SPIKE ENERGY MEASUREMENT AND CASE HISTORIES

By

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ABSTRACT

The early detection and fault analysis of rolling-element bearing problems are the primary reasons of using filtered high frequency analysis. Spike Energy measurement was developed in the late 1970's and has been used in various industries for machinery condition monitoring and fault diagnosis. As compared to other filtered high frequency enveloping methods, Spike Energy has a unique signal filtering and detection process. In addition to the traditional Spike Energy overall measurement, Spike Energy spectrum and Spike Energy time waveform have been developed and used for vibration analysis in recent years. In this presentation, the unique Spike Energy detection and signal processing are discussed. The Spike Energy measurement considerations and data interpretation are discussed in detail. Three case histories in bearing and pump applications are presented.

INTRODUCTION

Spike Energy measurement was originally developed to detect the signals emitted from defective rolling-element bearings. The term "Spike Energy" was used to describe the very short pulses, i.e., spikes, of vibratory energy generated by the impact of rolling-elements against microscopic cracks and spalls. Spike Energy is a measure of the intensity of energy generated by such repetitive transient mechanical impacts. These impacts or pulses typically occur as a result of surface flaws in rolling-element bearings, gear teeth or other metal-to-metal contacts, such as rotor rub, insufficient bearing lubrication, etc. The measurements showed that Spike Energy is also sensitive to other ultrasonic signals, such as pump cavitation, high pressure steam or air flow, turbulence in liquids, control valve noise, etc.

Spike Energy measurement utilizes an accelerometer to detect the vibration energy over a pre-determined high frequency range. The mechanical impacts tend to excite the mounted natural frequencies of the accelerometers as well as the natural frequencies of machine components and structures in this high frequency range. These resonant frequencies act as carrier frequencies and the bearing defect frequency modulates with the carriers. The intensity of impact energy is a function of pulse amplitude and repetition rate. The signal induced by such impacts can be measured by accelerometers and processed by a unique filtering and detection circuitry. The measured magnitude of the signal is expressed in "**gSE**" units (acceleration units of Spike Energy). Since its introduction, Spike Energy has been used successfully in many industrial applications and gained acceptance in various industries. Spike Energy measurement can provide early indications of machinery faults and is a very useful tool in vibration analysis. In addition to the traditional Spike Energy overall measurement, Spike Energy spectrum and Spike Energy time waveform were also developed and used in diagnostic analysis in recent years.

The Spike Energy measurement is inherently different as compared to the conventional vibration parameters, such as displacement, velocity or acceleration. In the conventional vibration measurements, the measured vibration signal is within the linear range of a transducer's frequency response curve. In the Spike Energy measurements, the Spike Energy frequency detection range is beyond the mounted resonant frequencies of most industrial transducers. Consequently, Spike Energy is sensitive to the transducer mounted resonant frequencies as well as mounting methods. It is important to understand such differences and to make proper selection of measurement parameters in order to obtain accurate and consistent measurement results.

In this paper, Spike Energy signal processing, especially its unique peak-to-peak detection and decay time constant features, is described in detail. The Spike Energy measurement considerations, including accelerometer mounting and data interpretation, are discussed. Four Spike Energy case histories in bearings and pump applications are presented.

SPIKE ENERGY SIGNAL PROCESSING

The flow chart of Spike Energy signal processing is shown in Figure 1. The vibration signal is measured by an accelerometer and filtered by frequency band pass filters. There are six selectable high pass corner frequencies, i.e., 100Hz, 200Hz, 500Hz, 1kHz, 2kHz and 5kHz. The low pass corner frequency is 65kHz, which is the upper limit of Spike Energy detection range. The purpose of using high pass corner frequencies is to reject low-frequency vibration signals, such as unbalance, misalignment and looseness. The amplitudes of defect frequencies of bearings and gears are usually much lower than those of low frequency components. Then, the filtered signal passes through a peak-to-peak detector, which not only holds the peak-to-peak amplitude but also applies a carefully selected decay time constant. The decay time constant is directly related to the spectrum maximum frequency (Fmax). The output signal from Spike Energy peak-to-peak detector is a saw-tooth shape signal. This signal is further processed to calculate Spike Energy overall magnitude as well as spectrum.

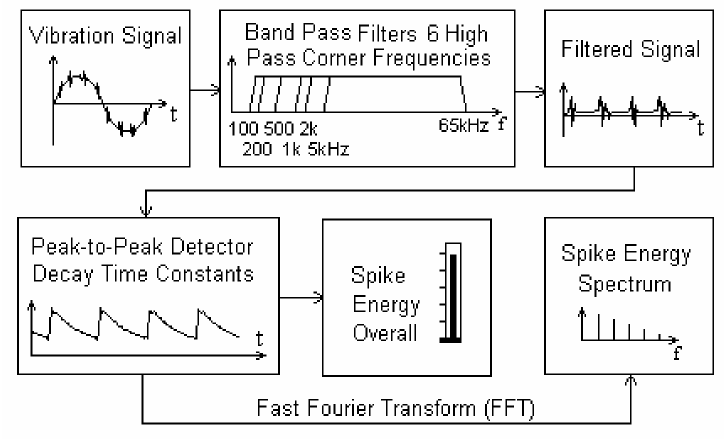
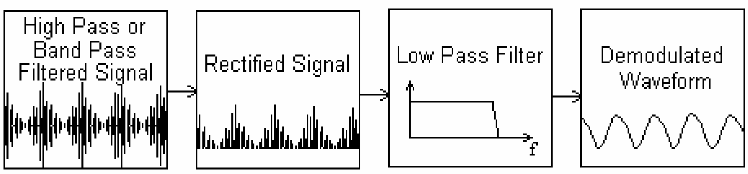


Figure 1. Flow chart of Spike Energy signal processing

The peak-to-peak detector in gSE circuit is unique and very sensitive to the defect frequency as compared to other envelope detection or demodulation method. A typical envelope detection processing is shown in Figure 2. In an envelope detection, the vibration signal is first passed through a high pass (or band pass) filter. The filtered signal is full wave (or half wave) rectified. Then, the rectified signal is passed through a low pass filter to separate the modulation (or defect) frequency from the carrier frequency. The low-pass filtering has an averaging effect on the rectified signal and the peaks are smoothed in the demodulated waveform. In contrast, Spike Energy detection circuit preserves the severity of defects by holding the peak-to-peak amplitude of the impulses. It also enhances the fundamental defect frequency and its harmonics by applying a proper selected decay time constant. The Spike Energy peak-to-peak detection is further illustrated in Figure 3.

Figure 2. Flow chart of enveloping (or demodulation) processing



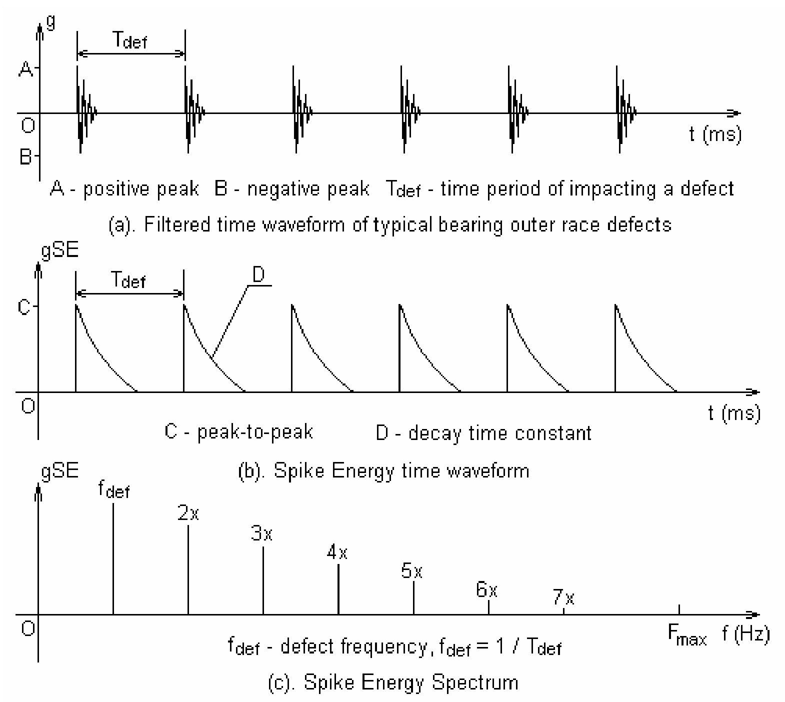


Figure 3. Spike Energy peak-to-peak detection

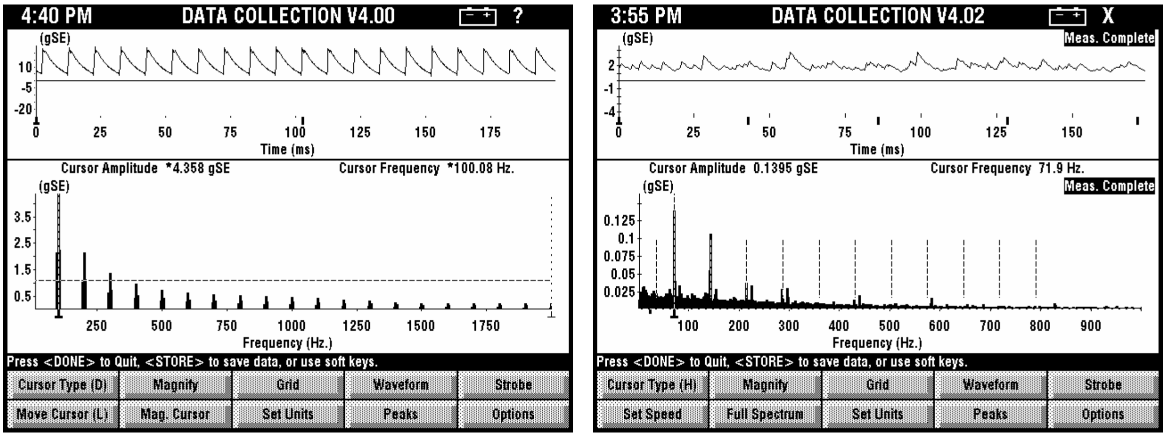
The decay time constant in Spike Energy measurement is a function of measured maximum frequency (Fmax) and it is automatically selected by either the instrument or host software. The decay time constant determines the shape of the saw-tooth signal from the Spike Energy peak-to-peak detector. In turn, it affects both the overall magnitude of Spike Energy and the harmonic terms in a Spike Energy spectrum. In order to obtain consistent Spike Energy overall readings, only one fixed decay time constant is used for the gSE overall measurement in both the instrument and host software. In Spike Energy spectrum measurement, smaller decay time constant is selected for higher frequency measurements since the defect impulse occurs more rapidly and the period of impact is more evident by using a shorter decay time constant.

The measured Spike Energy time waveform and spectrum are shown in Figure 4(a) and 4(b). The input signal for Figure 4(a) was from a signal generator with defect frequency at 100Hz. The Spike Energy time waveform shows a regular pulse train and exponential decay for each pulse. In this particular case, the decay time constant was selected so that the pulse decays to almost zero before the next pulse. The Spike Energy spectrum shows a typical defect frequency and its harmonics. The gSE time waveform and spectrum in Figure 4(b) were measured from a machine tool spindle. In Figure 4(b), the peak-to- peak detection and decay time constant are evident in the real machine gSE waveform. The defect frequency at 71.9Hz and its harmonics appeared in the gSE spectrum. In applications, the Spike Energy peak-to-peak amplitude can be determined from time waveform. For example, the peak-to-peak amplitude for Figure 4(b) was about 3.5 gSE pk-pk.

MEASUREMENT CONSIDERATIONS

Accelerometers and Mounting Methods

Spike Energy is a high frequency measurement and its readings can be affected by accelerometers and mounting conditions. Different accelerometers have different construction and natural frequencies. The mounted resonant frequencies of industrial accelerometers have wide range, generally between 10kHz and50kHz, depending upon transducers' construction and mounting. For displacement, velocity and



(a). Signal generator data (b). Spindle data

Figure 4. Spike Energy time waveform and spectrum

acceleration measurements, the results are usually consistent and repeatable regardless which transducer is used provided that the measurement is made within the transducer's linear frequency range. For Spike Energy measurement, the results very much depend on the transducer's mounted resonant frequency because most industrial accelerometers' mounted resonant frequencies are within the Spike Energy frequency detection range. As a result, the Spike Energy readings can be different if different accelerometers are used unless the accelerometers have exactly the same frequency response characteristics. This is, of course, a rare case. Therefore, it is necessary to always use the same accelerometer when collecting Spike Energy data to ensure the consistency. For the same reason, it is meaningless to compare the Spike Energy readings of one accelerometer to another and no attempt should be made to relate Spike Energy readings of different accelerometers.

Spike Energy measurement also requires more stringent transducer mounting as compared to other vibration parameters. This is due to the fact that different mounting methods can result in different mounted resonant frequencies. The best mounting method for collecting Spike Energy data is stud mounting. In this case, there is only one interface, i.e. accelerometer-to-machine. It allows more transmission of high frequency signal and obtains the most consistent results. Hand-held probes should not be used for Spike Energy measurement because they result in a significant loss of high frequency signal due to their low mounted resonant frequencies. It is a common practice to use magnet holders for quick periodic checks. There are two interfaces in this particular case, i.e., accelerometer-to-magnet and magnet-to-machine. In order to minimize the loss of high frequency vibration signals in the transmission path, the contact surfaces must be flat, clean, bare and free of rust and paint. The use of a light coating of silicon grease or lubrication oil between the interfaces will improve the transmissibility of high frequency vibration signals. For stud mounting, the threaded holes should be perpendicular to the mounting surface. The length of the stud should be shorter than that of the holes to allow direct contact between the accelerometer and the mounting surface. The cable connector should be sufficiently tightened to the accelerometer to prevent from rattling and producing erroneous readings. If the accelerometer is stud-mounted on a moving component of the machine, the extension cable should be attached to the component or the machine to minimize cable movements during the measurement. For magnet mounting, the magnet pole pieces should be free of dents, foreign materials and broken edges. Excellent surface contact from machine surface through any interfaces to the accelerometer is essential to obtain accurate and consistent Spike Energy data.

Figure 5 and Figure 6 illustrate the mounted resonant frequencies of different accelerometers and mounting methods. The frequency response curves of two accelerometers are shown in Figure 5. [1] Curve A and C are Rockwell Automation's Entek IRD Model 943 accelerometer and curve B is Rockwell Automation's Entek IRD Model 970. The accelerometers used for curve A and B are stud mounted on a shaker table and shaken at 1g with frequency sweeping from 0 to 50kHz. The stud mounted resonant frequency of the 943 appears at 22.75kHz with a large amplitude. The 970 has two smaller resonant frequencies at 31.25kHz and 32.50kHz.

Curve C is the same accelerometer used for curve A. The only difference is the mounting method. As compared with stud-mounted 943, magnet-mounted 943 has two lower resonant peaks at about 12.50kHz and 18.00kHz. The Model 943 also has a resonant frequency at about 32.00kHz.

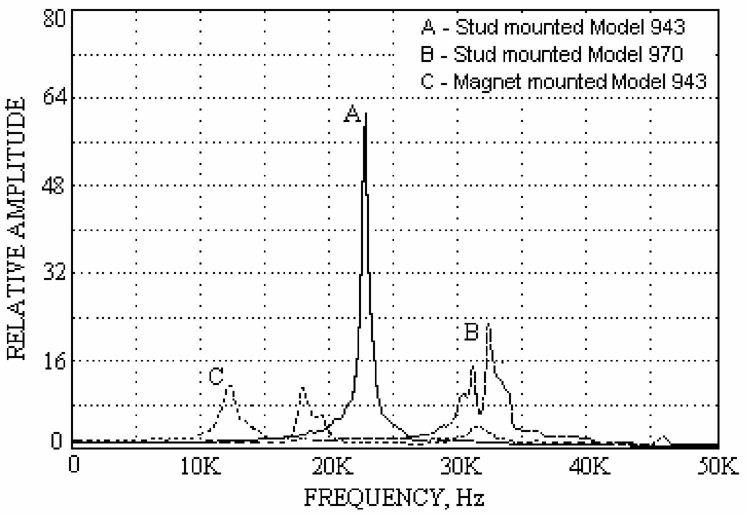
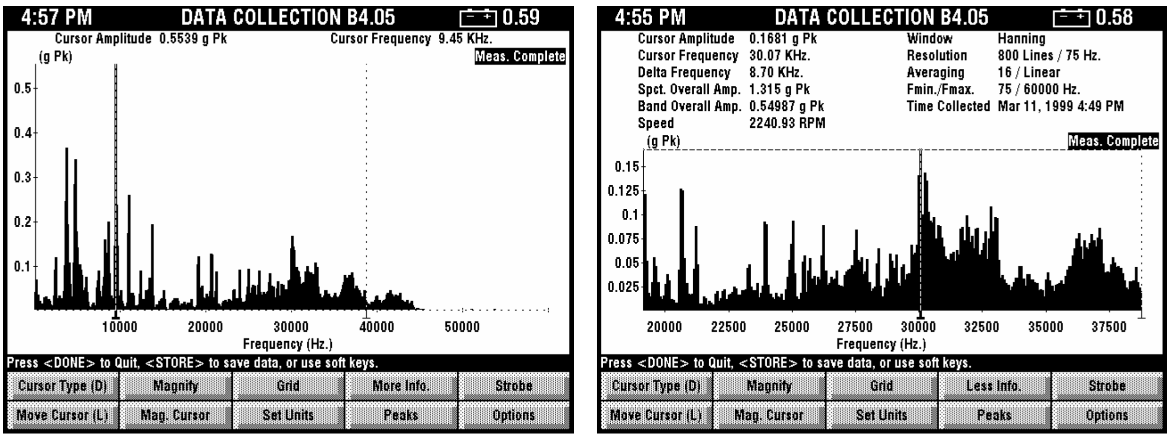


Figure 5. Frequency response of accelerometers [1]

The acceleration spectra of magnet mounted Model 943 measured from a belt-driven spindle are shown in Figure 6(a) and 6(b). Figure 6(a) is a broadband spectrum from zero to 60kHz. In this particular case, the high frequency contents were measured up to about 45kHz. There were almost no measurable frequencies beyond 45kHz due to the frequency limitation of magnet mounting. The large amplitude at 9.45kHz is the mounted resonant frequency of Model 943 accelerometer with the magnet holder. In this case, the two pole pieces had less than perfect surface contact with the spindle nose due to the curvature, which slightly lowered the mounted resonant frequency as compared to curve C in Figure 5. The zoomed-in spectrum in Figure 6(b) showed several peaks and haystack between 30kHz and 33kHz. This is the resonant frequency of Model 943 accelerometer, which was the small peak on curve C in Figure 5 at about 32kHz. These mounted natural frequencies of accelerometers are excited by the impacts of bearing flaws or other defects. The mounted resonant frequencies act as carrier frequencies for the defect frequencies. Since the mounted resonant frequencies vary with different



(a). Broadband spectrum with Fmax = 60kHz (b). Zoomed-in spectrum around 30kHz

Figure 6. Acceleration spectra of spindle vibrations measured by magnet mounted Model 943

accelerometers and mounting methods, the impact induced resonances occur at different frequencies and amplitudes. This will result in different Spike Energy readings.

Applications and Data Interpretation

In machinery condition monitoring applications, the most meaningful use of Spike Energy is to **trend** Spike Energy readings. Since Spike Energy is a high frequency vibration measurement, it is sensitive to machine dynamic characteristics, type of accelerometers, mounting conditions and measurement locations. In order to obtain consistent Spike Energy readings, it is important to always use the same accelerometer, the same mounting method, and the same measurement location on the machine. Lack of attention to these details may produce large differences in Spike Energy readings.

Depending upon machine dynamic characteristics, certain type of machines can be monitored largely based on trend overall Spike Energy magnitudes. One such application is the monitoring of sealless pumps [2, 3]. There are two types of problems associated with sealless pump operations. One is process related problems, such as dry running, cavitation, flow change, and internal recirculation. The other type is mechanical problems, such as rotor rub, excessive wear of thrust bearing and journal bearing. Conventional vibration measurements, such as velocity and acceleration, have not been very successful in the past to detect these problems because the internal rotor mass of a sealless pump is relatively small as compared to the rest of the pump. The internal processing fluid often creates confusing vibration signals to further complicate the problem. In contrast, Spike Energy is able to detect both mechanical and process related problems. The relationship between patterns of trend overall Spike Energy magnitudes and the sealless pump problems was established via experiments. As a result of Spike Energy monitoring, damage to sealless pumps has been consistently eliminated and the cost of pump overhauls and downtimes were reduced substantially.

In most applications, Spike Energy alone is not sufficient to judge machine conditions. Other vibration parameters, such as acceleration, velocity or displacement, should be used in conjunction with Spike Energy measurement. When Spike Energy readings are taken, one or more other parameters should also be taken at the same time so that the correlation between them can be established over time. When the trends of Spike Energy increase, it usually indicates that the problems of bearings, gears or other components may start to develop. It is not necessary to schedule repair at this time if other vibration parameters are still in an acceptable level. However, it is time to pay attention to the trends of acceleration and velocity. If acceleration readings exceed the allowable vibration limits but velocity readings are still acceptable, vibration spectrum analysis should be performed to confirm the problem and repair should be scheduled at a convenient future time. If velocity, acceleration and Spike Energy readings all exceed the allowable levels, the machine is approaching the end of its useful life. Sometimes, Spike Energy readings may decrease and, just prior to failure, increase again to excessive values. At this point, it is recommended to shutdown the machine to prevent the damage.

For conventional vibration overall measurements, there exist a number of general machinery vibration severity charts developed through the years. However, it is almost impossible to develop a universal overall level Spike Energy severity chart for general machinery applications. This is due to the fact that too many variables involved, such as different machine types, operating conditions, accelerometers, mounting methods, and ambient conditions. On the other hand, it is possible to develop an overall Spike Energy severity chart based upon empirical data for certain type of machines. The measurement conditions should be specified in the chart to ensure meaningful interpretation. One such chart [4] was developed in the past for ball bearing machine tool spindle application. In this particular case, the chart applies to the data taken from ball bearing machine tool spindles operating at idle condition with Rockwell Automation's Entek IRD Model 970 accelerometer and 65 lb magnet holder. Any discrepancy in the measurement conditions may result in misinterpretation. This chart may not be applicable to other machines or measurement conditions.

Harmonics and sidebands are common phenomenon in a vibration spectrum. Harmonics are integer multiples of either the shaft running frequency or certain rotation related frequencies, such as vane pass frequency (number of vanes times shaft rotational speed) or gear mesh frequency (number of gear teeth times shaft rotational speed). Harmonics are produced either by an event that repeats itself several times during one revolution or by a distortion or truncation of a sinusoidal-type signal. The typical harmonics of shaft running speed caused by low-frequency excitations are filtered out by gSE high pass filters. Therefore, harmonics of the shaft rotational speed in a Spike Energy spectrum means that the shaft rotational speed is modulated with high frequency carrier, such as gear mesh frequency. It indicates the problems associated with high frequency carrier, for instance a gear riding on a bent shaft.

Sidebands are the frequency components equally spaced around a center frequency. In practice, the sidebands are rarely symmetric to the center frequency due to non-symmetry of the machine or component. The center frequency is also called the carrier frequency and it may be the gear mesh frequency, multiples of bearing ball pass frequency, resonant frequency of a machine component/structure, or mounted resonant frequency of accelerometer. The sidebands are called modulation frequency, which is induced by modulation of a signal. There are two basic types of modulations, namely amplitude modulation and frequency modulation. Amplitude modulation is a variation in amplitude of a constant frequency signal. Frequency modulation is a variation in frequency of a constant amplitude signal. In general, amplitude modulation is associated with the change of loading condition and frequency modulation is associated with the speed variation.

In rolling-element bearing applications, sidebands are usually one of the bearing defect frequencies and its multiples. The bearing defect frequencies include ball pass frequency - outer race (BPFO), ball pass frequency - inner race (BPFI), ball spin frequency (BSF) and fundamental train frequency (FTF). Bearing defect frequencies are non-synchronous frequencies. Amplitude modulation occurs in rolling-element bearings because the vibration amplitudes vary when the defects on inner race or rolling-elements rotate in and out of the bearing load zone.

In gear applications, sidebands are either the shaft rotational speed or one of its multiples (nxrpm). Amplitude modulations are present when a gear mesh having an eccentric gear or a gear riding on a bent or misaligned shaft. In this case, a cyclic loading pattern occurs due to periodically forcing the teeth into the mesh. A minimum and maximum meshing force occur once per shaft revolution. As the eccentricity increases, the sideband amplitudes will increase. If gear has local fault that is associated with individual gear teeth or a small group of teeth, gear vibrations occur when the defect teeth are in mesh. Local gear faults include tooth space error, cracked or broken tooth, tooth surface damage, and hunting tooth problems. If there is a local gear fault, the gear angular velocity could change as a function of the rotation. As a result of the speed variation, frequency modulations occur that generate many sideband pairs.

In many cases, both amplitude and frequency modulation often coexist. For example, frequency modulation may also occur in the case of a gear riding on a bent shaft because the tooth space measured on the pitch circle will vary when the shaft is bent. In practice, sidebands are rarely symmetric with respect to the carrier frequency due to the non-symmetry of the loading condition as well as non-symmetric design of gear-shaft system. Since the modulating frequencies are caused by certain bearing, gear or other machine component faults, Spike Energy spectrum is very useful to diagnose these machinery faults.

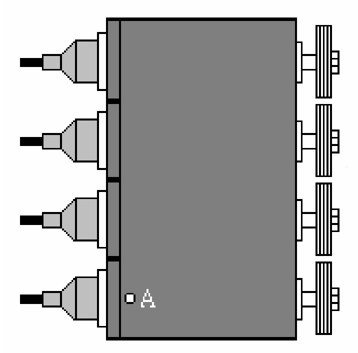
CASE HISTORIES

Four case histories in bearing and pump applications are presented. The first two cases were spindle bearing applications and showed how to use the Spike Energy measurement in fault diagnosis. The third case history was a centrifugal pump bearing application and showed the use of both velocity spectrum and Spike Energy spectrum to analyze pump bearing defects. The last case history dealt with sealless pump applications and showed strong correlation between the axial rotor position measurements and Spike Energy measurements.

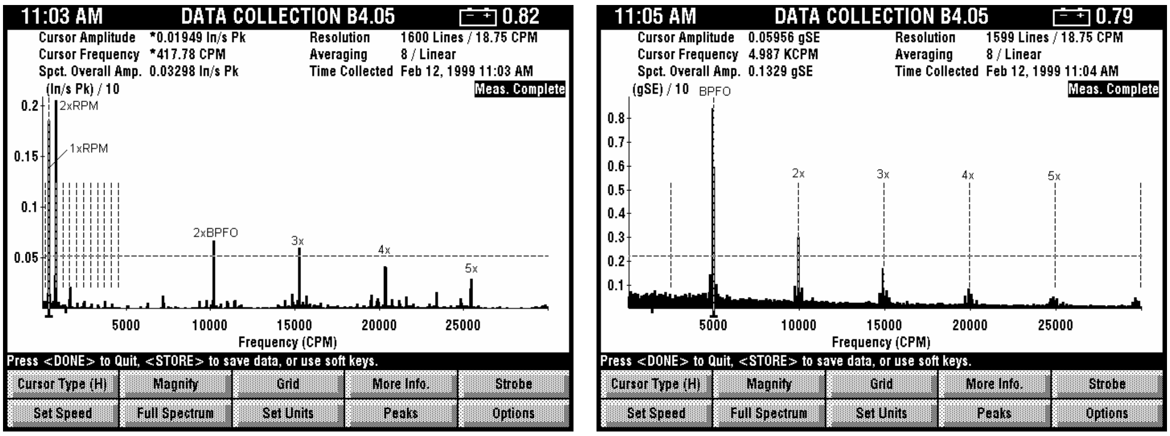
Case History I

The first case history deals with a four spindle cluster, as shown in Figure 7. This equipment is used for semi-finish boring operation. The box spindles are belt-driven and the bearings are ultra-light ball bearings. The spindle shaft running speed was about 417RPM. Spike Energy data were measured at the front bearing of the lowest spindle in the horizontal direction, i.e., location A shown in Figure 7.

Figure 7. Schematic of a four spindle cluster



The measured velocity spectrum and Spike Energy spectrum are shown in Figure 8(a) and 8(b). The velocity spectrum had a larger amplitude of 2xrpm than that of the 1xrpm, which typically indicates that the bearing lost its preload. [5] In this particular spindle, the loss of preload was due to bearing wear. The velocity spectrum also showed the multiples of ball pass frequency - outer race (BPFO). Although the 1xBPFO was not evident in the velocity spectrum, the bearing outer race defect was clearly showed on the Spike Energy spectrum. As shown in Figure 8(b), the bearing outer race ball pass frequency and its harmonics showed clearly in the gSE spectrum and this is a typical Spike Energy spectrum with a bearing defect. In this case, both velocity spectrum and Spike Energy spectrum identified the bearing wear and outer race problems.

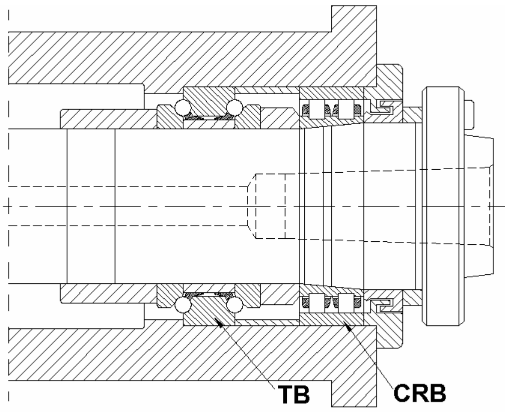


(a). Velocity spectrum (b). Spike Energy Spectrum

Figure 8. Measured spindle vibration data

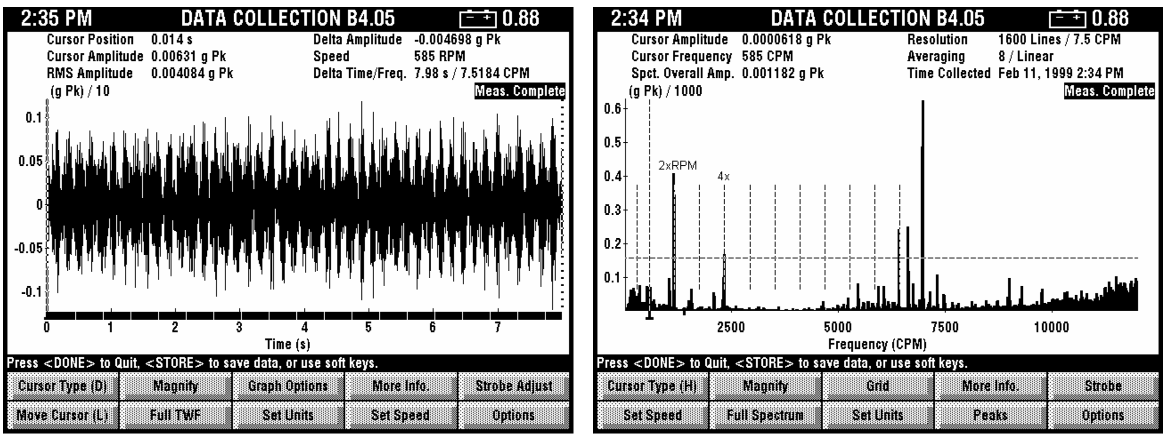
Case History II

The second case history shows the changes of bearing preload occurred in a new spindle during a test run. The spindle's front bearing configurations are shown in Figure 9. In this case, two bearings were used in the front end of the spindle, i.e., a tapered bore high-precision cylindrical roller bearing (CRB) and a double direction angular contact thrust ball bearing (TB). The double row cylindrical roller bearing is used for heavy radial loads to provide high radial load capacity and dynamic stiffness for machining. The double direction angular contact ball bearing is used to locate the spindle axially in both directions when the spindle is subjected to axial loads.

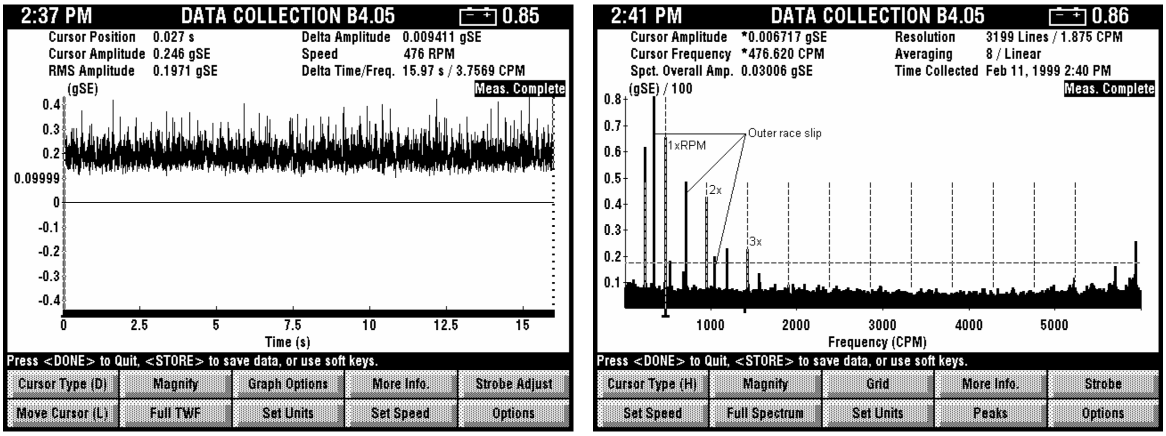


TB – Double direction angular contact thrust ball bearing
CRB – Cylindrical roller bearing
Figure 9. Spindle front bearing arrangements

In order to obtain sufficient dynamic stiffness and maximum running accuracy, the spindle bearings should be properly preloaded when mounted. [5] The cylindrical roller bearing has a tapered bore (taper 1:12) so that certain radial internal clearance or preload can be achieved by axial adjustment when mounting the bearing. The magnitude of the operational clearance or preload in a bearing depends on the running speed, load, lubrication and required dynamic stiffness. It also depends on the accuracy of the bearing seating. When setting the preload, temperature conditions in bearing should also be taken into account because the temperature increases or thermal growth will result in a reduction in clearance or an increase in preload. The tapered bore cylindrical roller bearing was difficult to set for proper bearing preload. It requires the use of special gauges to measure and, sometimes, mistakes are made even when the gauges are available. In this particular case, the bearing preload was purposely set a bit lower than manufacturer's recommended level to facilitate a higher operating speed. The acceleration and Spike Energy were measured during the test run. The measured time waveform and frequency spectrum at different spindle running speed are shown in Figure 10 through Figure 12.

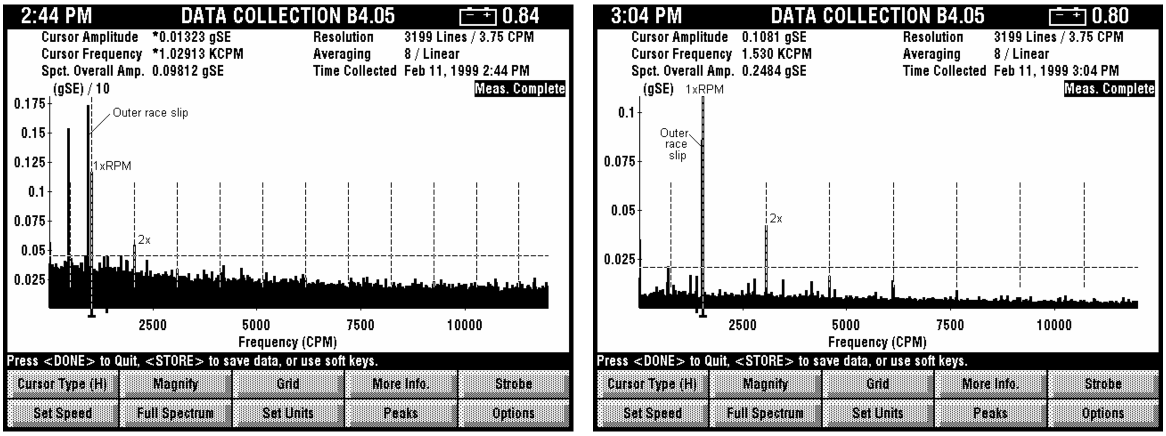


(a). Time waveform (b). Frequency spectrum
Figure 10. Acceleration measurements at 585 RPM



(a). Time waveform (b). Frequency spectrum

Figure 11. Spike Energy measurements at 476 RPM



(a). Measured at 1029RPM (b). Measured at 1530RPM

Figure 12. Spike Energy spectra

The time waveform and frequency spectrum in Figure 10 and Figure 11 were measured at a low spindle running speed, i.e., around 500RPM. Both the acceleration time waveform and Spike Energy time waveform showed pulsations caused by impacts, but the amplitudes were very low (less than 0.12g pk and 0.4 gSE pk-pk). The acceleration spectrum in Figure 10(b) showed high 2xRPM and 4xRPM component, which may suggest looseness-type problem. The spectrum also showed an amplitude of 0.6g pk at about 6875 CPM, which may be one of the bearing defect frequencies. The Spike Energy spectrum in Figure 11(b) showed clearly the frequency component at about 0.7xRPM and its harmonics (2x and 3x). Erratic phase readings were observed when phase measurement was made during the test run, indicating the heavy spot on the spindle shaft was moving. In this particular case, this sub-synchronous frequency was due to the bearing outer race slipping. The bearing inner race was hydraulically pressed onto spindle shaft and its position was measured by the gauge. The outer race was put into the bearing housing by heating the housing to 40^0C. The incorrect preload caused outer race slip problem. In addition to the slipping frequencies, the spindle 1xRPM running speed and harmonics also showed in the gSE spectrum due to the impacts of bearing outer race.

The outer race slip was reduced because of thermal growth when the spindle was running at a higher speed, as shown in Figure 12. At 1029RPM, the outer race gained speed to within 7.5 CPM of the spindle speed because the outer race's thermal expansion. In order to resolve the frequencies in the gSE spectrum, high frequency resolution, i.e., 3200 frequency lines in the spectrum, was used. As shown in Figure 12(a), the outer race slip frequency and half spindle running frequency still appeared but the harmonics of slip frequency disappeared.

The outer race slip was almost stopped when the spindle speed increased to 1530RPM, as shown in Figure 12(b). In this particular case, the speed difference between the spindle shaft and the outer race was within 3.75 CPM. If the data was taken with frequency resolution less than 3200 lines, the speed difference can not be identified. This case history showed that Spike Energy is a very useful tool in machine diagnostic analysis. The outer race slip problem was not evident in the acceleration spectrum but showed clearly in the Spike Energy spectrum. The phase measurement is also important in this case to verify the problem.

Case History III

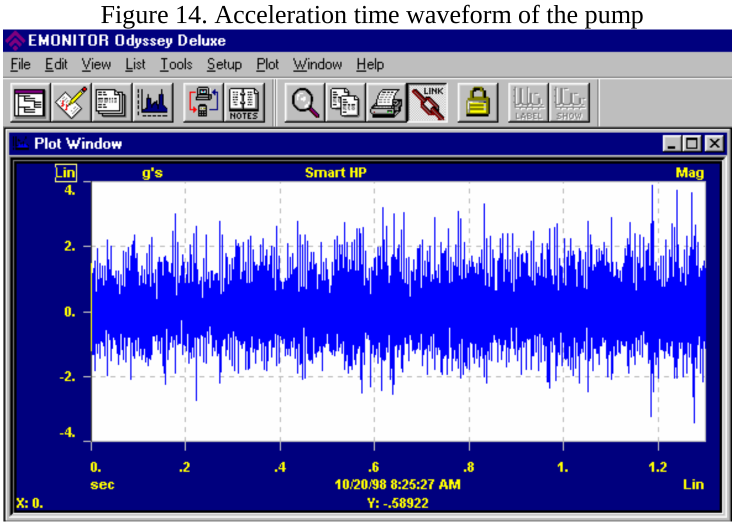
This case history concerns with a centrifugal pump used in a chemical processing plant. The pump unit consists of a vertical motor coupled to a vertical pump, as shown in Figure 13(a) and Figure 13(b). The running speed of the pump was 3575RPM. The vibration was measured on the pump frame close to the bearing. The data was taken by using Entek IRD Model 9000A accelerometer with magnet mounting.

(a). Motor-pump (b) Close view of the pump

Figure 13. Vertical pump unit

The measured time waveform of acceleration is shown in Figure 14. In this case, the impact was obvious and the amplitude was quite large at about 4 g pk. In fact, this pump was very noisy when it was running.

Figure 14. Acceleration time waveform of the pump



The measured Spike Energy overall was also high at 5.11 gSE indicating high impacts. The pump bearing defect was clearly identifiable in the velocity spectrum and Spike Energy spectrum, as shown in Figure 15 and Figure 16. In the velocity spectrum, the higher order harmonics of ball pass frequency – outer race (BPFO) were the main defect frequency peaks in the spectrum. The cage frequency or fundamental train frequency (FTF) was the sideband frequency around some of the high BPFO amplitudes. In the Spike Energy spectrum, harmonics of the FTF and BPFO were evident as defect frequencies. In this particular case, the pump bearing defect was captured by the periodic vibration measurements.

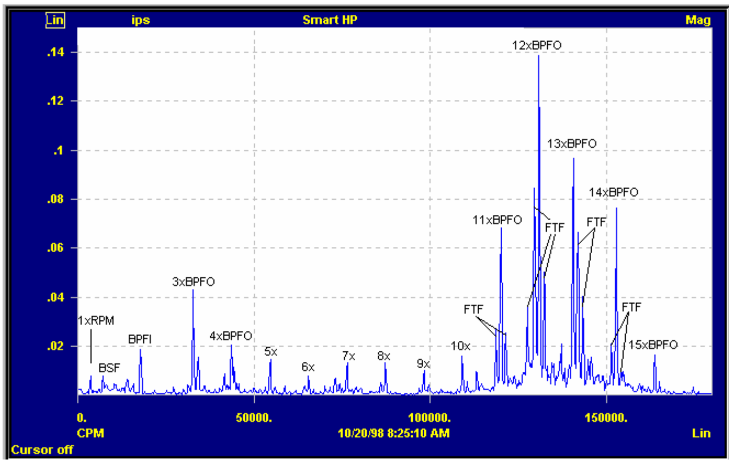


Figure 15. Velocity spectrum of the pump

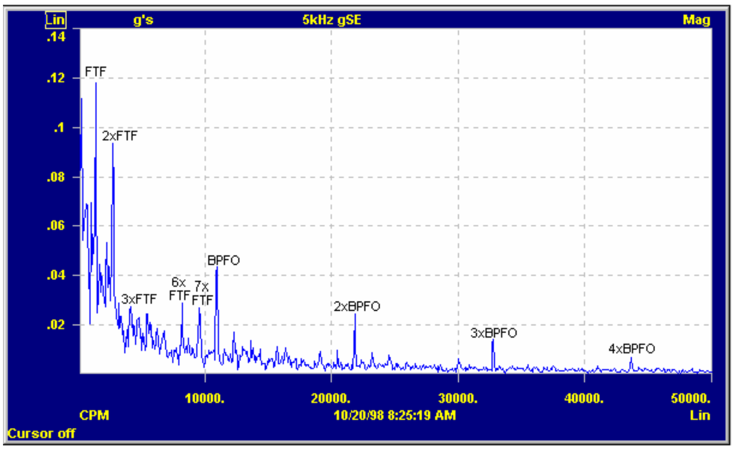


Figure 16. Spike Energy spectrum of the pump

Case History IV

The last case history discusses some test results of monitoring sealless pump using Spike Energy overall measurements. [3] Figure 17 shows the cut-section of a canned motor type sealless pump. [2] The canned motor pump has one rotating shaft that is an electric motor rotor with an impeller mounted on the shaft. The motor and pump casings are sealed such that there are no shaft penetrations, which is different as compared to conventional mechanical sealed pumps. The stator and motor rotor are protected from the processing fluid by a nonmagnetic containment shell. The rotor is supported by journal bearings. A portion of the pumped fluid is circulated to the motor to provide cooling and bearing lubrication.

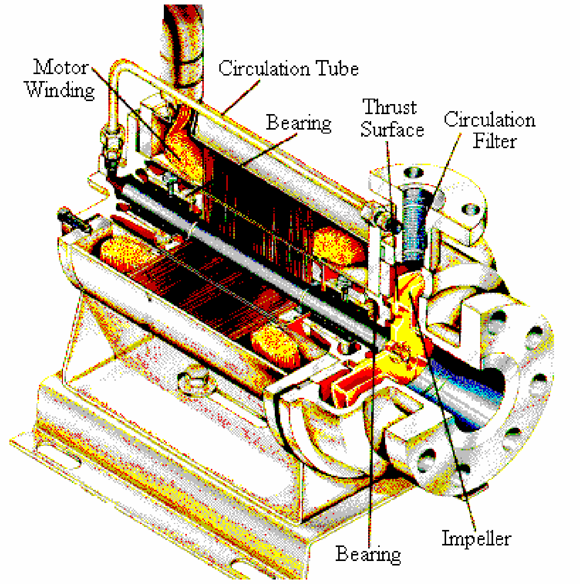


Figure 17. Canned motor design of sealless pump [2]

The size of canned motor pump used in the test was 3x1½x6 and the running speed was 3450RPM. The test pump was equipped with the manufacture's rotor position monitoring device, which monitors both axial and radial rotor position. Spike Energy overall was measured by Rockwell Automation's Entek IRD Model 911 accelerometer and the signal was processed by Rockwell Automation's Entek IRD Model 5802 Machine Monitor. The accelerometer was stud mounted on the head of a bolt that attached the pump casing to the main housing of the pump. [3] During the tests, the pump was subjected to fault conditions to simulate plant operation. The test results are shown in Figure 18 and Figure 19.

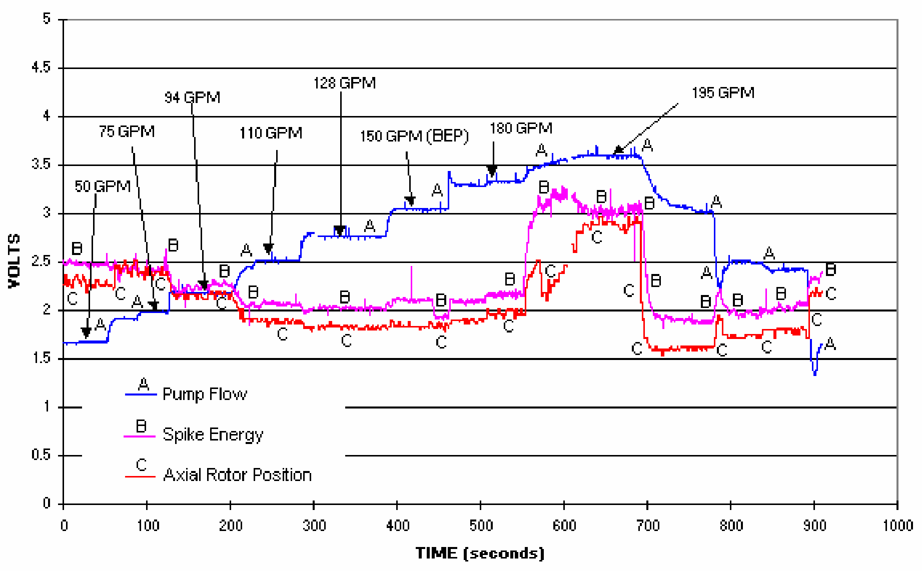


Figure 18. Flow changes (20 GPM increments) [3]

The testing data indicated a direct correlation between the axial rotor position measurements and the Spike Energy overall readings. Figure 18 showed the changes in measured data as a result of variation in flow over the range of 50 gallons per minute (GPM) to 190 GPM. When capacities (GPMs) greater than the best efficiency point (BEP) at 150 GPM, the rotor began to move toward the suction flange of the pump and Spike Energy began to move up and increase in width. The trend curves became wider in both rotor position and gSE as the fluid flow and rotor position responded to the changes in pumping conditions. Wider traces of both gSE and axial rotor position indicate abnormal operating conditions and should be avoided in pumps, especially in sealless pumps.

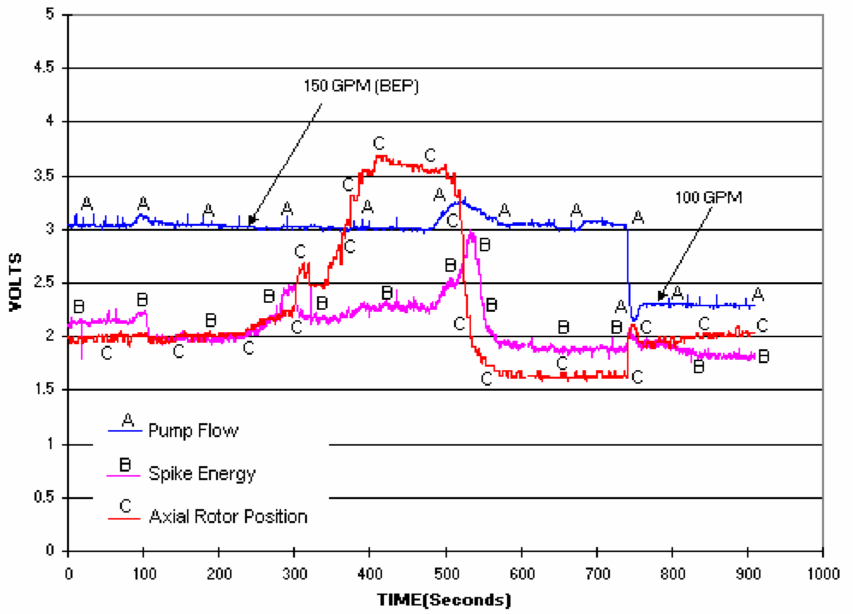


Figure 19. Reduced suction pressure (at constant 150 GPM) [3]

The test result of low suction pressure induced cavitation is shown in Figure 19. In this particular case, the suction pressure was reduced with the pump capacity held at a constant 150 GPM to observe the effects on both the axial rotor position and Spike Energy. As shown in Figure 19, the axial rotor position moved dramatically toward the suction flange as the suction pressure was reduced. Spike Energy overall increased with a widening trace width. When suction pressure was reestablished at atmospheric normal, the rotor moved back to its normal run position and the Spike Energy also returned to its normal level. Both test cases showed clear correlation between the changes in axial rotor position and Spike Energy. For sealless pump applications, continuous monitoring of both Spike Energy and rotor position will improve the reliability in determining pump operating conditions as well as the accuracy in pump fault diagnosis.

CONCLUDING REMARKS

Spike Energy measurement is a valuable tool in machine condition monitoring and fault diagnosis. The Spike Energy circuit has unique peak-to-peak detection and decay time constant features in its signal processing. As compared to other bearing defect detection processing, such as enveloping detection, Spike Energy detection not only preserves the severity of defects but also enhances the fundamental frequency of the defects. Since most industrial accelerometers' mounted resonant frequencies are within the Spike Energy frequency detection range, Spike Energy measurement is sensitive to types of accelerometers and mounting conditions. In order to obtain consistent Spike Energy measurement results, the following are important:

- The best mounting method for collecting Spike Energy data is stud mounting. To ensure consistency, the same accelerometer, the same mounting method and the same measurement location should always be used.

No attempts should be made to compare and relate Spike Energy readings under different measurement conditions. In most applications, Spike Energy alone is not sufficient to judge machine conditions. Other parameters, such as velocity and acceleration, should be used in conjunction with Spike Energy. Spike Energy severity chart can only be used when the machine type and measurement conditions match those specified in the chart.

• The most meaningful use of Spike Energy is to trend Spike Energy overall readings. The relationship between certain type of machinery faults and trend overall Spike Energy patterns can be established over time. Depending upon machine dynamic characteristics, certain type of machines can be monitored largely based on trend Spike Energy overall magnitudes. One successful application in recent years is to monitor sealless pumps using Spike Energy overall measurements.

• The defect frequency and harmonics in a Spike Energy spectrum are modulation frequencies. These frequencies are related to the high frequency carriers, such as gear mesh frequency, higher order harmonics of bearing defect frequencies, resonant frequencies of machine components and structures, or mounted resonant frequencies of the transducers. In general, the defect frequency in the Spike Energy spectrum does not represent low frequency faults, such as unbalance and misalignment. In some cases, the machinery fault is not evident in the acceleration or velocity spectrum, but shows clearly in the Spike Energy spectrum.

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