White Paper
August 2011

PeakVue Analysis for

Antifriction Bearing Fault Detection

Peak values (PeakVue) are observed over sequential discrete time intervals, captured, and analyzed. The analyses are the (a) peak values (measured in g's), (b) spectra computed from the peak value time waveform, and (c) the autocorrelation coefficient computed from the peak value time waveform.

Case studies of various classes of faults are presented to illustrate the PeakVue methodology. The classes of faults are (a) inner race defects, (b) outer race defects, (c) rolling element defects, and (d) cage related defects. All three analysis tools enable the identification of the defect and often the severity of the defect.

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Introduction

The peak value analysis (PeakVue) methodology introduced by Emerson for the analysis of impact-like events is proven to be an effective tool for identifying bearing defects.

Overview of Signal Processing for Vibration Analysis

The analog signal from the vibration sensor is generally routed through some analog signal processing, converted into a digital format and then further processed digitally. The vibration sensor often is an accelerometer whose output is expressed in g units. The signal processing may include conversion of the signal from acceleration to velocity units employing an analog integrator. The analog signal (g or velocity units) generally is passed through a high order low pass filter immediately before the analog-to-digital converter to remove any signal components which may be present at frequencies greater than the Nyquist frequency defined as one half of the sampling rate.

This provides assurance that the digital representation of the analog signal is correct, i.e., the band limited analog signal existing prior to digital conversion could be reconstructed from the digital signal.

Once a block of digital data is acquired at a constant sampling rate of desired length, typically a block size of 2n where n is an integer, the digital data are further processed. By far the most common processing for analyzing rotating equipment is the Fourier Transform, using a FFT algorithm to construct the spectrum either in acceleration or velocity units. The spectral analysis is helpful in separating the band-limited signal into periodic components related to the turning speed of the machine.

In addition to spectral analysis, auto-correlation analysis can be applied to the digital block of data representing the time waveform. These additional correlation analyses have not proven to be helpful to the normal spectral analysis, but it can be beneficial for analysis of time waveform acquired when employing PeakVue analysis.

In PeakVue analysis, no low pass filter at or slightly below the Nyquist frequency is employed. Instead, a high pass (or band pass) filter greater than or equal to the nyquist frequency is employed. The digital block of data consists of absolute maximum values, which the time waveform experiences over each time increment defined by the sampling rate. Hence the analysis of this representative time waveform is the analysis of peak values.

The analysis of this block of data consists of the peak values themselves and an identification of periodicity that is best accomplished using spectral analysis. The autocorrelation analysis has also been found to be very beneficial for the peak value time waveform.

Case Studies

These case studies demonstrate the signature accompanying various antifriction bearing faults for a wide variation in machine speed. The PeakVue time waveform will also be emphasized relative to trendability and fault severity assessment. The primary emphasis will be placed on the peak values in the PeakVue time waveform, the spectral peaks and presence or absence of sidebanding, and the periodic activity in the autocorrelation coefficient function.

The case studies presented are:

Outer Race Defects
- Pinion Stand Gearbox
- Crowd Motor

Inner Race Defects
- Crusher gearbox
- Precision13 drill head spindle

Ball or Roller Defect
- Chipper
- Rougher gearbox

Cage and others
- Lubrication
- Single stage rotary air compressor

Outer Race Defects

The first case study is from a **pinion stand gearbox** at a steel producing facility. The normal spectral data taken for a 1000 Hz bandwidth had g levels of ±2 g's and no indication of a bearing problem. The input shaft speed was about 360 RPM.

The PeakVue spectra and time waveform data are presented in Fig. 1. A high pass filter of 1000 Hz was used. Significant activity at the outer race defect frequency with many harmonics is present. The impact levels are as high as 37 g's.

Although many harmonics are present in the spectral data, it is obvious from the PeakVue time waveform that the time between impacts corresponds to the outer race fault frequency (the harmonics are of no physical significance). This is also demonstrated in the autocorrelation coefficient function presented in Fig. 2

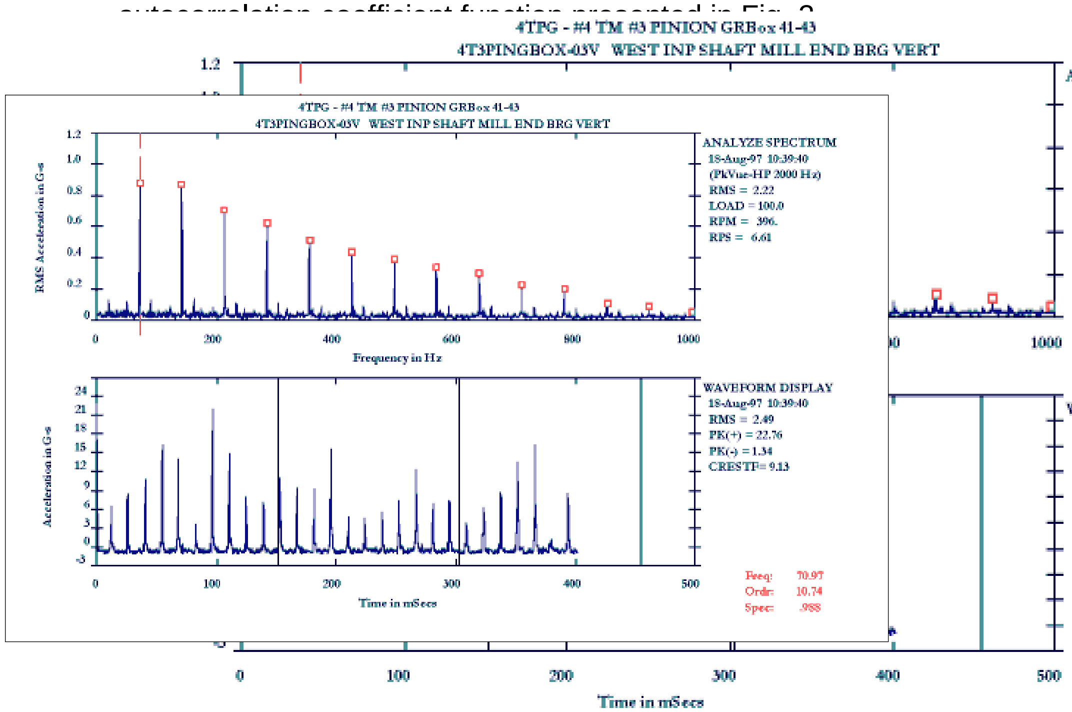


Figure 1: PeakVue Spectra and time waveform from input shaft of pinion stand gearbox

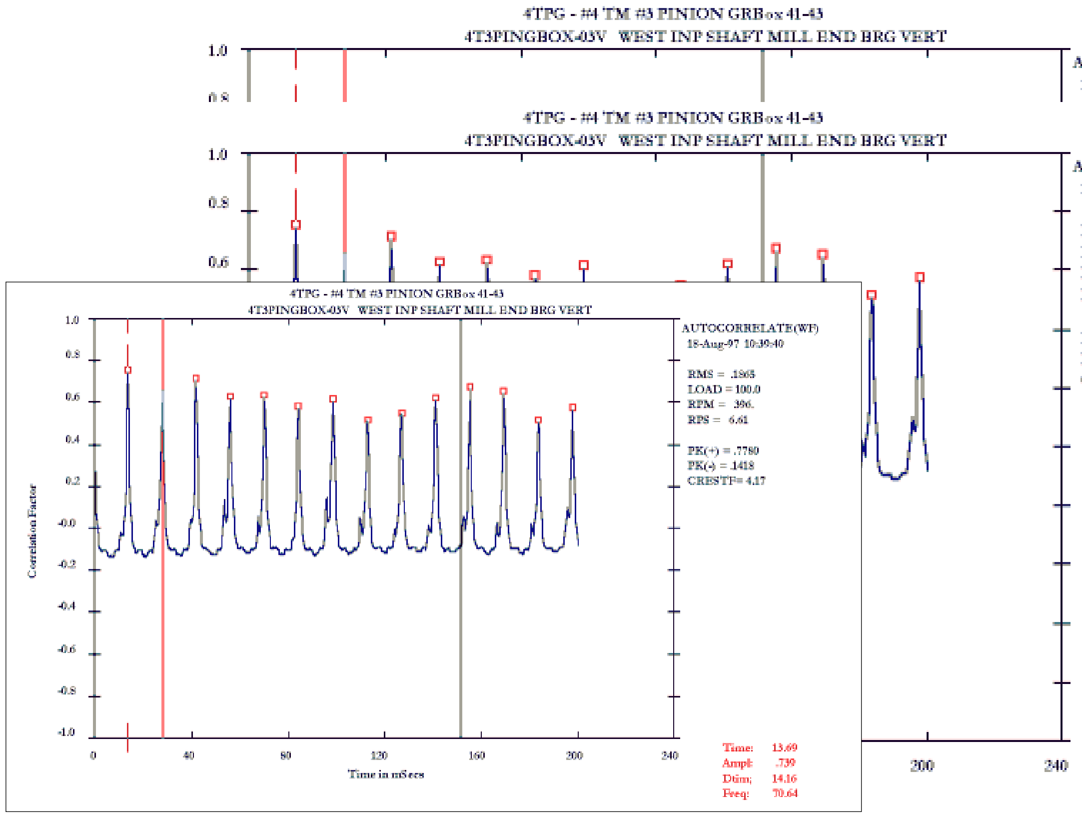


Figure 2: Autocorrelation coefficient from PeakVue time waveform in Fig 1

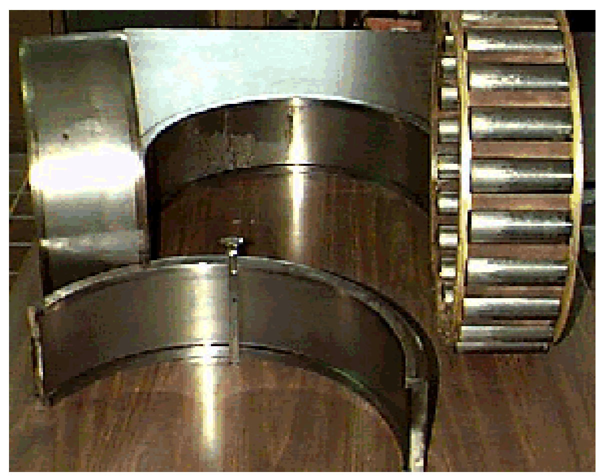


Figure 3: Photograph of defective bearing from the inlet of pinion stand gearbox

The impacting levels trended from 18 g's in July to a high of 37 g's in September. The levels had decreased to 14 g's in October prior to a bearing replacement.

The second case study is from a **centrifugal service water pump** rated at 12000 gpm driven by an 8 pole 700 hp motor.

Normal route-based vibration monitoring identified an outer race defect of reasonably low level (the peak-to-peak g level was 1.5 g's). The fault was identified as "alert" and hence was to be trended. On December 8, 1997, PeakVue was employed and showed both outer and inner race defects with a signal level of 10 g's. A second PeakVue reading was taken on December 22, 1997 and is presented in Fig. 4. The impacting levels had increased to 33 g's. The pump was then placed on the "fault" level and the bearing was replaced. The autocorrelation coefficient computed from the PeakVue time waveform is presented in Fig 5. The autocorrelation coefficient data shows the only activity of significance is the impacting from the outer race defect.

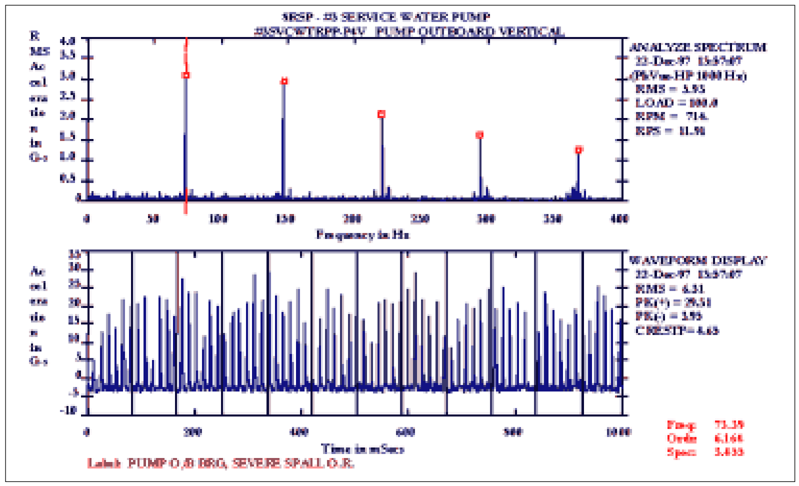


Figure 4: PeakVue spectra and time waveform from outboard on service water pump

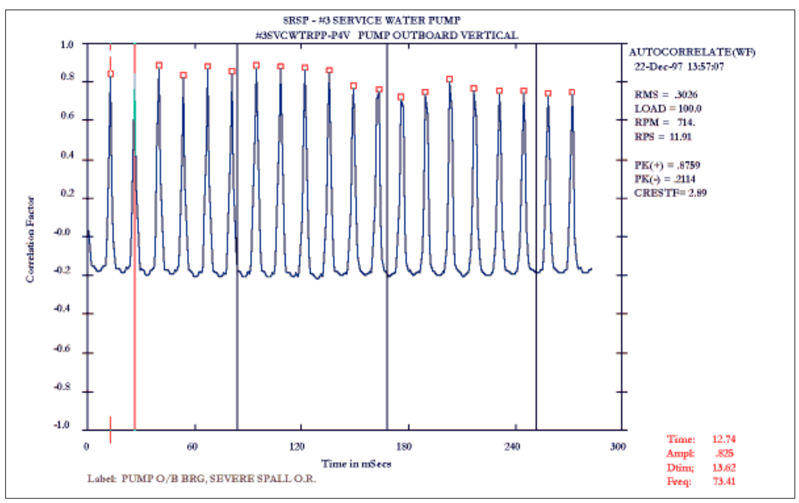


Figure 5: Autocorrelation coefficient from PeakVue waveform in Figure 4.

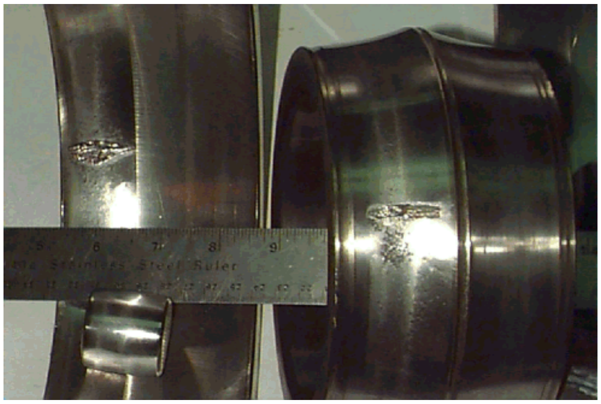


Figure 6: Photograph of defective service water pump bearing, showing inner and outer race spalling.

In this case, normal vibration data did identify the fault; however, the low levels observed did not place the fault at a level of significant concern. The impacting levels identified in PeakVue, excess of 30 g's, raised the concern level and initiated planning for replacement.

Inner Race Defects

The first inner race defect case involves a crusher gear box. The input shaft of this gear box has three bearings. The output of the gear box turns a crusher used at a mining site. The gear box, approximately 8 ft. 10 ft 20 ft, is powered by an eight pole 2000 hp motor.

The trend observed on this bearing using PeakVue was:

February 13, 1997: Cage defect dominant but no other bearing fault. Peak impacting 2.5 g's.

February 28, 1997: Inner race dominant with peak impacting of 5.5 g's.

March 20, 1997: Cage and inner race defeat with peak impacting of 6.6 g's.

March 27, 1997: Cage and inner race defeat with peak impacting of 3.5 g's.

The PeakVue data acquired March 20, 1997 are presented in Fig. 7. The cage activity at 6.23 Hz (0.42 orders) is identified. The inner race defect (129.75 Hz) at 8.72 orders is being sidebanded by running speed. The inner race defect was not detected in the normal spectral analysis.

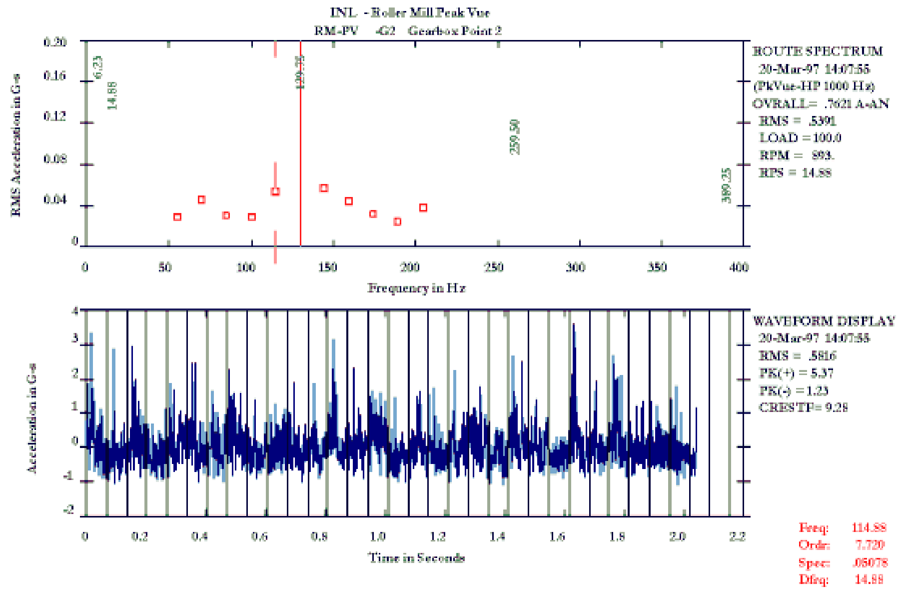


Figure 7. PeakVue spectra and time waveform from inlet of crusher gear box.

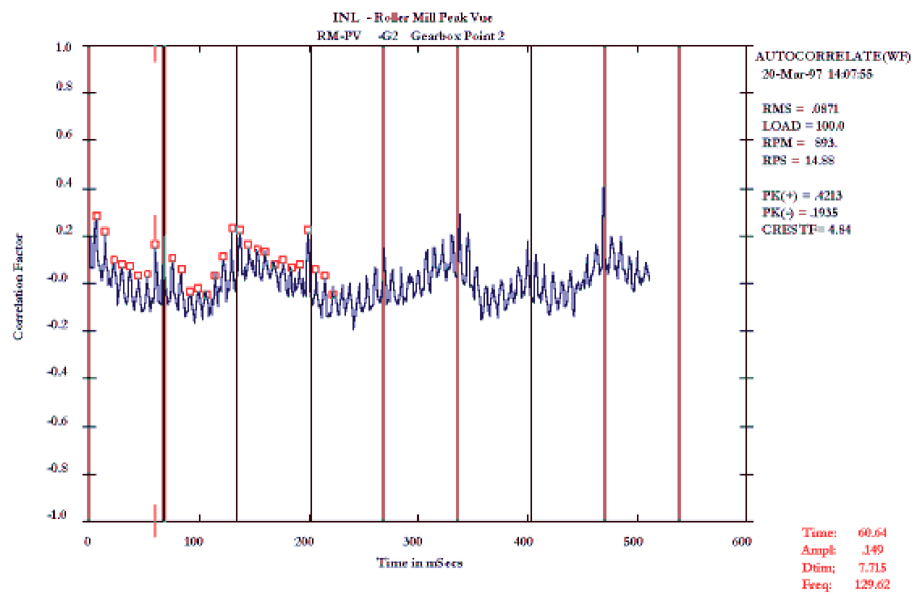


Figure 8. Autocorrelation coefficient from PeakVue time waveform of Figure 7.

The autocorrelation coefficient function computed form the PeakVue time waveform in Fig. 7 is presented in Fig. 8. The inner race defect is clearly evident with amplitude modulation at running speed. The peak g levels for an inner race are generally not as large as for those accompanying an outer race defect. This is expected since the stress waves accompanying an inner race defect will experience attenuation in reaching the outer peripherals (where the sensor is attached) of the machine.

The bearing was replaced in June, 1997. The inner race had deep spalling over an approximate 1 1.5 area.

The second case study deals with a precision 13 drill head spindle. Bearing defect, especially inner race defects, detection on these precision multi-drill head spindles have proven to be difficult to impossible using normal velocity spectral analysis. PeakVue methodology was applied to several of these multi-drill head spindles and demonstrated to be an effective tool for bearing defect detection. On the class of spindle monitored, the high-frequency accelerometer was magnetically attached to the base of the spindle and data acquired in the unloaded position. An alert level was set at 2.0 g's on the PeakVue time waveform. When this level was exceeded, an alert is set signifying a problem is present. PeakVue spectral analysis was then employed to identify the problem.

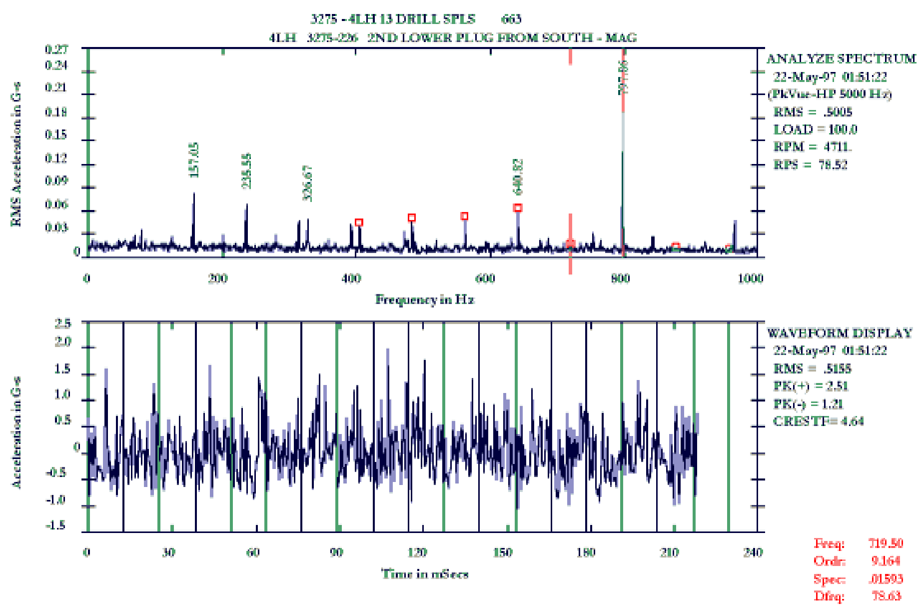


Figure 9. PeakVue spectra and time waveform from a spindle on a 13 multi-drill head spindle.

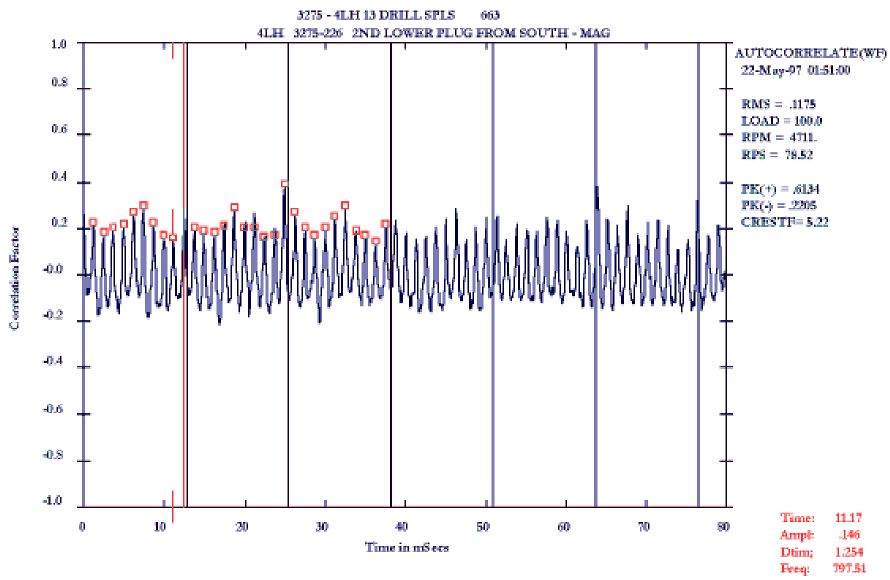


Figure 10. Autocorrelation coefficient from PeakVue time waveform acquired on the spindle of Figure 9.

The PeakVue spectra and time waveform for a spindle with a confirmed inner race defect are presented in Fig. 9. The inner race defect at 797.86 (10.2 orders) Hz is identified with side banding (twice running speed is dominant). The autocorrelation coefficient function computed form the PeakVue time waveform is presented in Fig. 10. The dominant activity here is at the inner race defect frequency. The bearing was replaced. The bearing had deep spalling on the inner race

Ball or Roller Defect

Following a shutdown where work was done on this chipper machine, the acceleration time waveform for a 500 Hz bandwidth spectra indicated some impacting may be occurring, see Fig. 11. The p-p g levels were less than 1 g which are not judged to be significant. The velocity spectra had a low 1x component but there were no obvious bearing faults.

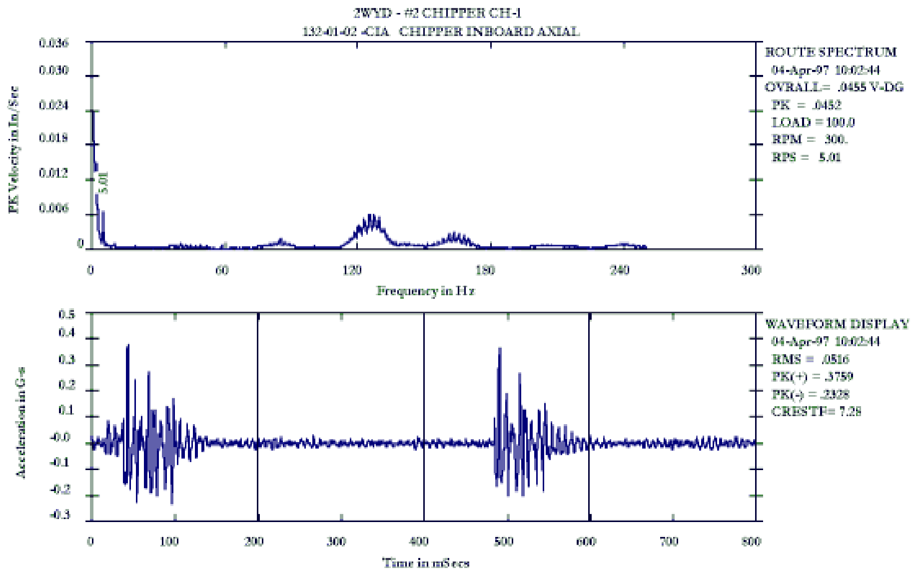


Figure 11. Velocity spectra and acceleration time wave form from inboard axial on a chipper.

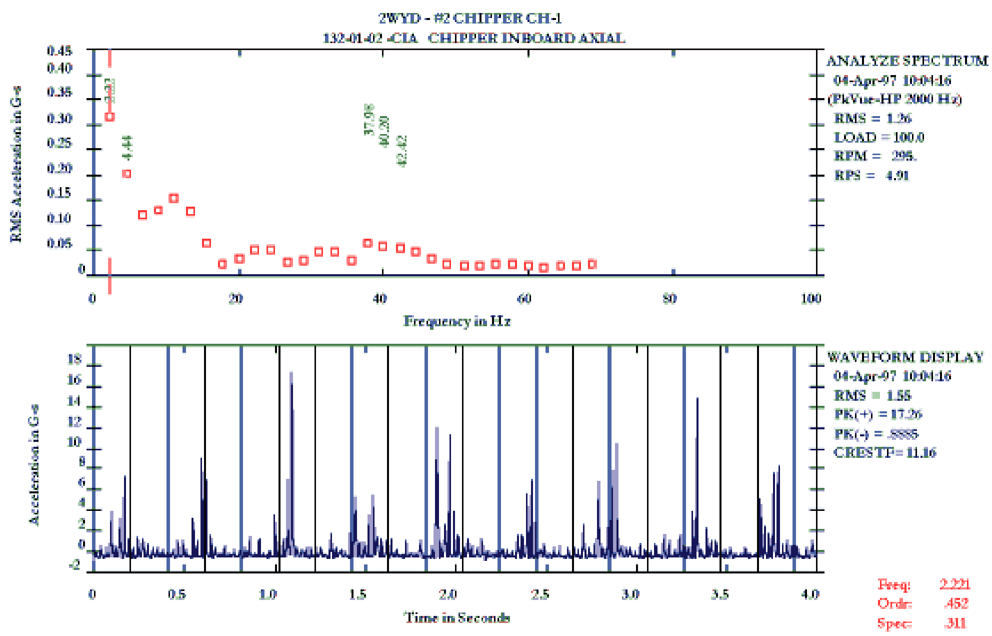


Figure 12. PeakVue Spectra and time waveform from inboard axial on chipper.

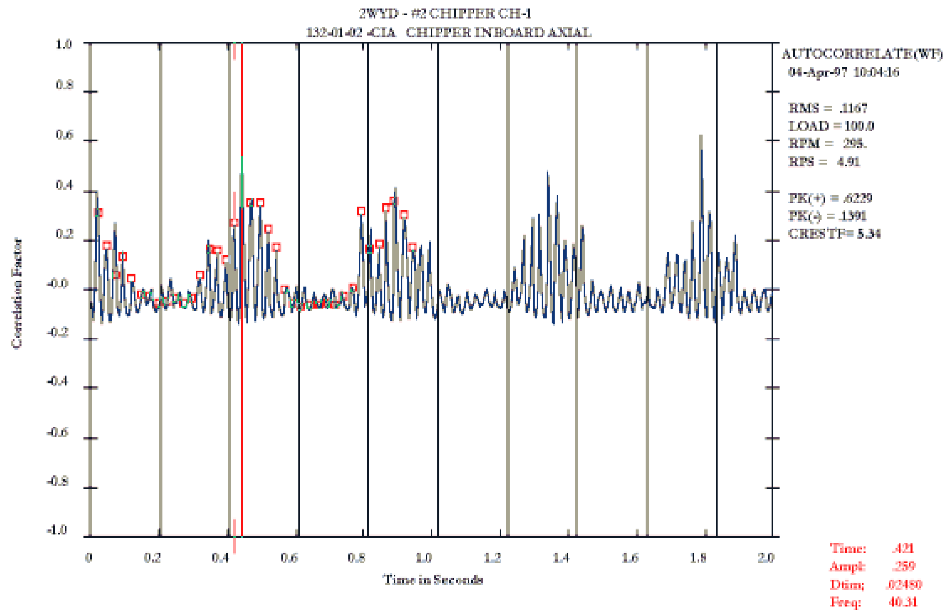


Figure 13. Autocorrelation coefficient from PeakVue time waveform of Figure 12.

A PeakVue data set was acquired at about the same time using a high pass filter of 2000 Hz. The resulting PeakVue spectra and time waveform are presented in Fig 12. The impacting level is near 20 g's and the cage and twice ball spin frequencies are dominant. This pattern is indicative of two impacts per revolution of the ball that is passing through the load zone at the cage repetition rate. From the PeakVue spectral data, it s not obvious whether the 38, 40.2, or 42.4 Hz peaks are representative of twice ball spin. The autocorrelation coefficient function data, presented in Fig. 13 clearly identifies the dominant activity is at 40.2 Hz which is twice the ball spin frequency. The autocorrelation coefficient data also clearly shows the defective ball going in and out of the load zone at the cage turning speed.

The root cause of this problem was found to be improper grounding of an electrical welder used during the recent outage.

When data was acquired on the inlet pinion shaft bearing on January 2, 1997, impacts in the 6 g range were detected with the PeakVue spectra showing ball spin fault modulated by cage. On February 9, 1997, the impacting level had increased to 9 g's. The PeakVue data are presented in Fig 14. The ball spin fault frequency is at 40.4 Hz and cage at 3.43 Hz. The autocorrelation coefficient is presented in Fig. 15 which emphasizes the cage and ball activity. A photo of the defective bearing is presented in Fig. 16.

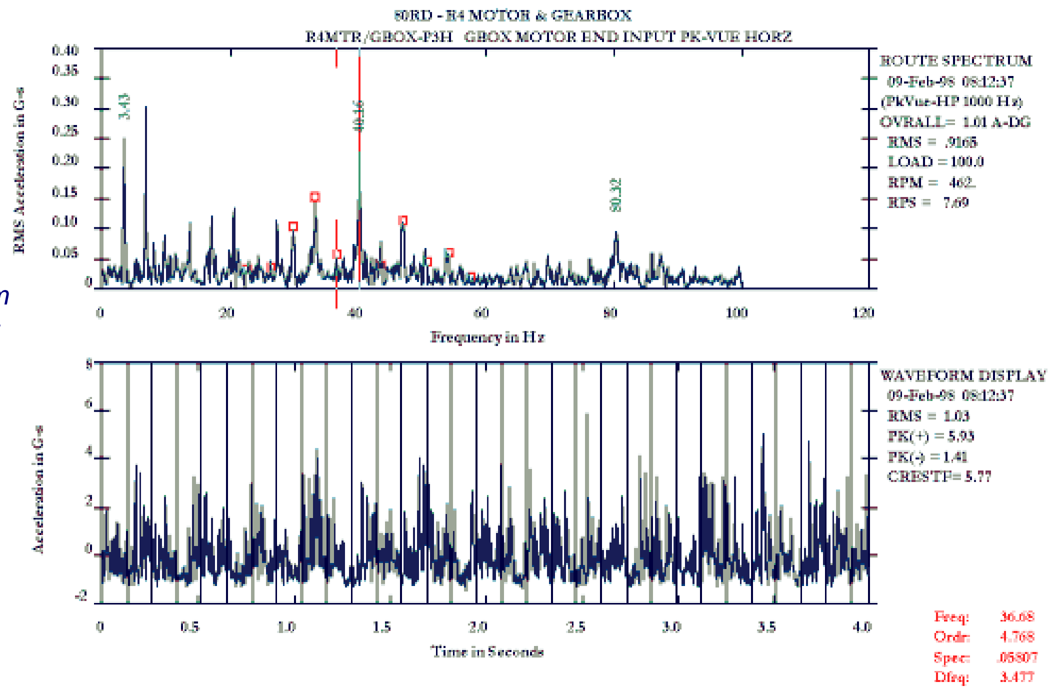


Figure 14. PeakVue Sspectra and time waveform from inboard pinion rougher gear box.

The bearing was replaced and PeakVue data acquired on February 12, 1997. The impacting level had decreased to less than 1 g. The normal vibration never showed any indication of a bearing problem.

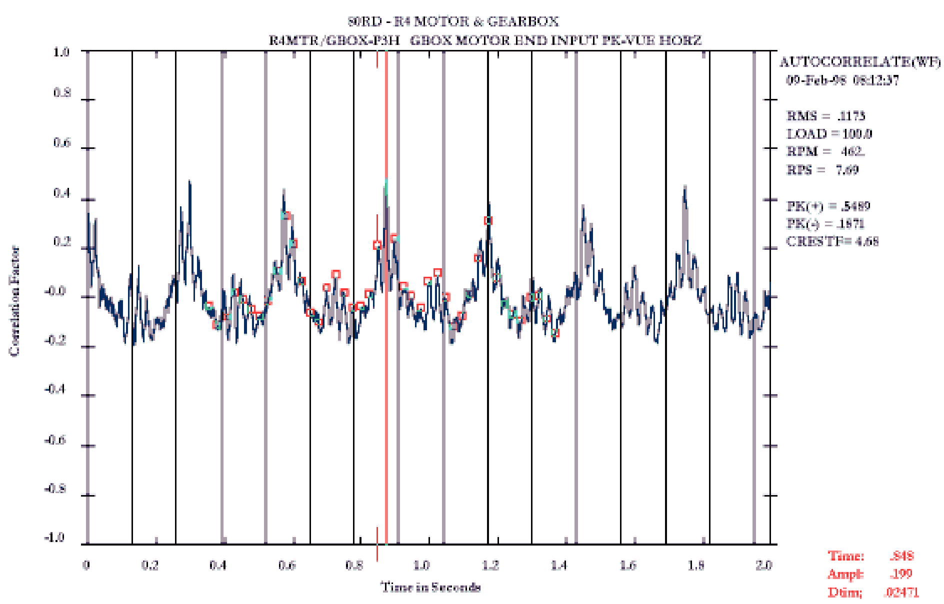
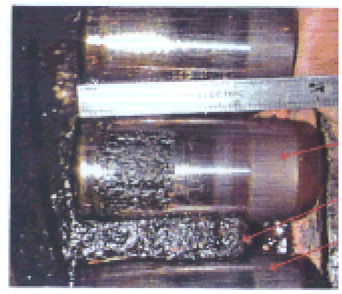


Figure 15. Autocorrelation coefficient from PeakVue time waveform of Figure 14.

Figure 16. Photograph of defective bearing highlighting the rollers.

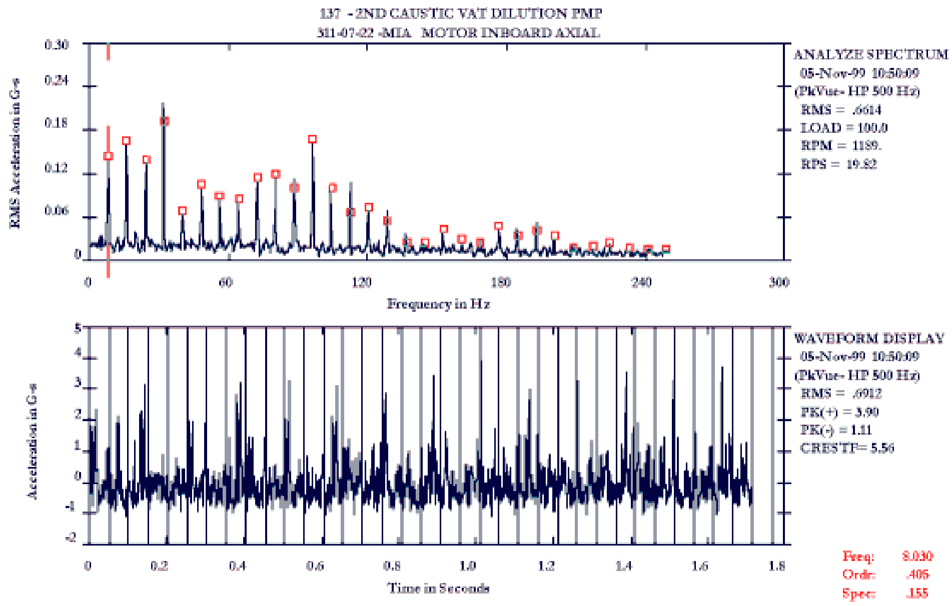


Cage and Other

When the cage frequency is present in the PeakVue spectral data, it may be indicative of problems other than cage. As seen in the previous section, cage frequency generally is present when a rolling element has a defect. This is postulated to be the case since the defective rolling element will pass through the load zone once per rotation of the cage. Cage frequency may also be present with other problems, e.g., lubrication related problems, heavily preloaded bearing, significant axial or thrust forces present, out of round inner race, et al. All these sources of cage activity have been observed more than once, but none have been observed sufficiently to state the presence of the specific problem will always manifest itself with cage activity in the PeakVue data. As examples, a lubrication problem as well as a suspected excessive thrust problem are presented below.

The PeakVue data from the inboard bearing on a motor (150 hp) directly driving a centrifugal pump are presented in Fig. 17.

Figure 17. PeakVue spectra and time waveform from Motor (Inboard Axial) driving direct coupled centrifugal pump.



The impacting levels are 5 g's which are not excessive for this speed machine but definitely indicative of a problem. The spectral data is dominated with cage and many harmonics. This is a NSK NU 318 bearing which has 13 rolling elements.

The autocorrelation coefficient data computed from the PeakVue time waveform are presented in Fig. 18. The only significant activity is the cage activity.

A photo of the defective bearing is presented in Fig. 19. The rolling elements show indication of "skidding," but the dominant problem is the "caked" residue of lubricant (grease).

This bearing is being replaced with a rolling ball element bearing. The problem of grease being "pushed out" is not uncommon with cylindrical rollers in low radial load applications.

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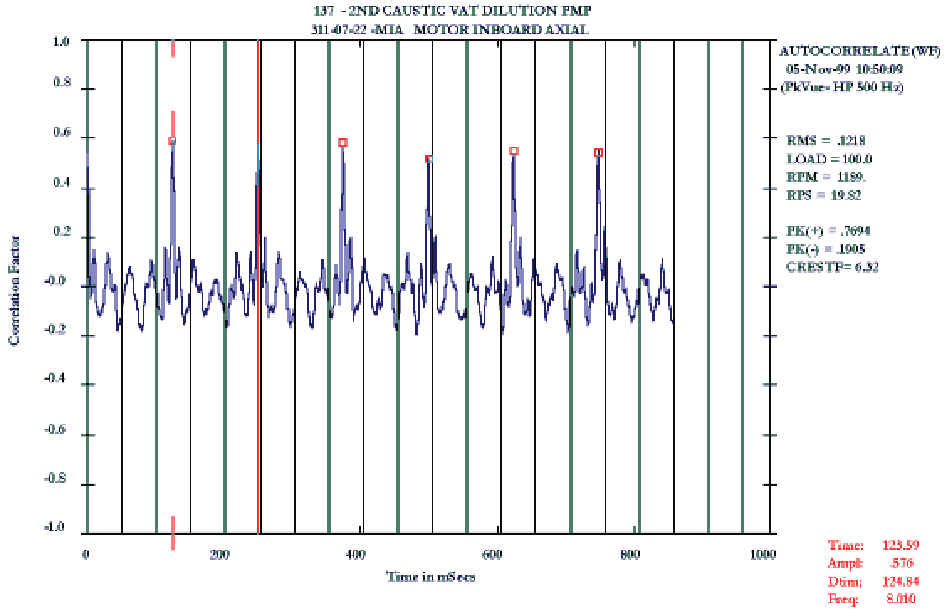

Figure 18. Autocorrelation coefficient from PeakVue time waveform of Figure 17.

Figure 19. Photography of the defective bearing highlighting the "caked" residue of lubricant and skid of roller 5.

The compressor from which data was acquired was a recent replacement of a unit that had experienced catastrophic failure (rotary had penetrated the housing). PeakVue and normal vibration data was acquired on the motor and on both ends of the two rotary screw elements. The normal data was typical of a smooth running rotary screw compressor.

The sensor (accelerometer) used was a 10 mV/g sensor attached to the surface via a rare earth flat magnet. The surface was not machined and the paint was not removed. The lack of surface preparation will attenuate the higher frequency energy getting to the sensor. For routine monitoring, the surface should be prepared at the places where the accelerometer should be mounted.

The PeakVue data taken with the sensor mounted vertically over the outbound bearing on the male 4 vane rotary screw are presented in Fig. 20. Given how the sensor was mounted, the 30 g peak impacts seen in the PeakVue time waveform are considered significant. The activity are primarily many harmonics of cage frequency. The autocorrelation coefficient data presented in Fig. 21 also identifies cage as the dominant source of the activity.

This type activity has been observed before in cases where a) lubrication problems are present, b) where heavy preloads are present, c) where out-of-round race ways are present, and d) where heavy thrust loads are present.

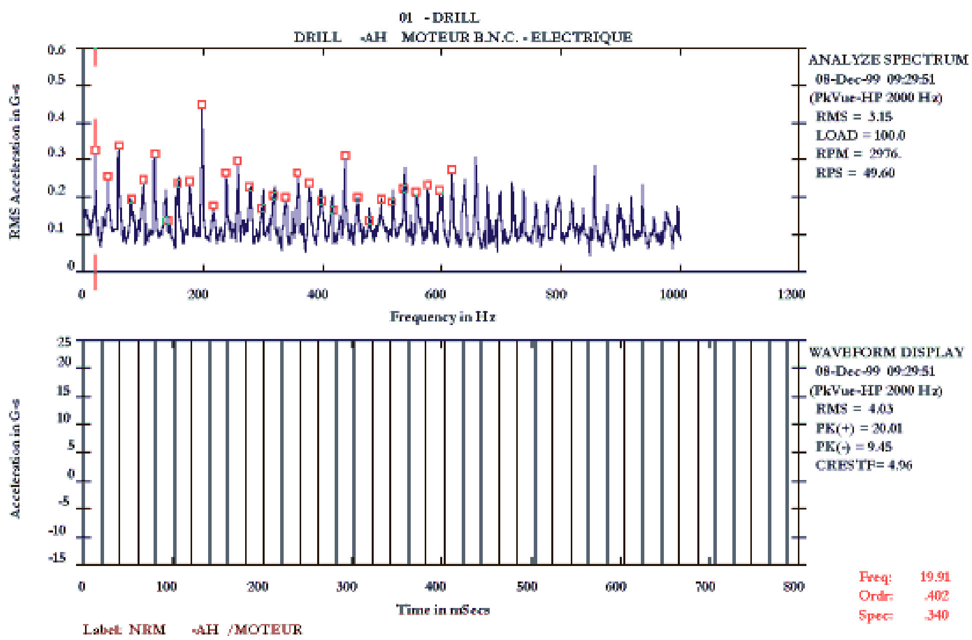

Figure 20. PeakVue Spectra and Time Waveform on the outboard bearing of the male rotor and simple stage compressor.

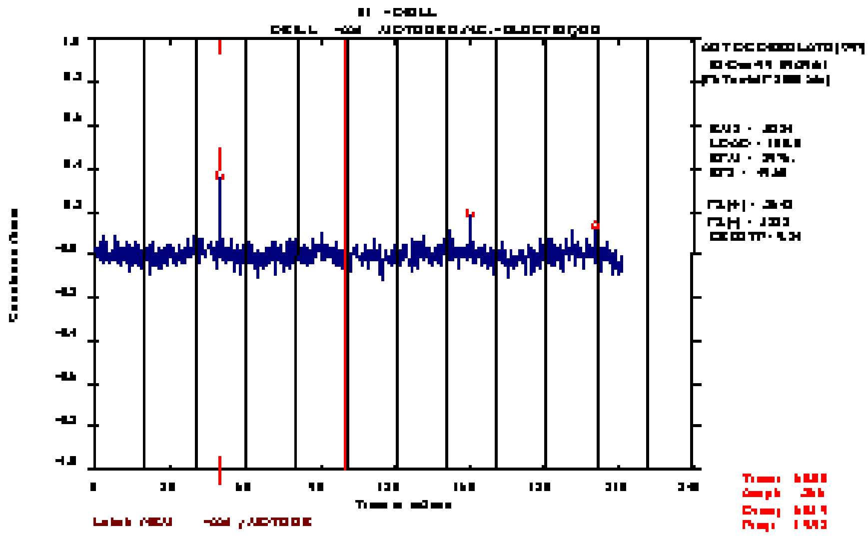

Figure 21. Autocorrelation coefficient from PeakVue time waveform of Figure 20.

Given the "newness" of this compressor and lack of similar activity on the female rotary screw, the lubrication problem is placed low on the suspected source. This leads to the conclusion that there could be excessive thrust for the bearing or out-of-round race way. In any event, cage activity generally is an indicator of a developing problem and should be trended closely.

Conclusion

The PeakVue methodology has proven to be a very useful tool for bearing defect detection in applications where normal spectral analysis has proven to be ineffective e.g., large gear boxes, slow speed machinery, etc. The PeakVue time waveform provides trendable information that can be classified as to the type of fault and speed of machinery. For example, detectable impact levels form an inter race defect will be a factor of two or so less than the detectable impacts levels form an outer race defect of the same severity level and machine speed. The impacts levels will decrease with speed of the machine at the rate of the square root to linear reduction of speed. As a rule of thumb, the ratio of speed to 0.75 power provides adequate adjustment for speed changes.

Impacting levels form defective inner race will generally be modulated with shaft turning speed. In a similar matter, rolling element defects will be modulated at the cage frequency.

Lubrication problems, heavily preloaded bearings, and excessive thrust often shows up in the PeakVue spectra as cage frequency with many harmonics.

The autocorrelation coefficient function provides useful assistance in identifying the dominant source (s) of periodicity in the PeakVue time waveform. The periodicity is identified in the PeakVue spectra but often have many harmonics which can mask the dominant source.

When bearing faults manifest themselves in both the PeakVue data and normal velocity spectral data, it is highly recommended that both methods be trended for fault severity specification.