Using PeakVue Plus Technology for Detecting Anti-Friction Bearing Faults

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PeakVue™ is an established technology developed by Emerson that is proficient in detecting faults in roller element bearings and gear teeth. In rotating machinery, stress waves can occur because of impacting, fatigue cracking, scuffing and abrasive wear. Stress waves are generated by the sudden displacement of small amounts of material in a very short time period.[1,2]The most frequent occurrences of these waves in rotating machinery are observed during fault initiation and progression of both rolling element bearings and gear teeth. Embedded into Emerson's machinery health products, PeakVue is designed to detect these short bursts of stress waves which occur at the known repetition rate of roller element bearings and gear teeth faults.

The PeakVue technology has successfully been the primary method of detecting faults in roller element bearings and gear teeth for over 20 years. While the technology provides a leading indicator for predicting machine failure, it still requires a skilled analyst to determine the root cause. PeakVue Plus is a patented extension of PeakVue developed to automate this analysis and present user-friendly results. To show the power of PeakVue Plus, examination of a bearing fault from the perspective of an analysist using PeakVue will first be presented. The unseen details of analyzing the same bearing using PeakVue Plus will then be shown for comparison.

Determining faults with PeakVue data requires analysis of a PeakVue waveform for severity indication along with spectral and autocorrelation analysis to separate periodic and non-periodic data. The amount and type of periodic data relative to the non-periodic data signifies the nature of potential fault(s) present.

To illustrate the diagnostic power of PeakVue consider a case where monthly route data indicated a potential roller element bearing defect along with an associated lubrication issue on the tending side of a calendar roll. The immediate calculations to follow are based on data available to the user and is what an analyst performs to determine the type fault along with an estimated severity. Steps required by an analyst to predict a bearing issue and severity follow:

1. Determine maximum peak (MaxPk) in PeakVue waveform.

2. Perform autocorrelation on PeakVue waveform.
    a. Find largest peak in autocorrelation waveform after first 3% of waveform.
    b. Estimate the percent periodic energy by taking the square root of value found in 2a (see equation 1).

3. If Estimated percent periodic energy (Est%PE) is greater than or equal to 50%
    a. Mechanical bearing severity = (Est%PE)*(MaxPk)/(Fault level)
    b. Lubrication bearing severity = (100-Est%PE)*(MaxPk)/(Fault level)

4. If Estimated percent periodic energy is less than 50%
    a. Lubrication bearing severity = MaxPk/(Fault level)

The PeakVue waveform displayed in Figure 1 shows the maximum peak of 8.337 g's relative to a fault limit of 7.767 g's for the calendar roll bearing. The relative closeness of the maximum peak in the PeakVue waveform to the fault level indicates a bearing issue. A look at the associated spectrum and autocorrelation waveform will provide information as to the type fault. The associated spectrum in Figure 2 indicates an outer race fault is present. The estimated severity is determined using the maximum peak of the PeakVue waveform and the percent periodicity estimate predicted from the autocorrelated waveform (Figure 3). The autocorrelation waveform is derived from the PeakVue waveform.

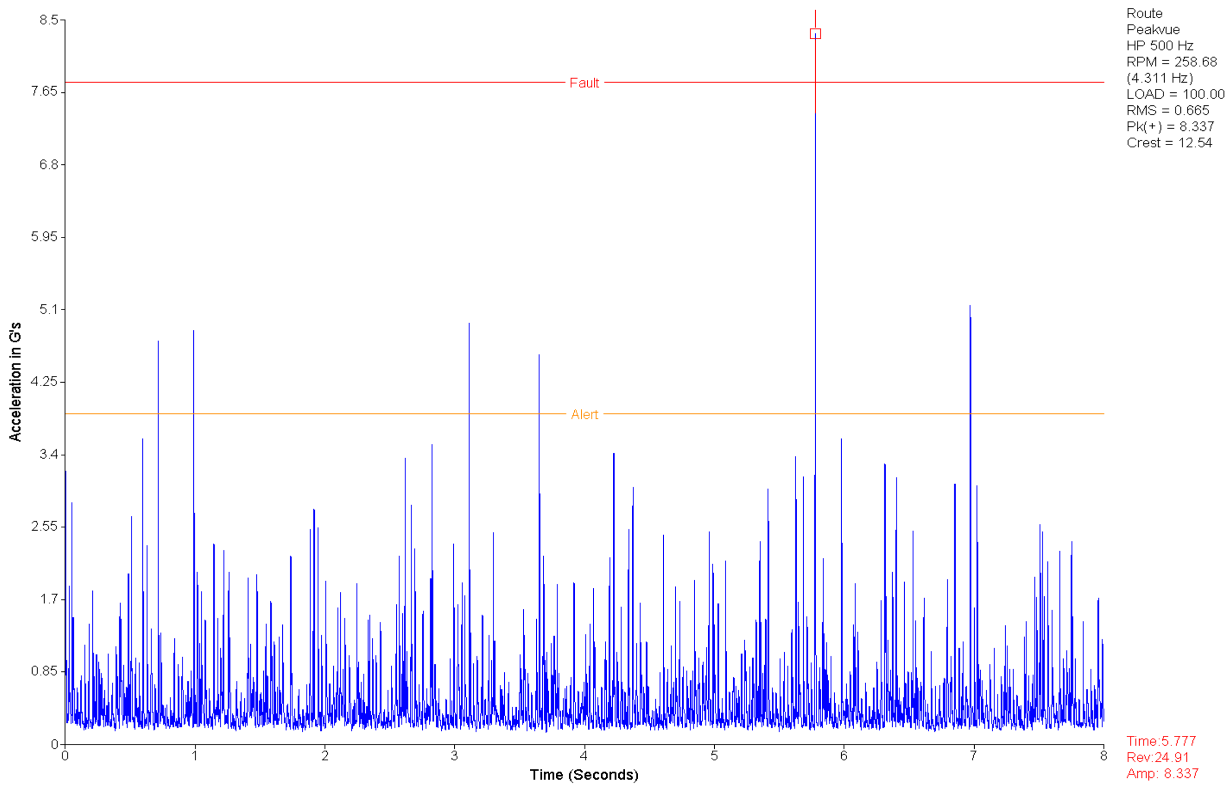

Figure 1. PeakVue Waveform for tending side of a calendar roll. Maximum peak is 8.337 g's. Fault level is 7.768 g's.

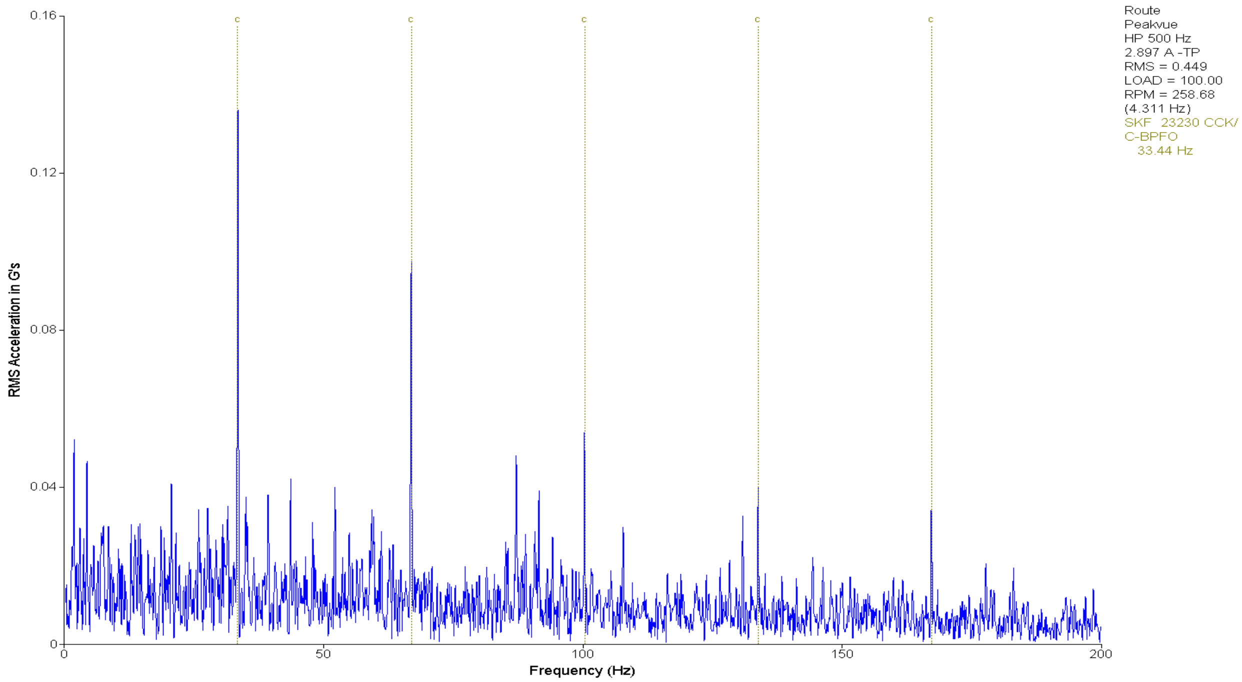

Figure 2. Spectrum derived from waveform in Figure 1. Outboard bearing fault marked.

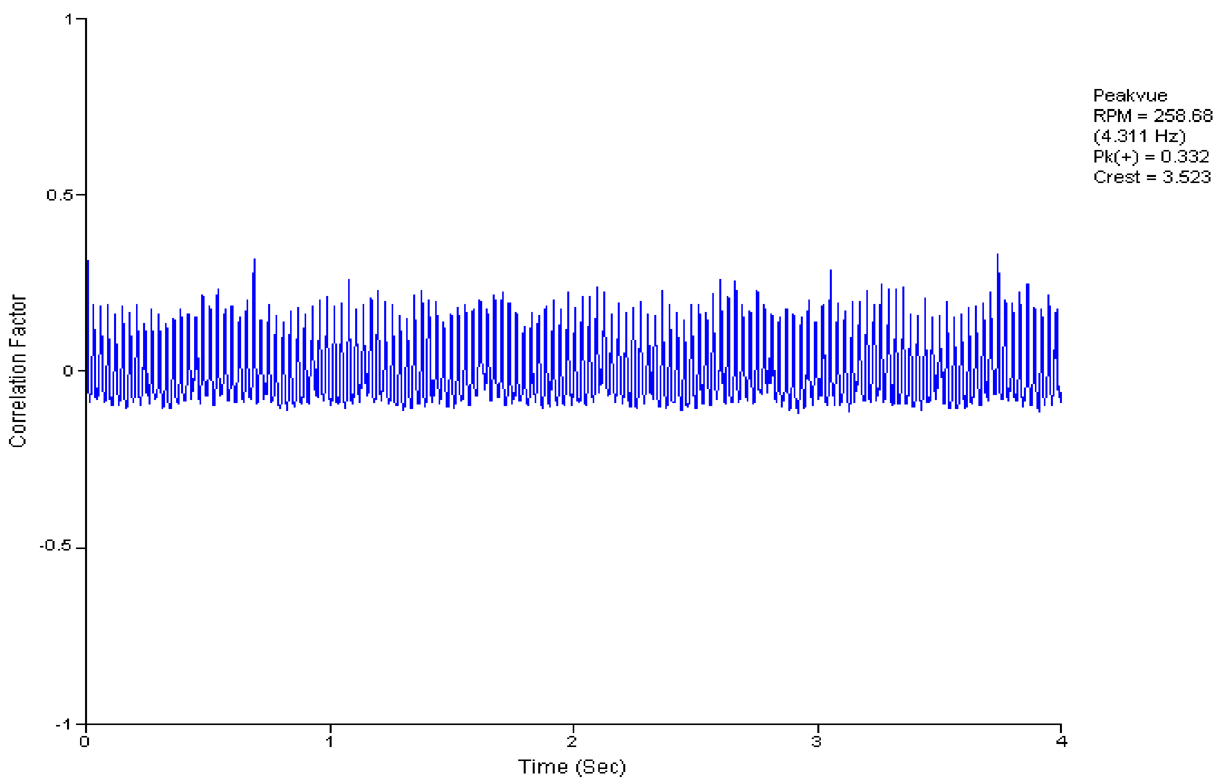

Figure 3. Autocorrelated waveform of PeakVue waveform displayed in Figure 1. Maximum peak correlation factor value is 0.332. Est % Periodic Energy = 57.62%

The largest peak in the autocorrelation waveform provides an estimate as to how much energy in the PeakVue spectrum is due to a mechanical fault (BPFO in this case). Using equation 1, the estimated percent energy in the PeakVue waveform contributing to a mechanical issue is 57.62% ((sqrt(0.332))*100). Multiplying the maximum peak value from the PeakVue waveform (8.337 g's) by the estimated percent energy value (0.5762) produces (4.804 g's) a representative estimation of the contribution of a mechanical fault to the bearing health. The ratio of this mechanical contribution (4.804 g's) to the fault level (7.7678) provides an estimate to the severity of the mechanical issue relative to the fault value. The resulting severity for this example is 61.8% of fault ((4.804/7.7678)*100%).

Almost any time a mechanical fault is present, lubrication issues are present. Lubrication is indicated in the autocorrelated waveform as non-periodic energy. The non-periodic energy estimated form the autocorrelated waveform is 42.38% (100-57.62). Therefore, the estimated lubrication severity is 45.5% ((0.4238*8.337/7.7678)*100%) of fault level. Note, from the autocorrelation, the relationship between the estimated periodic energy and non-periodic energy is approximately 1:1 down to 50%. Below 50% periodic energy is not predictable, and the estimated non-periodic energy is piece-wise linear relative to the square root of the largest peak.

The PeakVue technology is a proven and reliable method for detecting and assigning a severity to roller element bearing and gear teeth faults. It does however require an experienced analyst to effectively understand and use the technology. Emerson has continued to improve the PeakVue technology with several PeakVue Plus patents which incorporate all the analysis steps necessary in the PeakVue technology to provide a simplified predictive prediction relative to roller element bearing and gear tooth health.

PeakVue Plus is a term that encompasses the use of periodicity and analytics to improve and/or simplify analysis of PeakVue measurements. PeakVue Plus calculates periodicity to differentiate between periodic mechanical events (such as bearing and gearbox faults) and random non-periodic events (such a lubrication issues). *PeakVue Plus* incorporates the evaluation of PeakVue periodicity data along with known shaft speed(s) to derive the nature and severity of machine problems. In its most basic form, it differentiates between mechanically induced impacting (e.g. bearing/gear) and random impacting (e.g. lubrication) on a machine.

By combining the results of the maximum peak amplitude of the PeakVue waveform, periodicity derived from an autocorrelation of the associated PeakVue waveform and turning speed, an estimate as to the condition of a roller element bearing can be predicted. The combination of the results from these parameters can give indication as to the severity of a bearing fault and/or any lubrication issues that may be present. In a similar manner, the condition of the teeth in a gearbox can be determined as well as the health of the roller element bearings in the gearbox. Detection of faults within a gearbox will not be covered in this article but is the subject of a future article.

PeakVue Plus presents the results of the analysis in an easy to understand format. One such format is to provide diagnostic gages; one indicating the presence and severity of a maintenance/bearing fault and one to indicate the presence and severity of a lubrication issue. Keep in mind, a gage is just one method to easily convey the bearing/gearbox condition. However, there are many other ways to show bearing/gearbox condition(s) such as test tubes, red-yellow-green light displays to name a few.

To understand the PeakVue Plus process for diagnosing roller element bearing condition, steps required to diagnoses a bearing fault with PeakVue Plus will be discussed. To aid in understanding the calculations involved in the PeakVue Plus process, the bearing on the tending side of a calendar roll discussed in the example above will be evaluated. Typical turning speeds of the calendar roll range between 255 RPM and 290 RPM. It is important to note that the speed of the roller must be constant while data is acquired. The bearing evaluated in this example has an outer race (BPFO) fault.

PeakVue Plus will only evaluate data with sufficient resolution and an appropriate Fmax. For resolution, a minimum acquisition of 30 cycles of turning speed is required to evaluate all bearing frequencies. Therefore, the acquisition time (t) required to achieve 30 cycles of turning speed is 30/(turning speed (RPS)) or 1800/(turning speed (RPM)). The Fmax requirement for a PeakVue Plus analysis is: Fmax ≥ 30.5 x (running speed).

PeakVue Plus relies on obtaining a reliable speed. When a tachometer is not available, the user must either input an accurate speed or simultaneously acquire a velocity spectrum with the PeakVue data. When exact speed is unknown, a speed algorithm is employed on the velocity spectrum to determine the precise speed. This algorithm relies on the user providing the nameplate speed. Once the nameplate speed is verified as reasonable, the process of finding the speed from a velocity spectrum proceeds. The resulting speed is used in the calculations for the PeakVue Plus. In the AMS Wireless Vibration Monitor, speed is determined from a velocity spectrum acquired simultaneously with the PeakVue waveform/spectrum.

The steps to produce indication of the bearing fault condition are as follows:

1. Acquire PeakVue (original) waveform data. The PeakVue waveform for this example is shown in Figure 1. The setup for this measurement is Fmax = 200 Hz at 1600 lines and a PeakVue high pass filter set to 500 Hz. Figure 2 displays the PeakVue spectrum derived from this waveform for reference.

2. Determine the maximum peak amplitude (MaxPk) of the waveform in step 1. For the waveform shown in Figure 1, **MaxPk=8.337 g's**.

3. Calculate the associated autocorrelation waveform from step 1. Figure 3 displays the autocorrelated waveform derived from the waveform in Figure 1.

   The process of performing autocorrelation on a waveform produces a waveform of periodic signals, theoretically without the presence of noise or any signal not periodic.

4. Percent Periodic Energy is defined as the percentage of energy in the PeakVue (original) spectra that is related to periodic signals. The Percent Periodic Energy can be estimated from the autocorrelation waveform as:

$$\boldsymbol{Est}\ \%\ \boldsymbol{Periodic\ Energy} =$$

$$100 * \sqrt{MaxPeak\ (after\ 3\%\ of\ autocorrelation\ waveform)} \qquad \text{(eq. 1)}$$

   This estimate is good for values above 50%. Below 50% the relationship between the MaxPeak and periodicity is piecewise. Between 30% and 50% the estimated percent periodic energy is equal to the results of equation 1 divided by 2. For results of equation 1 with values below 30%, the estimated percent periodic energy is zero.

That is, if 30% ≤ Est % Periodic Energy (eq. 1) ≤ 50%, then

Est % Periodic Energy = (Est % Periodic Energy (eq. 1))/2 (eq. 2)

if Est % Periodic Energy (eq. 1) < 30%, then

Est % Periodic Energy = 0

In Figure 3, the maximum peak amplitude after the first 3% of the autocorrelation waveform is 0.343. Therefore, the **Est % Periodic Energy is 57.6%.**

5. Determine the Fault amplitude limit level based on recommended alarm levels for PeakVue data or user input based on experience.
6. Determine Severity:
   a. Calculate: General Severity (GS) = MaxPk/(Fault limit) (eq. 3)

   b. Normalize by multiplying answer equation 3 by desired maximum gage value “x” such that:

      Normalized General Severity (NGS) = *General Severity*0.8*x*. (eq. 4)

      The constant value of 0.8 is multiplied in the NGS equation so the fault value is 80% of full scale of the gage

      For example, if x=100.

      Then, NGS = General Severity*0.8*100.

      The calculated General Severity (eq. 3) for the tending side calendar roll bearing is:

      General Severity = 8.337 g’s/ 7.767 g’s = 1.0733

      And the Normalized General Severity (eq. 4) is:

      NGS = 1.733 * 0.8 *100 **= 85.86**

7. For Est % Periodic Energy greater than 50%, a bearing fault is possibly present. Calculation of the severity of the bearing fault follow:
   a. A patented algorithm runs an FFT on the autocorrelated waveform and relates this periodic spectrum with the PeakVue spectrum to produce a set of periodic peaks. The actual percent periodic energy is calculated as the ratio of the total energy of the periodic peaks to the total energy of the PeakVue spectrum. This “actual” percent periodic energy is a more accurate value than the Est % Periodic Energy parameter and will provide better estimates of bearing health.

When the turning speed is known (either from a tach or using the speed algorithm), periodic peaks can be classified as synchronous and non-synchronous. Synchronous periodic peaks are peaks associated with the running speed and harmonics of running speed. For a gearbox, there will be as set of synchronous periodic peaks associated with each shaft speed. All periodic peaks not associated with running speed are non-synchronous periodic peaks.

i. If non-synchronous periodic peaks are present, a possible bearing issue is suspected.

$$\textbf{Bearing Fault Severity (BFS)} = GS\ x \left[\left(\frac{(Energy\ of\ the\ located\ non\text{-}synchronous\ periodic\ peaks)^2}{(total\ energy\ of\ the\ associated\ PeakVue\ spectrum)^2}\right)\right] \quad \text{(eq. 5)}$$

And

$$\textbf{Gage Bearing Fault Severity (BFS)} = NGS\ x \left[\left(\frac{(Energy\ of\ the\ located\ non\text{-}synchronous\ periodic\ peaks)^2}{(total\ energy\ of\ the\ associated\ PeakVue\ spectrum)^2}\right)\right] \quad \text{(eq. 6)}$$

ii. If synchronous periodic peaks are present such that the Percent Synchronous Energy is greater than 10% of the total energy of the PeakVue spectrum and the measurement is not on a gearbox, an inner race fault (BPFI) condition is suspected and BFS is calculated as:

$$\textbf{Bearing Fault Severity (BFS)} = GS\ x\ Percent\ Periodic\ Energy/100 \quad \text{(eq. 7)}$$

And

$$\textbf{Gage Bearing Fault Severity (BFS)} = NGS\ x\ Percent\ Periodic\ Energy/100 \quad \text{(eq. 8)}$$

Where:

$$\textbf{Percent Periodic Energy} = \left(\frac{(Energy\ of\ located\ periodic\ peaks)^2}{(total\ energy\ of\ the\ associated\ PeakVue\ spectrum)^2}\right) x100 \quad \text{(eq.9)}$$

and

$$(Energy\ of\ located\ periodic\ peaks)^2 = (Energy\ of\ the\ located\ non\text{-}synch\ periodic\ peaks)^2 + (Energy\ of\ located\ synch\ periodic\ peaks)^2 \quad \text{(eq. 10)}$$

A plot showing the synchronous periodic and non-synchronous periodic peaks for this example is shown in Figure 4.

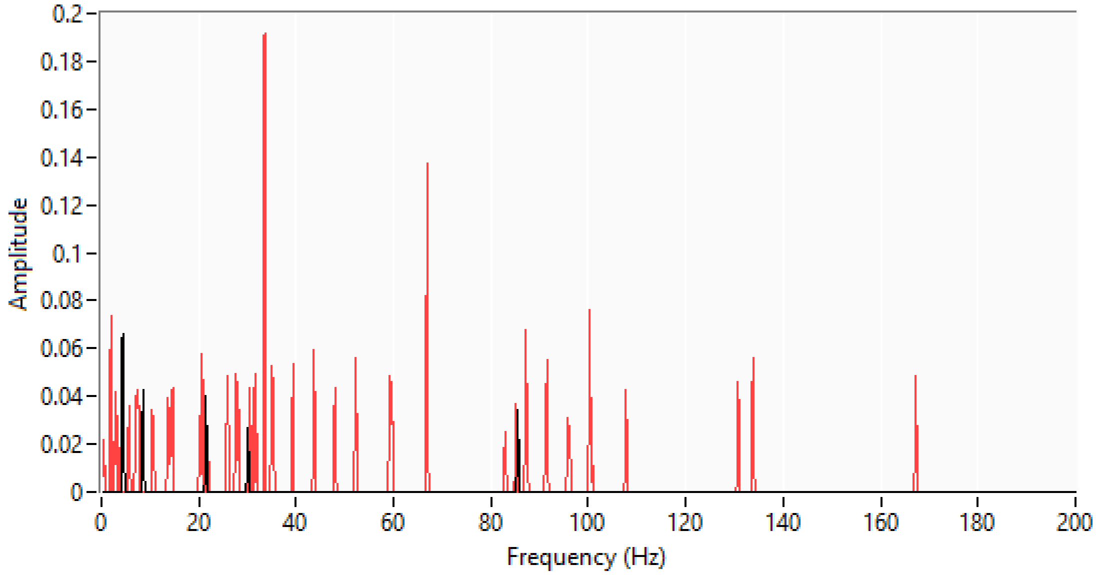

Figure 4. Periodicity plot associated with the PeakVue spectrum. Note: all peaks highlighted in black are periodic synchronous peaks while peaks highlighted in red are non-periodic synchronous peaks.

Since the energy of the synchronous periodic peaks is less than 10% of the total PeakVue spectrum, only the non-synchronous periodic peak energy will be used to calculate the mechanical bearing severity. The energy of the non-periodic synchronous peaks for this example is 0.5259 g's. The total energy of the PeakVue spectrum is 0.7759 g's. Entering these values into equation 5 produces the severity of this bearing fault as:

Bearing Fault Severity = 8.337/7.767 *[(0.5259)^2/(0.7759)^2]*100% = 49.3%

The bearing fault severity estimated in PeakVue Plus is 49.3% of the fault level. This differs slightly from the estimate calculated by an analyst in PeakVue (61.8%). The difference in Bearing Fault Severity estimates is due to the fact the PeakVue Plus calculates actual periodicity percentages where an analyst using PeakVue relies on percentage estimates of periodicity. Even though these severity estimates differ, it is important to note that both processes provide indication of a bearing fault at an early to moderate stage of bearing failure.

Gages are utilized in PeakVue Plus to provide a normalized bearing fault severity. The fault level will always be 80% of the full scale. Therefore, by entering the appropriate values into equation 6 produces the severity of this bearing fault on a scale of 1 to 100 (remember, fault level is equated to 80 on this scale).

Gage Bearing Fault Severity = 85.86 *[(0.5259)^2/(0.7759)^2]*100% = 39.4%

Figure 5 displays an example of a gage showing the Bearing Defect severity for this calendar roll bearing.

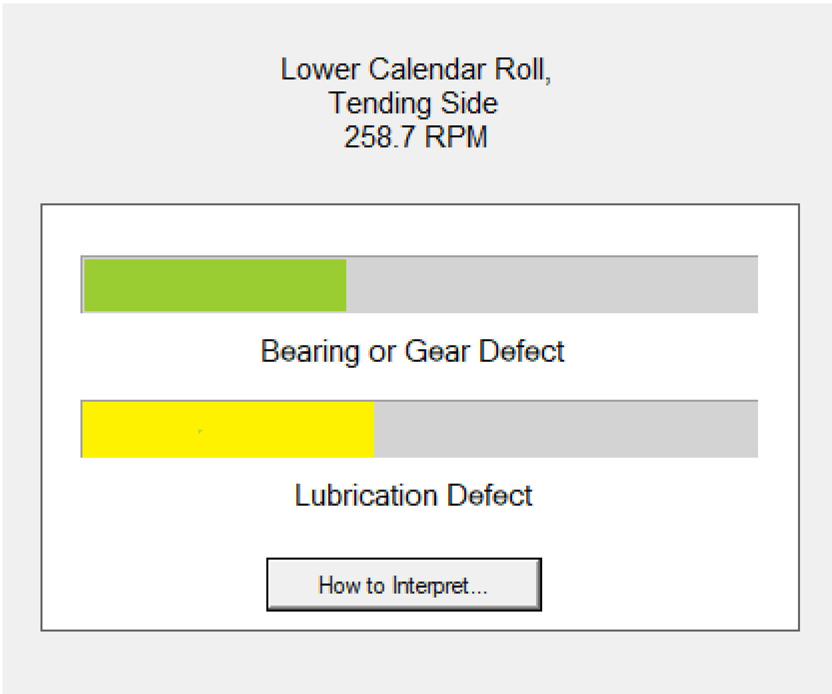

Figure 5. Mechanical and Lubrication gages indicating bearing severity for the tending side of a calendar roll.

8. When Est % Periodic Energy ≤ 50% and MaxPk > Alert limit, bearing conditions related solely to lubrication are indicated. Lack of lubrication can also occur in a bearing with faults. Therefore, lubrication severity is also calculated for bearings with indicated mechanical faults.
9. The severity of the lubrication problem is dependent upon the MaxPk value of the originating waveform and the Percent Noise (also called Percent Non-Periodic Energy) indicated from the associated autocorrelation waveform.
    a. Percent Non-Periodic Energy (%NPE) is defined as the percentage of energy in the PeakVue (original) spectra that is related to random vibration (signals).
        i. Percent Non-Periodic Energy is calculated by subtracting the periodic energy from the energy in the associated PeakVue spectrum as shown below:

$$\%NPE = 100 * \frac{(PeakVue\ Spectrum\ Energy)^2 - (Energy\ of\ located\ periodic\ peaks)^2}{(PeakVue\ Spectrum\ Energy)^2}$$

(eq. 11)

b. Lubrication severity is defined as:

Lubrication Severity *= [GS]*[%NPE/100]* (eq. 12)

And relative to a gage display of the lubrication fault,

Gage Lubrication Severity *= [NGS]*[%NPE/100]* (eq. 13)

The **Percent Non-Periodic Energy for the bearing in this example is 50.85%**. therefore, the lubrication severity as calculated in equation 12 is 54.6 while the lubrication severity for the gage (eq. 13) with a range of 0 to 100 is **43.7**.

Figure 5 displays an example of a gage showing the bearing Lubrication Defect severity. Notice the lubrication severity relative to the fault level from a hand-calculated user is 45.5% while PeakVue Plus estimates a 54.6% value. Again, the slight difference in estimates is because a user derives periodicity and hence non-periodicity based on an estimate of percent periodicity calculated from the autocorrelation waveform. The PeakVue Plus technology uses a more rigorous patented process producing a more accurate value for the non-periodic energy, and thus lubrication severity.

Based on the PeakVue Plus evaluation, a bearing defect was suspected on the tending side of the lower calendar roll. Once the bearing fault was discovered, the customer needed the bearing to last for two more weeks before a shutdown was scheduled. A PeakVue measurement was acquired daily and the bearing lubricated when necessary until the two-week window was reached. Figure 6 displays the outer race defect for this bearing. The bearing defect gage in Figure 5 indicates an early to moderate stage of a bearing defect. This is confirmed as the appearance of false brinelling is seen in Figure 6.

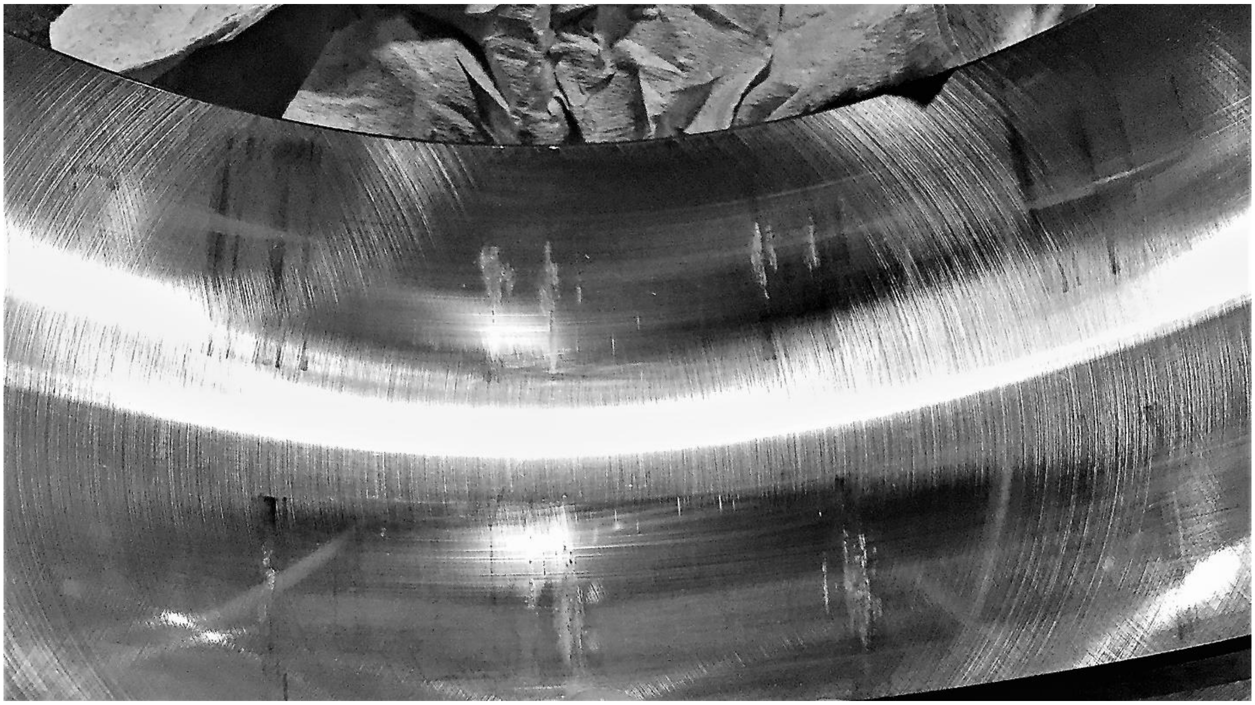

Figure 6. Outer race defect of a bearing on the tending side of a lower calendar roll.

The PeakVue technology has long been a very reliable method to detect roller element bearing faults at any stage of degradation. PeakVue Plus further enhances the technology by finding the periodicity components to automate the process of predicting mechanical and lubrication failures in roller element bearings. The steps required to determine the condition of a bearing mounted on the tending side of a calendar roll was shown. PeakVue Plus takes the PeakVue Waveform and accomplishes all the tedious calculations to provide a simple severity for mechanical and lubrication issues associated with anti-friction bearings.

The PeakVue Plus technology for roller element bearing analysis is incorporated in many of Emerson's predictive maintenance software and hardware products. PeakVue Plus for bearing analysis was first implemented as an analysis expert application in the AMS 2140. It is a prominent feature in the AMS Wireless Vibration Monitor. It is found as a PeakVue waveform analysis aid in both AMS Machinery Manager and Machine Works software. It is also incorporated in the rule-based analysis of AMS Asset Monitor.

References

1. Dr. Adrian A. Pollock, "Acoustic Emission Inspection," *Metals Handbook*, Ninth Edition, Vol. 17, ASM International (1989): pages 278-294.
2. William H. Hoppman II, "Effect of impact on Structures." *Shock and Vibration Handbook*, ed. by Cyril M. Harris, 4th Edition, McGraw-Hill.