A Specialized Comparative Analysis of Advanced Bearing Fault Detection Techniques

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Abstract

Bearings are among the most critical rotating components in industrial equipment, and their failure can lead to significant machine downtime, costly damages, and potential safety hazards. This study presents a comprehensive and technical comparison of four advanced bearing fault detection techniques—PeakVue, SPM HD, HD ENV, and Spike Energy. By analyzing their operational principles, frequency sensitivity, diagnostic capabilities, data acquisition methods, and implementation requirements, this paper highlights each method's strengths, limitations, and suitability for different industrial scenarios. The results aim to support condition monitoring professionals in selecting the most effective technique based on machine type, fault progression, operational environment, and application-specific constraints.

Keywords: PeakVue, SPM HD, HD ENV, Spike Energy

1. Introduction

Bearings are critical components in rotating machinery, and their failure can lead to unexpected downtime, reduced productivity, and significant maintenance costs. Therefore, the development of advanced methods for condition monitoring and early fault detection in bearings has always been a priority in industry and maintenance engineering. In recent decades, various technologies have been developed for this purpose, each employing different physical principles and signal processing techniques to detect bearing faults with high accuracy and at early stages.

This paper focuses on four prominent methods that are analyzed and compared:

- **PeakVue**: A technology developed by Emerson, based on high-frequency impact energy analysis.
- **SPM HD**: The next-generation shock pulse method developed by SPM Instrument, specifically optimized for low-speed applications.
- **HD ENV**: An advanced digital signal processing technology for extracting information from noisy signals, based on enveloping principles.
- **Spike Energy**: One of the earliest methods for recording impact energy, developed by Entek IRD, with widespread industrial use.

This study provides a technical analysis and comparison of these four methods to identify their strengths, limitations, and suitability across various operational conditions.

2. Overview of Diagnostic Techniques

2.1 PeakVue

PeakVue technology, developed by Emerson, is considered one of the most reputable and widely used methods for fault detection in bearings and gears. This method is based on the analysis of high-frequency stress waves generated by minor impacts, fatigue cracks, and wear. The advanced version of this technology, also called PeakVue, automatically analyzes both periodic and non-periodic energy components using signal autocorrelation, allowing it to differentiate mechanical faults from lubrication issues. A key feature of this method is its ability to provide operator-friendly, scaled outputs—such as a percentage-based fault severity indicator. Notable advantages of PeakVue include its high sensitivity, the ability to analyze data with or without a tachometer, and its suitability for a wide range of machinery.

2.2 SPM HD

The SPM HD (Shock Pulse Method – High Definition) technique is based on the generation of shock pulses caused by the contact between rolling elements and their raceways in bearings. Specifically designed for very low-speed applications—even below 1 RPM—it utilizes a dedicated transducer with a resonant frequency of 32 kHz.

This technology measures two key parameters:

- **HDm**: The maximum shock pulse intensity, used to detect mechanical faults.
- **HDc**: The frequency level at which more than 200 pulses per second are detected, used to assess lubrication condition.

Key advantages of SPM HD include the ability to normalize data based on shaft diameter and rotational speed, effective suppression of low-frequency noise, and high sensitivity for early-stage fault detection.

2.3 HD ENV

HD ENV is a modern technology based on the principles of enveloping, designed to deliver precise and reliable information about gear and bearing faults—even in noisy industrial environments. By combining low-noise hardware with advanced signal processing algorithms, HD ENV effectively extracts fault-related information using standard accelerometers. It provides three key outputs:

- **HD ENV Time Signal**
- **HD ENV Spectrum**
- **HD Real Peak**: A numerical value used for trending and alarm setting.

Key advantages of HD ENV include high accuracy in complex environments, early-stage fault detection capabilities, and reliable performance on machinery with significant background noise.

2.4 Spike Energy

Spike Energy is one of the earliest techniques for bearing fault monitoring, developed in the 1970s by Entek IRD. It is based on capturing the energy of extremely short-duration pulses generated by the impact of rolling elements on cracks or defect points. Unlike conventional enveloping, this method uses a peak-to-peak detector and a specific time constant to preserve the true intensity of the impacts. The output is expressed in **gSE** (acceleration units). Spike Energy is highly sensitive to sensor placement and mounting conditions; therefore, accurate results require a fixed sensor and proper mounting setup.

3. Comparative Analysis

This section presents a comparative analysis of the four technologies based on several key criteria. The focus is on parameters that significantly impact operational performance and diagnostic accuracy.

Table. 1. comparative analysis of the four technologies

Comparison Criteria	PeakVue	SPM HD	HD ENV	Spike Energy
Physical Signal Basis	Stress waves	Shock pulses	Enveloped high-frequency elastic waves	Ultra-short shock pulses
Sensitivity to Early Faults	Medium to High	Very High	Very High	Medium
Low-Speed Performance	Acceptable (under specific conditions)	Excellent	Good	Limited
Fault/Lubrication Differentiation	Yes (via periodic/non-periodic analysis)	Yes (via HDm and HDc)	No	No
Resistance to Environmental Noise	Relatively resistant	Resistant	Highly resistant	Sensitive
Sensor Requirement	No (uses standard accelerometer)	Yes (dedicated SPM sensor)	No (uses standard IEPE accelerometer)	Yes (sensor with specific resonance)
Ease of Interpretation	Very good (scaled output)	Good (color-coded and scaled indicators)	Requires expert interpretation	Requires expert interpretation
Spectral Analysis Capability	Yes	Yes	Yes	Yes
Key Strengths	User-friendly graphs / Combination of energy & periodicity	Excellent for low speeds / High clarity	Strong performance in noisy environments / Accurate signal extraction	Focus on true impact intensity and amplitude
Limitations	Requires skilled analyst for manual interpretation	Requires dedicated sensor / Higher initial cost	Complexity in setup and result interpretation	Highly sensitive to sensor installation conditions

4. Conclusion and Final Recommendation

A comprehensive review of the four technologies—**PeakVue**, **SPM HD**, **HD ENV**, and **Spike Energy** reveals that none of these methods alone is universally optimal for all applications. Each has distinct strengths and limitations that make it more or less effective depending on specific operational scenarios.

- **PeakVue** is a suitable choice for general industrial applications involving medium to high-speed machinery, particularly where simple and user-friendly interpretation is required. Its ability to differentiate between mechanical faults and lubrication issues is a major advantage.

- **SPM HD** is the most effective solution for low-speed or ultra-low-speed machinery such as industrial presses, wind turbines, and heavy-duty mining equipment. The combination of a dedicated sensor and robust algorithm enables highly accurate early fault detection.

- **HD ENV** proves especially valuable in complex and noisy environments, such as multi-axis machines, intricate gearbox systems, or areas with multiple vibration sources. When traditional techniques fall short, HD ENV excels with its advanced signal processing capabilities.

- **Spike Energy**, despite being one of the oldest techniques, remains useful for basic periodic monitoring and detecting impact intensities especially in systems prone to cavitation, seal-less pumps, and lubrication-sensitive applications. However, it is less suitable for in-depth diagnostics or dynamically changing conditions.

5. Experimental Review of Methods in Bearing Fault Diagnosis

5.1. PeakVue – Bearing Fault Detection in a Calendar Roll

In Stewart's paper, data from the drive-side bearing of a calendar roll was presented, where the maximum PeakVue wave peak was 8.337g's and the reference failure level was 7.767g's. The autocorrelation chart revealed that 57.6% of the signal energy exhibited periodic characteristics, indicating mechanical fault involvement.

Results:

- **Mechanical fault intensity:** approximately 61.8%

- **Lubricatio`n issue intensity:** 45.5%

PeakVue Plus analysis, through precise signal analysis and providing a percentage distinction between mechanical faults and lubrication issues, has simplified early fault detection and maintenance decision-making.

The pattern in the time domain repeats with each rotation, and the distance between the small peaks corresponds to BPFI (Ball Pass Frequency Inner race) have important information. The resulting spectrum also shows a distinct line at BPFI and sidebands with an order of 1 (1 Order).

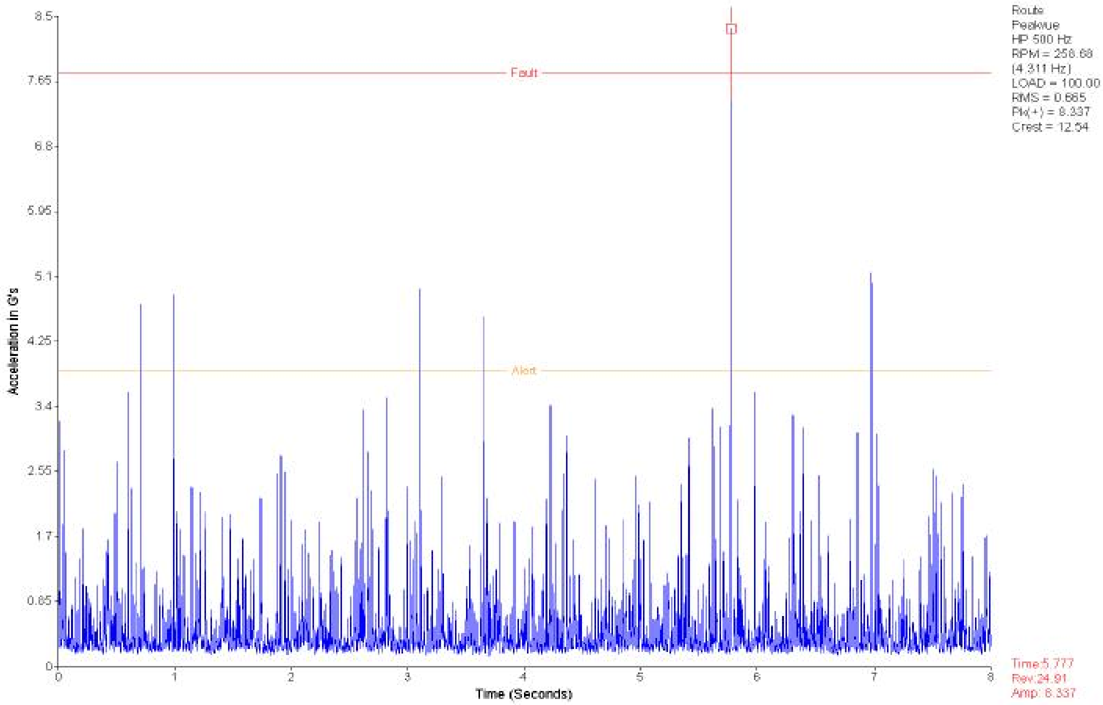

Fig. 1. The PeakVue waveform is shown, with a maximum peak of 8.337 g's compared to the failure threshold of 7.767 g's for the bearing.

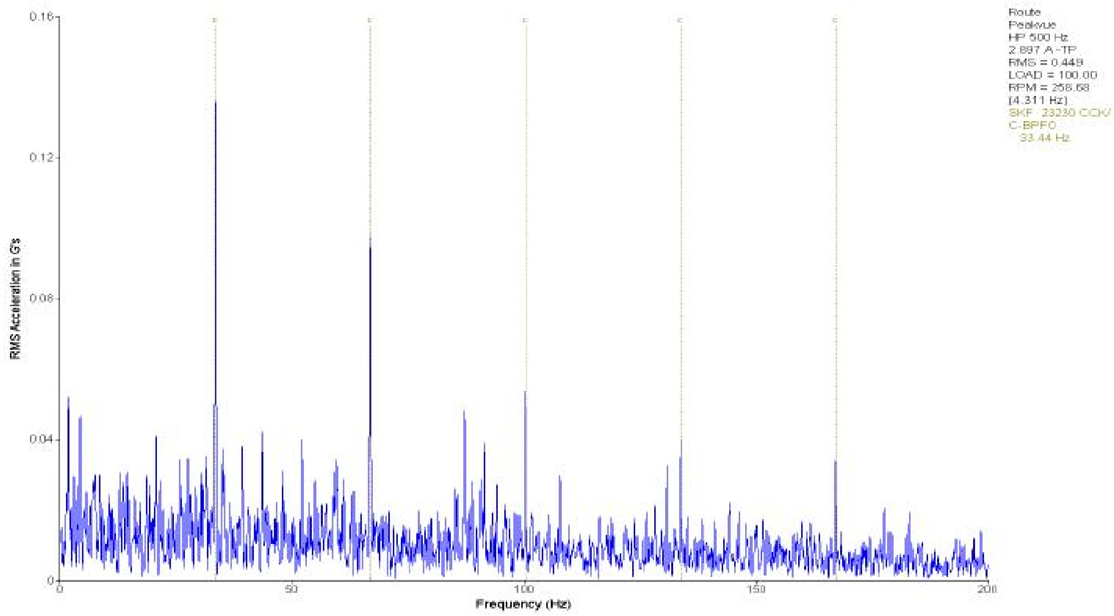

Fig. 2. The spectrum derived from the waveform in Figure 1 shows that a fault is present on the bearing's outer race.

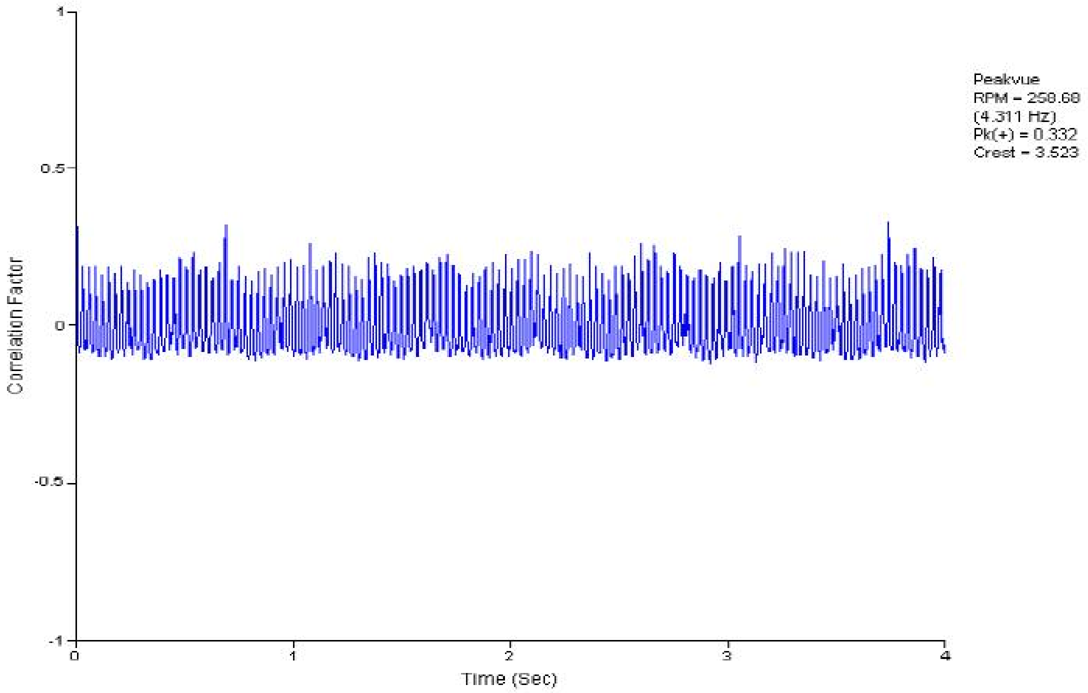

Fig. 3. The same crack in the inner raceway of the bearing is also visible in the spectral domain.

A further examination of the same spectrum, as shown in Fig. 4, reveals additional interesting details: in fact, a peak related to BPFI at zero frequency (0 Hz) is also present. This peak is not directly shown in the spectrum, but the sidebands to the right of this line at zero frequency are visible. This phenomenon is a result of the Enveloping process.

The raw SPM signal is typically symmetrical around zero, meaning it includes both positive and negative peaks, with the average of the signal close to zero. However, during the Enveloping process, the signal is rectified to positive values, and its envelope is extracted, causing the symmetry of the signal to disappear and a DC shift to occur. The DC shift means that a component at zero frequency appears along with sidebands in the spectrum, which is exactly what is observed in the spectrum. It is important to note that this phenomenon also occurs in vibration enveloping techniques, but it is not observed in unprocessed vibration analysis. Additionally, note that the first spectral line is precisely located at (1 Order), i.e., 1 time the rotational speed.

A common misconception is that the 1X peak in the SPM HD spectrum always indicates a single impact (hit) occurring per revolution. While this may be true in some cases, the more typical scenario is that there is an issue with the inner raceway of the bearing, and the 1X peak is actually the first sideband or component modulated at the 1X frequency. In other words, the presence of a 1X peak does not necessarily indicate a single impact per revolution, but it could be the result of frequency modulation related to a fault, such as BPFI, with the rotational frequency of the shaft.

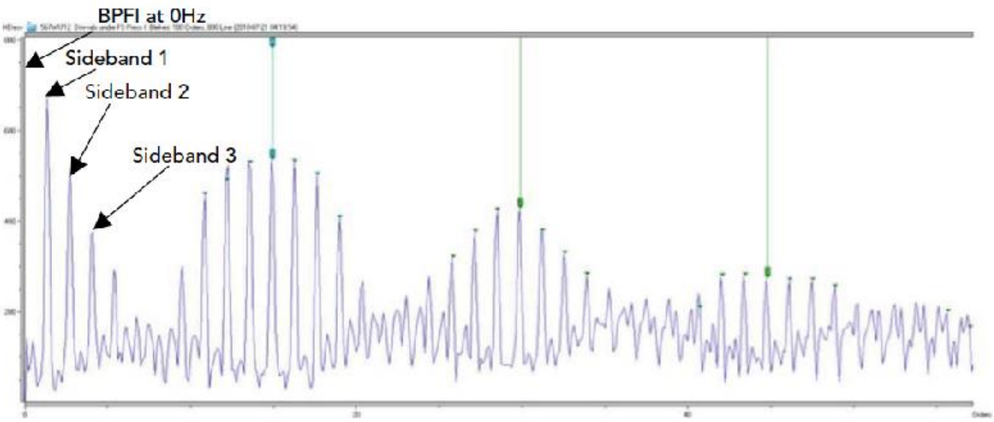

Fig. 4. A more detailed and in-depth examination of Fig. 3.

5.2. HD ENV – Roller Fault in the Suction Roller Bearing

The suction roller involves a paper machine at a paper mill in Sweden. The suction roller is a key component in the press section of the paper machine, and its primary function is to dewater the paper pulp. In this investigation, HD ENV technology was employed using vibration sensors mounted on the suction roller. After only a few measurements, a clear fault was detected in one of the rolling elements of the bearing.

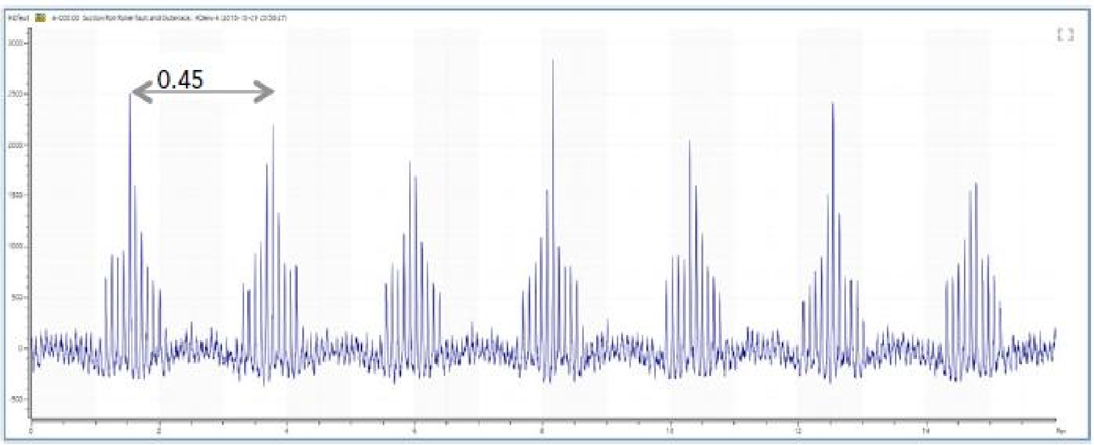

Fig. 5. Time signal from the suction cylinder bearing at a rotational speed of 240.24 RPM, indicating damage in one of the rolling elements along with clear modulation caused by the bearing cage.

This type of bearing (SKF model 230/670CA with a shaft diameter of 670 mm) is very expensive, but due to the high sensitivity of the HD ENV method, it was determined that only one of the rollers was damaged. Therefore, it is likely that the bearing can be repaired and reused without the need for a complete replacement. This case serves as an excellent example of the importance of early fault detection, which not only prevents production downtime but also leads to significant cost savings in bearing replacement.

The clear modulation observed in the time signal in Fig. 5 can be explained by examining Fig. 6. This figure illustrates a bearing under load, where the gravitational force generates a downward vertical load. The transparent red area represents the resulting load zone. When a damaged roller enters this load zone, elastic waves are emitted due to the impact of the damaged area against the inner and outer rings. At the center of this zone, where the forces are at their maximum, the generated elastic wave also reaches its highest amplitude.

Fig. 6. A bearing with a downward-directed load zone (indicated by the transparent red area).

The fundamental cage frequency (FTF), also known as the cage rotation frequency, is specified as 0.45 in the datasheet for this bearing. This means the bearing cage rotates 0.45 turns for every full revolution of the shaft. In the displayed time signal, the spacing between groups of peaks is exactly equal to 0.45X, clearly indicating the presence of a defect in one of the rollers.

5.3. Spike Energy – Bearing Wear and Outer Race Damage

This case study involves a system consisting of four clustered spindles, as shown in Figure 9. This equipment is used for semi-finish boring (reaming) operations. The box-type spindles are belt-driven and utilize very lightweight ball bearings. The spindle shaft operated at approximately 417 revolutions per minute. Spike Energy data was measured at the front end of the lowest spindle in the horizontal direction, specifically at location A indicated in Fig. 7.

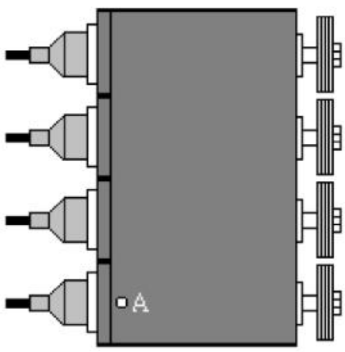

Fig. 7. Schematic illustration of the four clustered spindles and the data acquisition location.

The measured velocity spectrum and Spike Energy spectrum are shown in Fig. 8a and 10b, respectively. The velocity spectrum exhibited a higher 2xRPM amplitude compared to 1xRPM, which typically indicates that the bearing has lost its preload. In this particular spindle, the loss of preload was due to bearing wear. The velocity spectrum also revealed harmonics of the Ball Pass Frequency Outer Race (BPFO). Although the 1xBPFO component was not prominent in the velocity spectrum, outer race damage was clearly evident in the Spike Energy spectrum. As shown in Figure 10b, the BPFO and its harmonics are clearly visible in the gSE spectrum, representing a typical Spike Energy signature of bearing damage. In this case, both the velocity and Spike Energy spectra identified issues related to bearing wear and outer race defect.

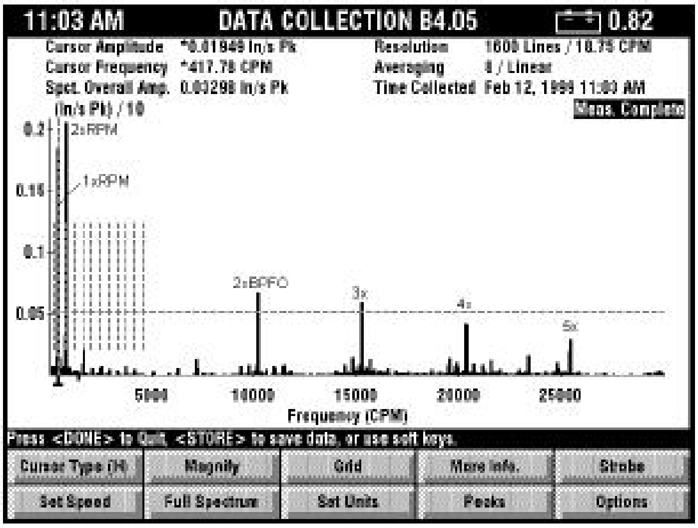

Fig. 8a. Velocity spectrum.

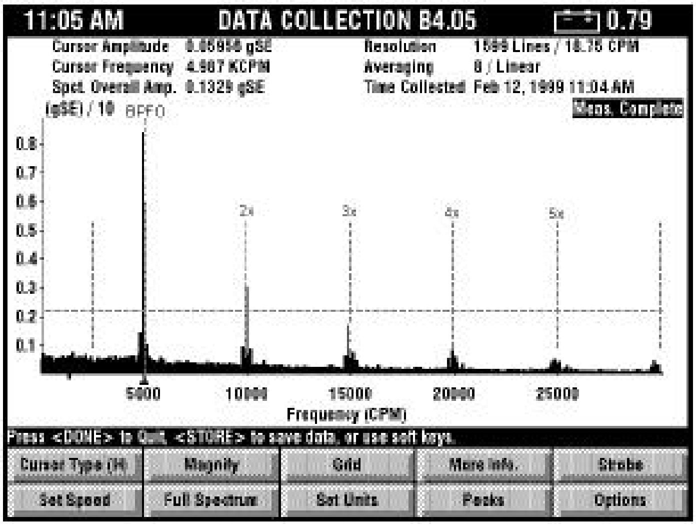

Fig. 9b. Spike Energy spectrum.

6. Conclusion

For comprehensive condition monitoring, a hybrid approach that integrates multiple technologies is highly recommended. For instance, combining **PeakVue** and **HD ENV** can offer both early fault warning and user-friendly interpretation, providing enhanced diagnostic coverage and decision-making reliability across a broader range of applications. Also, both of the velocity and **Spike Energy** spectra identified issues related to bearing wear and outer race defect.

Spike Energy is one of the earliest techniques for bearing fault monitoring.

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