Meaningful R.E.B. Analysis

- There are lots of product offerings, tools, and techniques available.
- Sometimes just making the choices can be a bit intimidating and overwhelming.
- We need to take away some of the “mystery”.
- We need to make the best of the situation.
- We will now examine the history, scientific terminology, and industry jargon.

Getting Down to Basics

- A bearing carries the load by round elements placed between two pieces.
- Relative motion of two pieces causes rolling, with very little resistance or friction.
- Started with logs on the ground with a stone block on top!  
  (Log at back was moved to front, sequentially.)
- Rolling elements in a circular bearing are captive and do not fall out under load.
- R.E.B. offers a good trade-off on cost, size, weight, carrying capacity, durability, accuracy, low friction, ...... and the list goes on.
Why Do Bearings Fail?

- Poor design.
- Misapplication.
- Poor installation.
- Improper loading.
- Poor care and maintenance.

Design Engineering – Application Engineering – Maintenance

Take a Proactive Approach

- Choose the correct bearing for the application.
- Employ proper bearing installation techniques.
- Utilize proper skills in assembly, balancing, alignment, etc.
- Follow proper lubrication schedule.
- Use care in storage, shipping, and handling.
- Ensure proper operation.
- Train everyone on the value of these good practices.
- Take the time to do the job right!

Facts on Bearing Life / Failure

- Less than 10% achieve design life. **
- 16% fail due to handling and installation.
- 14% fail due to contamination.
- 36% fail due to inadequate lubrication.
- 54% fail due to fatigue issues (excessive loading).
- Any extra loading (e.g. misalignment, unbalance, resonance) reduces life by a cubed function.

\[ L_{10} = \left( \frac{16,667}{\text{RPM}} \right)^* \left( \frac{\text{rated load}}{\text{actual load}} \right)^3 \]

- 10% extra loading cuts life by 1/3
- 20% extra loading cuts life by half!

** Source: SKF Bearing Journals.

What is L10 Life?

- It is the life expectancy for 90% of the population.
- Full load life is estimated at 1,000,000 revolutions.
- Sounds impressive, but at 3600 RPM, this is only 4.6 hours!
- Guidelines:
  - Light load is at < 6%.
  - Normal load is 6% to 12%.
  - Heavy load is at >12%.

From a few months to years at continuous 365/24 usage.
What Do We Wish To Accomplish?

• Early detection of even the slightest fault appearing with the bearing.
• Avoidance of any down time and secondary damage due to bearing failure.
• Pinpoint the faulty component and possible cause of the excessive vibration.
• Decide a corrective course of action.
• Follow-up and verify.

Familiar Key Elements: Detection – Analysis – Correction – Verification

The Detection Technologies

• Vibration analysis and acoustic emission.
• Oil and wear particle analysis.
• Infrared thermography.

Each technology has its place and should be used where appropriate. (Many times, they are complementary.)

Vibration and the Sources

• We can typically break vibration down to 4 main components:
  – Forced vibration due to unbalance, misalignment, blade and vane pass, gear mesh, looseness, impacts, resonance, etc.
  – Resonance response due to impacts.
  – Stress waves or shock pulses.
  – Frictional vibration.

It’s All About Pattern Recognition

• Vibration measurements provide us with four basic spectrum (FFT) patterns:
  – Harmonics - Almost always caused by the TWF shape.
  – Sidebands - Due to Amplitude or Frequency Modulation.
  – Mounds/Haystacks - Random vibration occurring in a frequency range.
  – Raised Noise Floor - White noise or large random events.
What Are We Looking For?

• Detection of even the slightest metal-to-metal contact from impacting components or inadequate lubrication in a bearing.
• A slight ringing caused by a bearing fault resonating a natural frequency in the machinery setup.
• Presence of high-frequency, low-energy vibration.
  – Sometimes noted as raising the “carpet level” in the noise floor in acceleration readings – especially at high frequency.
• Capability to detect an incipient failure with senses that transcend normal human abilities – sight, sound, touch, smell, etc.

Note: It is not important as to what natural frequency is excited; the measurement just needs to be repeatable.

Isn’t It Just Math?

Yes. Just know FTFI, BSF, BPFO, and BPFI.

Tell-Tale Signs in Acceleration

Presence of very small peaks at High Frequency!
A Look at Geometry …

Impacts per Revolution

Ball Bearings

Roller Bearings

Fortunately .. It’s All Worked Out

Note: BPFI = BPFO = Number of Elements; typically a 60/40 relationship.

(See data at left: 33.50 + 6.651 = 20 rolling elements.)

Also, sometimes estimated as:

BPFI = N/2 + 1.2
BPFO = N/2 - 1.2

What Are The Typical Failure Stages?

• STAGE 1:
  – Presence of ultrasonic frequencies (typically well above 5kHz) that are barely detectable.
  – Very low amplitudes appearing in the acceleration measurement.
  – Life remaining at this point is 10-20%.

Typical Failure Stages?

• STAGE 2:
  – More ringing occurring, and presence of frequencies of 500Hz to 5kHz.
  – Fault frequencies show up with modulation (sidebands).
  – Time waveform of acceleration shows impacting (flat-topped or notched).
  – Bearing life down to 5-10%.
Typical Failure Stages?

• STAGE 3:
  – Energy spreads more down the spectrum.
  – Defect frequencies begin to be more prominent.
  – More harmonics and sidebands show up.
  – Wear tend to flatten out peaks and patterns.
  – Bearing temperature increase is now apparent.
  – It is time to order parts and start an action plan!
  – Bearing life is now 5% or less.

Typical Failure Stages?

• STAGE 4:
  – 1X energy begins to increase as clearance is quite noticeable.
  – Broadband spectral noise is evident by a raised noise floor.
  – Failure is eminent!
  – 1% life is remaining at best.

What Do The Experts Say?

What Causes This Vibration Energy?

• Contact between two metal surfaces.
• A shock (or pressure) wave is created.
  – Analogy is the wave set up by an earthquake or tsunami.
  – A ripple from a pebble tossed in a pond is another example.
• Resulting signal propagates through the metal surfaces when there are no air gaps to filter (good metal-to-metal contact).
How Can We Detect Early Signs?

- Special instrumentation and detection circuits.
- Special signal processing.
- Detection of small spikes with short duration and ringing characteristics.
- A small tell-tale signal in the presence of lots of noise and higher amplitudes (a high dynamic range > 95dB).
- Accelerometer with a solid mounting.
- Good measurement practices.
- Special measurement for defect detection, plus normal readings in 3 axes.

How Have Solutions Suppliers Addressed This Need?

- Lots and lots of competitive and complementary offerings, some dating back to the early 70’s:
  - Spike Energy™ and Spike Energy Spectrum™ ESP™ (Envelope Signal Processing)
  - HFD™ (High Frequency Detection)
  - SEE™ (Spectral Emitted Energy)
  - PeakVue™
  - Shock Pulse™
  - Stress Waves
  - Enveloping (or Demodulation)
  - Cepstrum

The Choices …

Is There a Common Thread?

- All methods are based on a fundamental concept: There are repetitive impacts in the machine structure that indicate bearing faults, gear damage, looseness, cavitations, and similar faults.
- Machine/bearing resonances (or sensor resonance) are excited by the impacts – similar to striking a bell.
- Repetitive fault frequencies can be identified with special signal processing – filtering, peak detection, and frequency analysis.
- Careful measurement and collection methods are essential to enable this technique.
- Advanced signal processing technology and instrumentation available today make this a proven analysis tool in routine data collection programs for Predictive Maintenance (PdM).
What Do We Need To “See”?

- Spikes from impacts.
- Ringing from a natural resonance being excited.
- Demodulation (or other method) to determine and “see” the repeated fault frequency.
- Frequency Determination on ‘Impact Rate’ to isolate the fault.

What Are the Basic Requirements?

- Solid Transducer Mounting.
- Mounting Target and Orientation Maintained.
- Mounted in Load Zone of Bearing Housing.
- Best Possible Mechanical Interface for Transmission of Energy.
- High Frequency Energy Detection Method.
- Detection of Repeated Fault and Ringing Condition.
- Ability to Strip Out Low Frequencies Associated with Actual Running Speed.
- Ability to Demodulate (Envelope) Signal or Determine the Peaks of the Repetitive Fault Frequency.
- Ability to Detect Repetition Fault Frequency.
- Ability to Show Resulting Signature (FFT) and Compare the Pattern to Published Data.

The Measurement Challenge

- The mounting method is of key importance.
- We cannot “see” high frequency vibration unless the mount is a solid mechanical interface.

What Does “Demodulation” Really Mean?

- It is analogous to stripping out the information from an AM radio broadcast.
  - Spanning the band for the station frequency (540-1600 KHz) and picking off the broadcasted signal.
- First need to incorporate a high-pass or band-pass filtering.
- Eliminate any high amplitude signals associated with 1X and multiples up to about 10X.
- Include only the fault frequencies exciting inherent resonance.
- Intensify and draw out repetitive components of the fault.
- Convert to frequency for display of the pattern.
- Amplitudes will show up as a distinctive “saw-tooth” or “comb” harmonic pattern of the actual bearing fault.
More on **Amplitude Modulation**

- Amplitude Modulation (AM)
  - One frequency (carrier) is getting louder and softer at another frequency (the modulating frequency).
  - AM is mono. Mono is 'one', which implies one sideband on each side of the carrier.

The **Instrument Signal Processing** ...

The raw signal includes low frequency running speed harmonics:

These are removed by band-pass filtering:

Then envelope detection is applied:

Finally the result is displayed in the frequency domain:

The “comb” or “saw tooth” pattern.

**Can The Reading Be Trended?**

- Yes, but consistency of measurement is of utmost importance.
  - Same hardware.
  - Same measurement location.
  - Solid mounting in good mechanical transfer path.
  - Same conditions.
Case History Example

- Automotive paint facility.
- 250 HP motors running 6-foot bladed exhaust fans.
- Motor running at 1792 RPM.
- Fan belt driven and running at 820 RPM.
- Bearings known.
- Excessive vibration reported.
- Initial measurements made of vibration with acceleration, velocity, and demodulation.
- Source of problem is identified, corrective action is recommended.
- Bearing SKF 22218CCK changed out at next production break.
- Let’s take a look at initial results first, then Before/After comparisons.

First, Acceleration

Next, Velocity

Now, Demodulation
After the Fact, but not obvious

Velocity – Before and After

Note the significant reduction in amplitude.

Acceleration – Before and After

Note the reduction of the high-frequency energy.

Demodulation – Before & After

Note that the distinctive peaks are gone!
Another Recent Finding

- Low speed machine turning at 394 RPM.
- Bearing known as FAG 23906B.
- Fault frequencies known:
  - BPFI is 18.889
  - BPFO is 16.111
  - BSF is 6.2
  - FTFI is 0.46
- Low vibration amplitudes, but somewhat noisy.
- High frequency acceleration data was taken along with routine measurements, no demod.

First, The High Frequency Data

Next, the Time Waveform

Finally, the FFT with Overlays
Pre-requisites and Procedure

- Bearing part number(s) must be known.
- Fault frequencies must be known and preloaded.
- Running speed must be accurately recorded.
- Bearing faults excite natural resonances in the machine components or transducer.
- The fault frequency is recurring.
- A technique is available to detect the repetition rate in time.
- The fault frequency (if present) can be shown in an FFT display with bearing data overlays.

Summary Remarks

- Machinery vibration measurements in time waveform and spectrum can provide early (tell-tale) signs of rolling element bearing defects.
- Special signal processing techniques (now available in most portable data collectors) can detect impacting spikes and pinpoint a specific fault frequency.
- Comparing the resulting signature (pattern) to published fault frequencies can pinpoint the root cause of the problem.
- Field experiences in PdM over 30 years have proven the concepts to be very accurate and reliable.
- Considerable cost savings (in maintenance and production) are afforded by use of this technology.

Questions / Discussion on Rolling Element Analysis?

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