of the coupling running speed.
      - This condition if severe enough may cause internal misalignment of the gearing causing additional issues.

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies

  - Bearings
    - Sleeve
      - Oil Whirl – Approximately ‘0.35 to 0.45x ’ of running speed.
      - Excessive shaft to bearing looseness
        - Increased ‘1x’, multiples of ‘1x’
      - Mechanical looseness – ‘1x’ multiples
    - Rolling Element Bearings
      - BPFI, BPFO, BSF, FTF
      - Looseness issues

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies
  - Resonances
    - Perform resonance studies or calculations to identify frequencies in question.
      - Structural
      - Fabricated gearbox panels
      - Rotor/Gears
  - Balance
    - Rotor/Gears
    - Coupling
  - Eccentricity/Backlash
    - Higher amplitudes of GMF
    - Sidebands around GMF

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies
  - Pitch Line Runout
    - This is an similar to an eccentricity issue
    - Shows higher GMF and sidebands
  - Apex Runout
    - Double Helical or Herringbone gears
    - May show axial frequencies at ‘1x of the problem gear, multiples of ‘1x’, and if errors occur on both gears possibly sum and difference frequencies.
  - Rubs
    - Seals
    - Lack of lubrication to bearings/gears
    - Can show fractional ‘1x’ frequencies

Gearbox Spectral Components and Monitoring Methods

- Additional Component Frequencies
  - Ghost Frequencies
    - A relatively rare defect that shows up as a frequency typically higher than GMF, but is not high enough to be a GMF multiple.
    - Manufacturing errors that are driven by vibration from the manufacturing drive train. Typically can be traced to the number of teeth on driving the cutter and cutter rpm.

Gearbox Spectral Components and Monitoring Methods

- Fundamental Frequency Analysis
  - How do we go about identifying and evaluating the problem?
    - Gather Known Facts
      - Nameplate data
      - Equipment component information
      - Equipment maintenance history
        - Include equipment repair costs
      - Equipment operating and historical data
        - Include production loss costs
      - Available vibration data
    - Area Inspection
      - Use all appropriate safety precautions
      - Inspect the equipment installation; look, listen, and feel.
      - Notice any structural (floor) changes in vibration close to or farther away from the machine

Gearbox Spectral Components and Monitoring Methods

- Fundamental Frequency Analysis
  - Additional Vibration Data
    - Collect any additional vibration data that is desired.
      - Horizontal, vertical, axial
      - Phase
      - Various frequency spans and resolutions
      - Waveforms
  - Evaluation
    - Is the issue a nuisance problem?
    - Is the issue a critical equipment problem?
    - Is the problem a recent or gradual change?
    - Are all the frequencies of interest identified?
    - What are the vibration energy levels?
      - Is there a large difference between the waveform overall energy and the spectral overall energy?
    - Is the equipment unique or one of many?
    - Is there available data on similar machines?

Gearbox Spectral Components and Monitoring Methods

- Fundamental Frequency Analysis
  - Recommendation will be based on the following:
    - Available Information and Resources.
    - Available Analysis Tools.
    - Analyst Experience.
    - Criticality of Machine and Process.
    - Availability of Repair Opportunities.
    - Goals of the Maintenance and Operations Groups
      - Do they want early indications?
      - Do they want to know ‘I need to do something now’?
    - Cost Variabilities – Production loss, repair/replacement, etc.

Gearbox Spectral Components and Monitoring Methods

BENTLY® Nevada

• Transducer Selection and Monitoring

- Transducer Selection
  - Be aware of the data collection transducer’s (and system’s) limitations relative to the monitoring application.
    - Frequency Range
    - Sensitivity Range
    - Natural Frequency Range
    - Mounting Sensitivity
    - Weight and Size
    - Temperature limitations
    - Measurement Units vs. Desired Analysis Units
  - Typical Transducers
    - Accelerometers – General, high frequency, and low frequency
    - Velocity Probes – Seismic and Piezoelectric
    - Non-contact Eddy Current

Gearbox Spectral Components and Monitoring Methods

- Transducer Selection and Monitoring
  - Transducer Selection - continued
    - What do we want from the measurements and monitoring?
      - Repeatability
      - Reasonable Accuracy
      - Effective Measurements
    - Can the monitoring equipment measure the typical changes that may occur in the vibration signature?
      - Need to compare the monitoring system design with the equipment design and typical fault development.

Gearbox Spectral Components and Monitoring Methods

- Transducer Selection and Monitoring
  - Transducer Selection - continued
    - Casing Measurements – Accelerometers and Velocity Probes
      - Very good for equipment with rolling element bearings.
      - Can be limited when dealing with sleeve bearing equipment.
    - Non- Contact Eddy Current Probes
      - Very good for equipment with sleeve bearings.
      - Can be limited on higher frequencies such as GMF.
      - Can be limited on obtaining bearing defect frequencies from Rolling Element Bearings

Gearbox Spectral Components and Monitoring Methods

- Transducer Selection and Monitoring

  - Example – Sleeve bearing equipment and use of accelerometer vs. eddy current probe.

    - Accelerometer will show you the casing movement, not the direct shaft movement.

      - How much of the shaft movement is transmitted (or damped, or multiplied)?

      - Many of the frequencies will be transmitted, the concern is what is the real ‘energy’ level of the shaft vibration.

      - Orbit (movement shape) of the shaft within the bearing clearance is also ‘inferred’ and not directly measured.

Gearbox Spectral Components and Monitoring Methods

- Transducer Selection and Monitoring
  - Example cont. – Sleeve bearing equipment and use of accelerometer vs. eddy current probe.
    - Eddy current probe will show you the actual shaft movement within the bearing clearance relative to the bearing housing (or mounted location).
      - Shaft movement within the bearing is directly measured.
        - Position of the shaft within the bearing and shape of the movement (orbit) can be very useful.
        - Phase reference of the shaft movement can also be critical during analysis of changing vibration signature.
        - Location of the shaft at standstill can also be used to determine whether sleeve bearing has significantly ‘wiped’ or not.

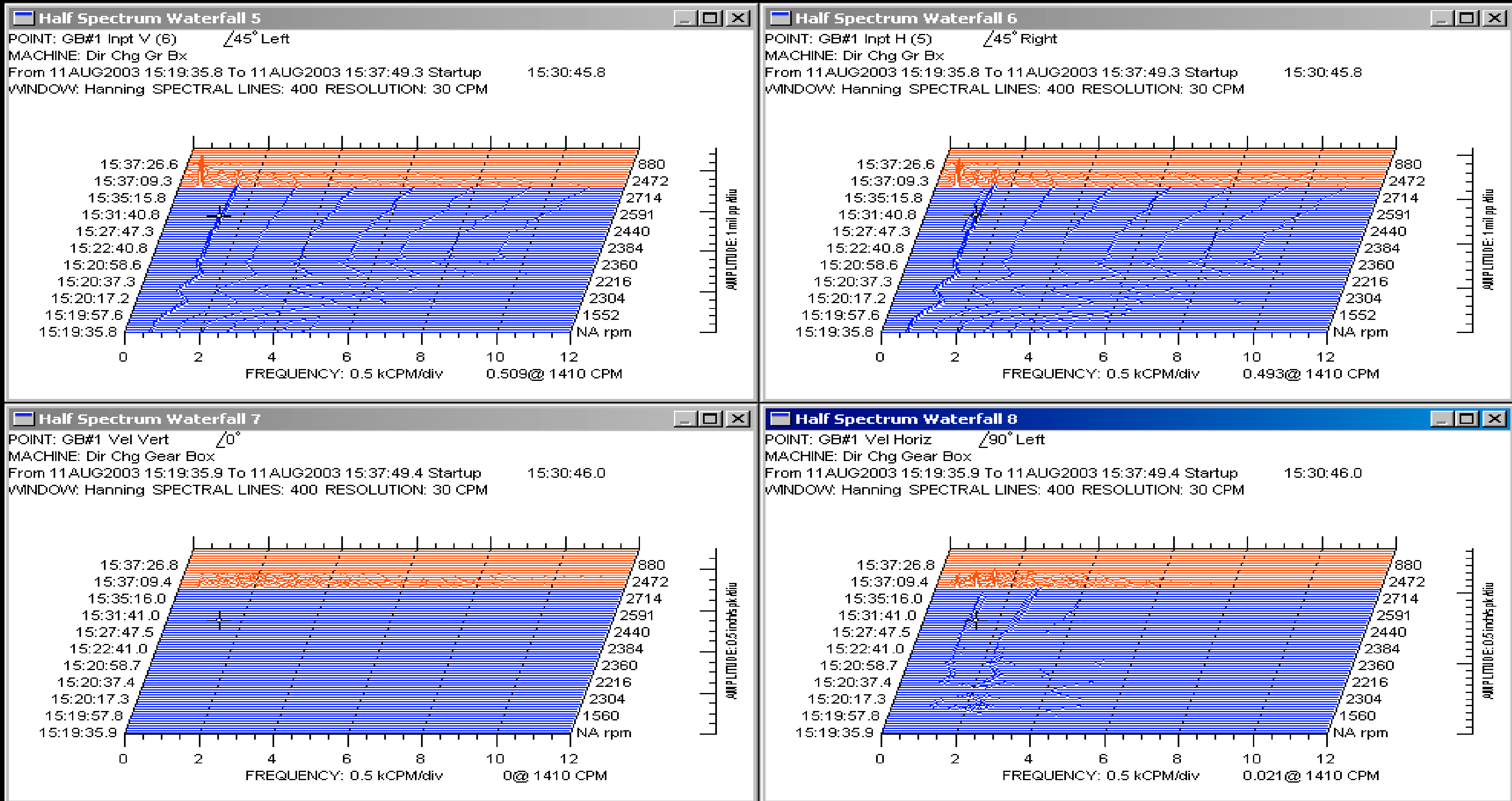
Gearbox Spectral Components and Monitoring Methods

BENTLY Nevada

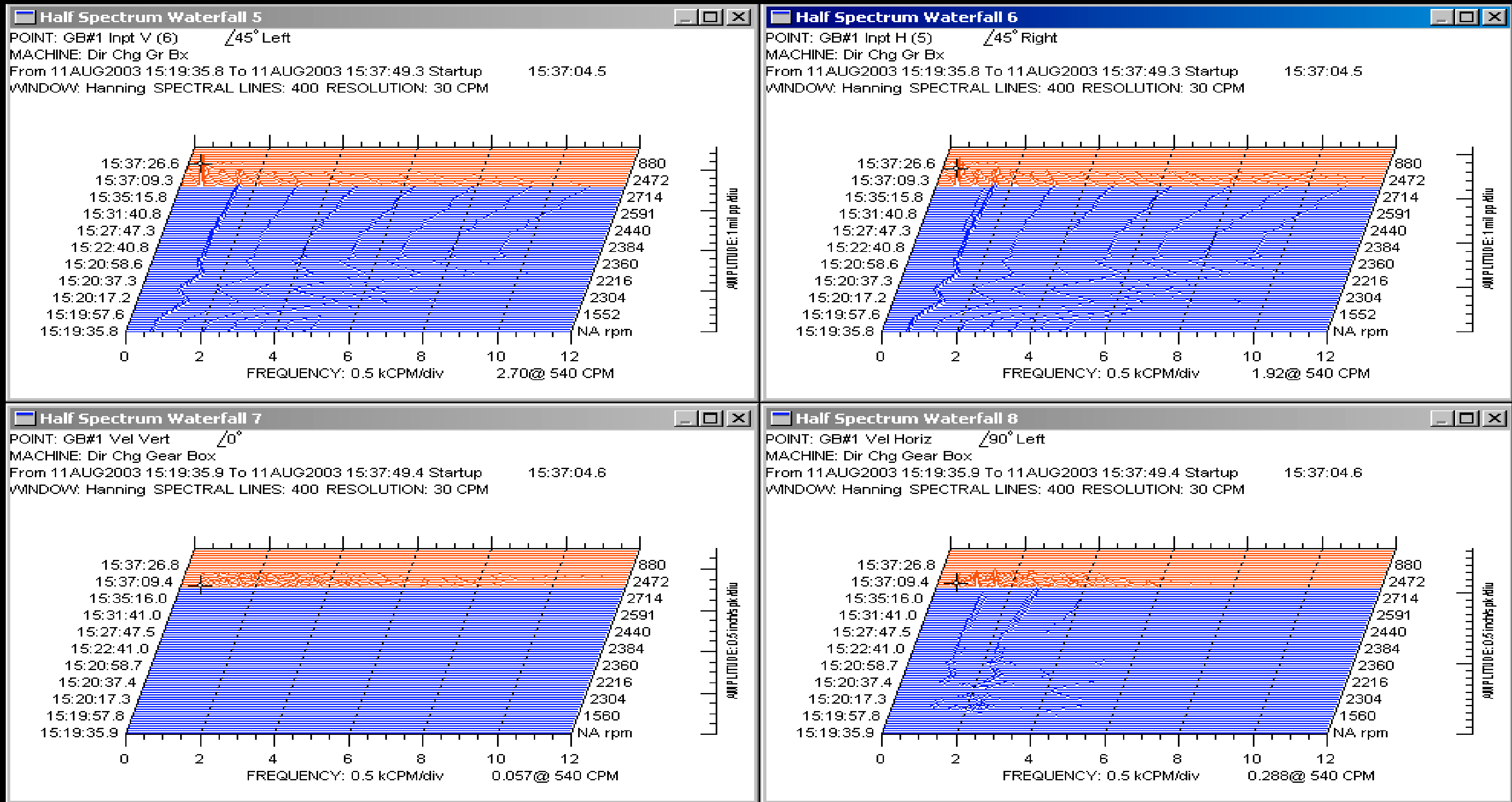
- Transducer Selection and Monitoring
  - Eddy Current Probe vs. Accelerometer
    - Amplitude level variations
      - Have seen reductions and increases in amplitudes shown in casing dependent on machine design, installation, and fault.
        - Large 650 MW Turbine – 25+ mils on shaft during balance resonance, 3+ mils measured on bearing pedestal.
        - 14,000 HP Boiler Feed Pump – 1.4 mils on casing during steady operation, 5+ mils on shaft.
        - However, casing or support resonances can appear to reverse this condition and allow shaft and housing to reach extreme amplitude levels.

Gearbox Spectral Components and Monitoring Methods

BENTLY® Nevada



Gearbox Spectral Components and Monitoring Methods



Gearbox Spectral Components and Monitoring Methods

- Transducer Selection and Monitoring
  - Monitoring
    - Once you have reliable, accurate, and effective data

We are looking for Change!!

- Set up the desired functions in the monitoring database
  - Various alarms
  - Various plots
  - Various trends

- Set up the desired functions for the most likely faults first and leave yourself some leeway for the unexpected!

The End

Any Questions?