An Automatic Harmonic Activity Locator (HAL) Algorithm and Its Application in Machine Vibration Diagnosis

By Jim Wei, Application Engineer • SKF

Introduction

SKF Reliability Systems has developed a spectral data mining and screening algorithm that automatically performs the same type of "qualitative" interpretation as a human analyst. It does this by "quantifying" the existence of harmonic series that give "qualitative" indications of the presence of certain mechanical failure mechanisms. Using the computational power of the personal computer to rapidly sift through data to search for the often subtle indications of harmonic series buried within the spectra, the Harmonic Activity Locator (HAL) algorithm provides the analyst with an indication that there is, or is not, something in the data that requires further investigation. SKF, supplier of 20% of the world's bearings, has validated the effectiveness of this algorithm in identifying the need to focus on thousands of machines in its extensive vibration database.

Why develop HAL?

Spectrum analysis is a powerful tool used to diagnose various problems that a machine might develop. The absolute amplitudes of specific spectral components, implemented through the use of spectrum band alarms, allow the analyst to set limits on when a problem is identified by the component's amplitude exceeding preset thresholds. The spectrum band alarm is a powerful tool for focusing on mechanically identifiable spectral components, and assigning alert and danger thresholds to those components for reporting to the analyst when either criterion is exceeded. Its limitation, in some circumstances, is that it requires specific components to reach certain preset limits without regard for the character of the data. HAL was designed to identify the presence of these series of harmonics regardless of the amplitude of any of the individual harmonic components. In many mechanical cases, harmonic series can be identified in spectra long before any of the individual components reach their alert or danger thresholds.

Table 1 presents just a few of the common rotating machinery problems and their signature features in the vibration spectrum. SKF's HAL algorithm mimics the way a human would detect a harmonic series, visually. To be specific, it uses a feature extraction process. The absolute vibration level is irrelevant when there are spectral peaks separated by a constant distance in a spectrum. The key is to identify peaks that stand out from their immediate neighboring spectral lines and that are separated by a constant distance. These two distinct features tell the analyst that the spectrum contains one or more harmonic series.

Table 1

Selected mechanical problems and their expected spectral features

Problems	Symptom	Candidate for harmonic indicator?
Imbalance	A single spectral peak at running speed	No
Resonance	A single spectral peak at the structural resonance frequency	No
Mechanical looseness	Harmonic series with fundamental frequency at half of the running speed	Yes
Misalignment	Harmonic series with fundamental frequency at running speed	Yes
Rotor rubbing	Harmonic series with fundamental frequency at half of the running speed	Yes
Bearing damage	Harmonic series with fundamental frequency at characteristic frequency of specific defect types	Yes

How does the HAL algorithm detect a harmonic series?

The HAL algorithm provides an index number indicative of the existence of harmonic series for each mechanical component identified in a measurement. The algorithm first identifies all the peaks within each mechanical fault component's fundamental frequency search window. The frequency search window's location and width are determined by the characteristic frequency of the problem being investigated. For example, if misalignment is the target of the investigation, the center frequency of the search window will be the machine running speed; the recommended width of the search window will be 2% of the center frequency.

Once the peaks within the search window are identified, the HAL algorithm takes each identified peak that is potentially the measured fundamental frequency of a probable harmonic series, finds its harmonic frequencies, and averages the amplitudes at these frequencies. The harmonic average amplitude is then divided by the average of all non-harmonic spectral line amplitudes to result in the HAL index number. For example, if the spectrum were perfectly flat, the HAL index would be 1.

Due to the normalization process, the HAL index is non-dimensional and independent of absolute vibration amplitude, focusing specifically on the pattern defined by the appearance of spectral peaks that are harmonically related. This particular feature of the HAL algorithm enables a universal alarm threshold for detecting harmonics series, independent of the spectrum measurement domain or location and orientation of the sensor. SKF Reliability Systems has processed hundreds of thousands of spectra through the HAL algorithm. Based on extensive empirical review, SKF Reliability Systems has determined that a HAL index below 2,5 provides a low level of confidence in the presence of harmonic activity, and an index above 3,5 provides a high level of confidence in the presence of significant harmonic activity associated with the evaluated fundamental frequency. Used as a screening tool, all spectra with a HAL index greater than 2,5 should be reviewed for significant mechanical problem indications, whereas spectra with a HAL index below 2,5 can most likely be skipped by the analyst when no other screening method (such as band alarms) indicates a problem.

Implementation of HAL algorithm

The Machine Analyst /HMI software is an add-on module for SKF's Machine Analyst application. With the HAL algorithm implemented, the software allows the user to specify rules for applying HAL to individual points that have FAM information in the Machine Analyst database. Users can trend the HAL index and use HAL to automatically process an entire database to pick out any measurement that has harmonic series in the spectrum. Users can turn on or off any particular measurement at any point for HAL index computation, and set HAL alarm levels (low confidence index, high confidence index). The advantage of using the HAL algorithm is illustrated in the following two case histories.

HAL application case history 1

HAL warning ahead of other measurements

This case history uses a paper machine database that has a defective inner race bearing in the press section. Velocity and acceleration envelope filter 3 measurements were selected in SKF Machine Analyst/HMI to validate the HAL index. The HAL index for the inner race defect computed for the envelope 3 measurement exceeded 3,5, as shown in **fig. 1**. This level of active harmonic activity warns that an inner race defect is developing. However, the overall readings for both envelope 3 and velocity, at the time, did not show any evidence of the potential inner race problem as shown in **figs. 2** and **3**. The bearing problem was discovered by the maintenance crew, to be due to the upward trending of the envelope 3 measurement, shown in **fig. 2**. The faulty bearing was replaced shortly thereafter.

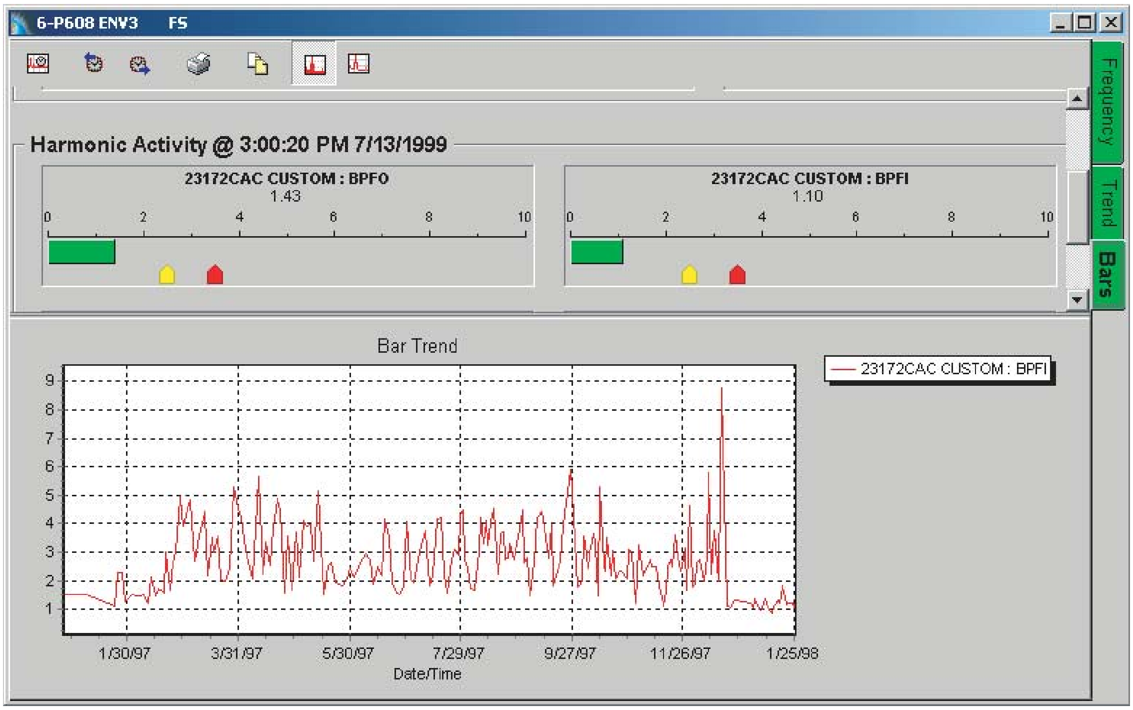

Fig. 1. HAL index trend for inner race detect computed for envelope 3 measurement.

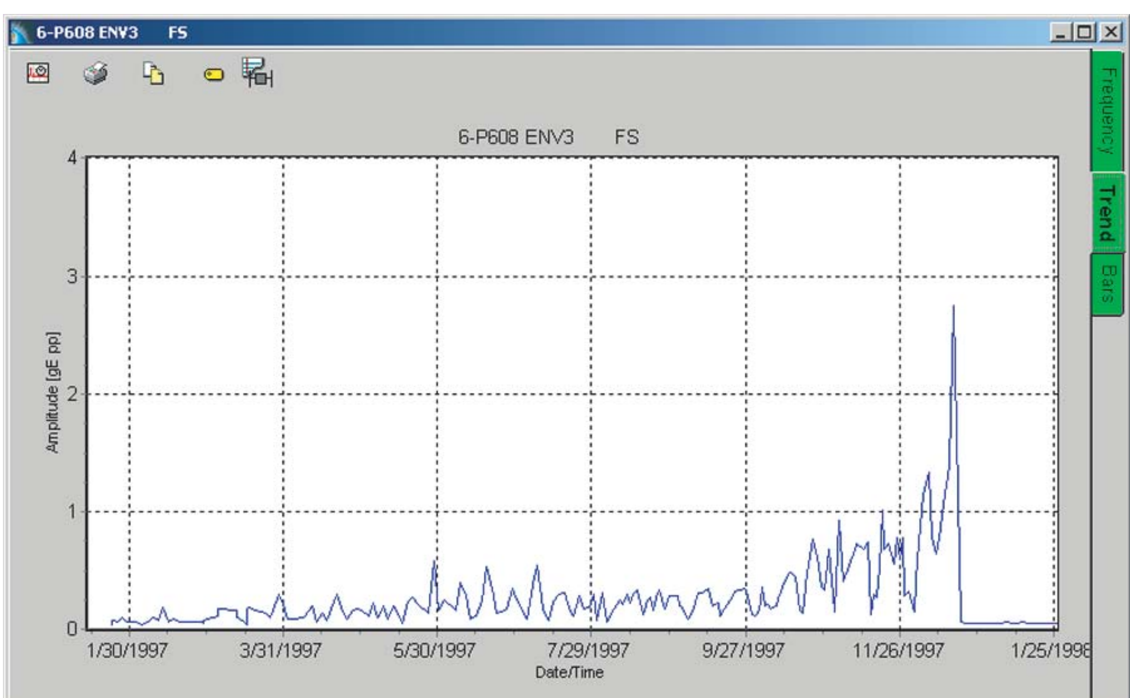

Fig. 2. Enveloping measurement trend.

During the entire 10-month period, when the HAL index repeatedly showed warning of the inner race defect, the velocity measurement (→ **fig. 3**) did not show any evidence of the bearing defect until the very last moment before the bearing was replaced. Inspection of the enveloping measurement spectra reveals that the inner race defect frequency and its harmonics were indeed present earlier, as shown in **fig. 4**. However, the amplitudes of enveloping reading at the time were still very low, indicating an early onset of the inner race defect.

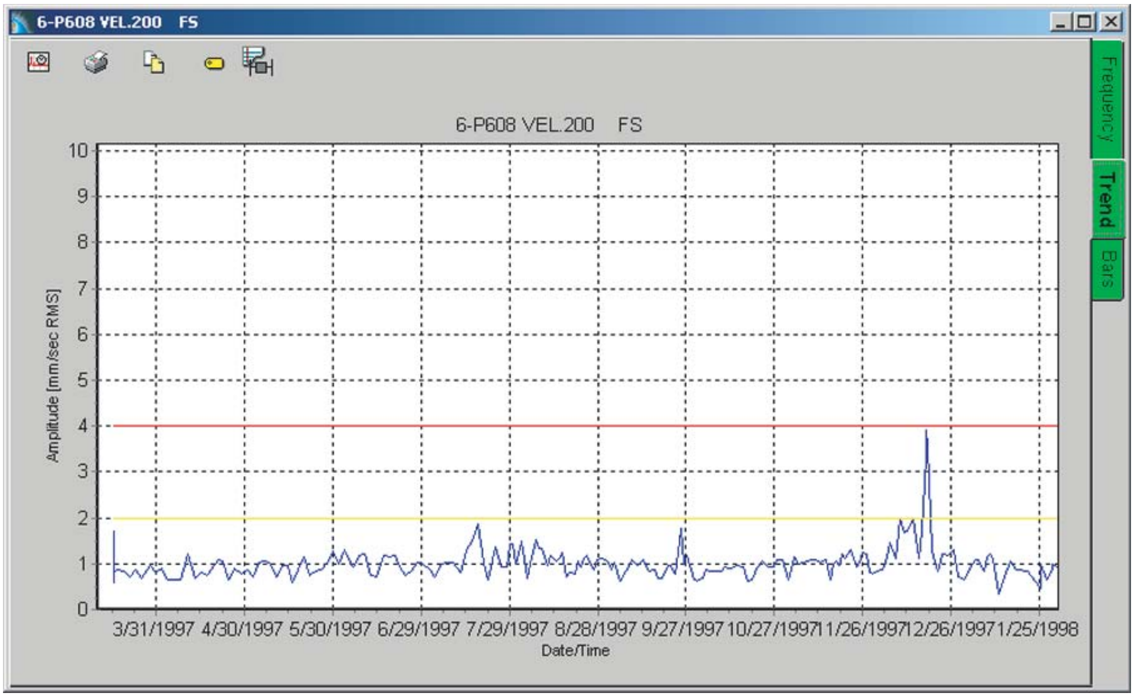

Fig. 3. Velocity measurement trend.

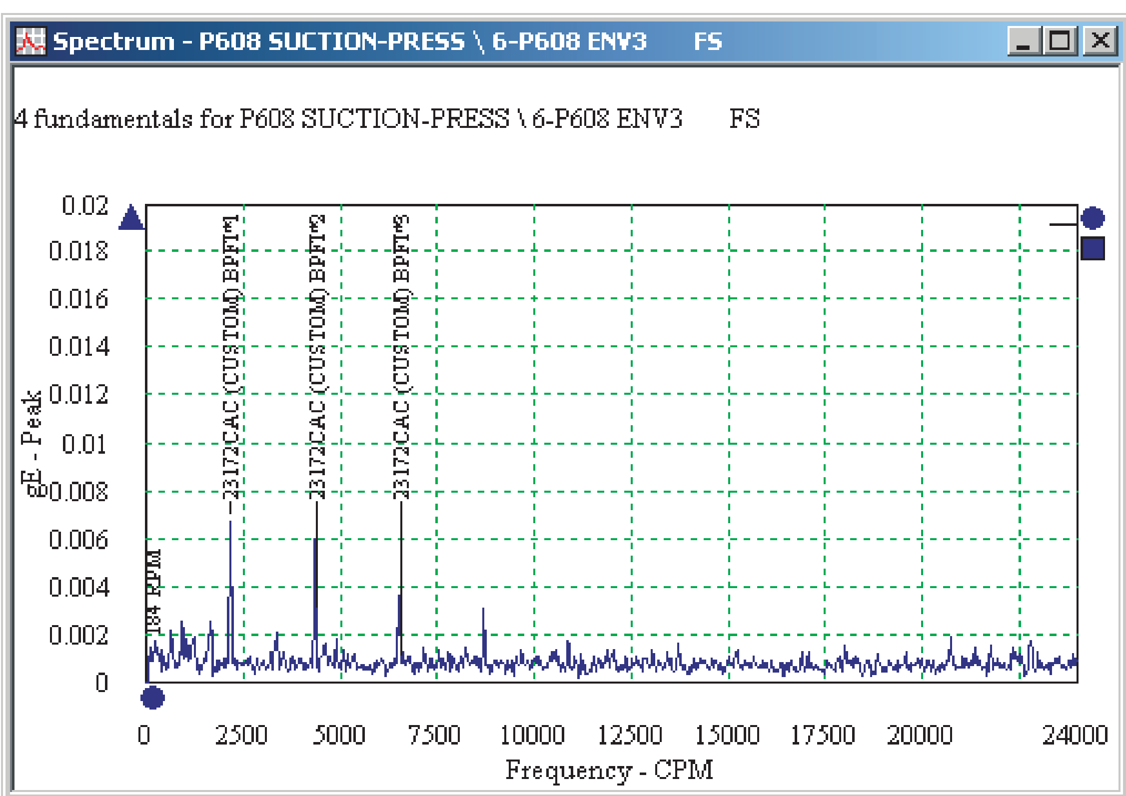

Fig. 4. Spectrum of enveloping measurement; HAL index for BPFI is 3.01.

SKF

HAL application case history 2

HAL identifies harmonic series in a spectrum infested with spectral peaks

This is again a damaged bearing case in a paper machine. The bearing defect was detected by both HAL and the overall envelope 3 measurement at around the same time, as shown in **figs. 5** and **6**. The spectrum of the envelope 3 measurement, shown in **fig. 7**, however, is dominated by many spectral peaks that are not related to the particular bearing defect being developed. The existence of other spectral peaks, which could potentially confuse or distract the analyst, did not affect the HAL index.

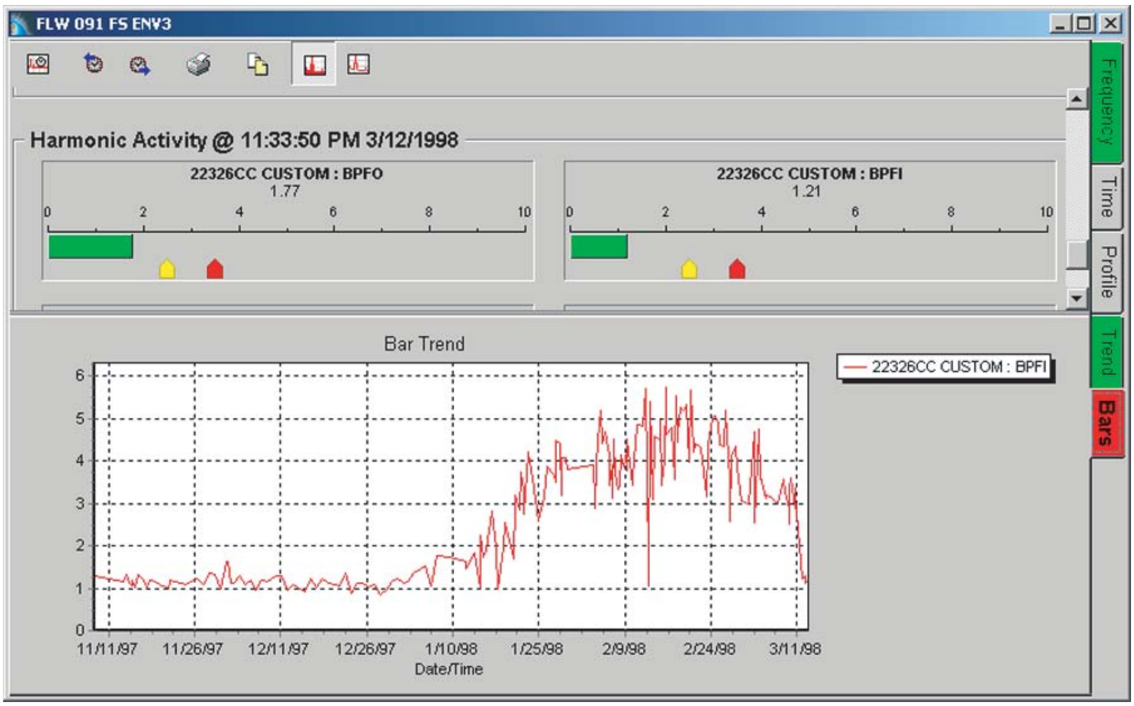

Fig. 5. HAL index trend for BPFI.

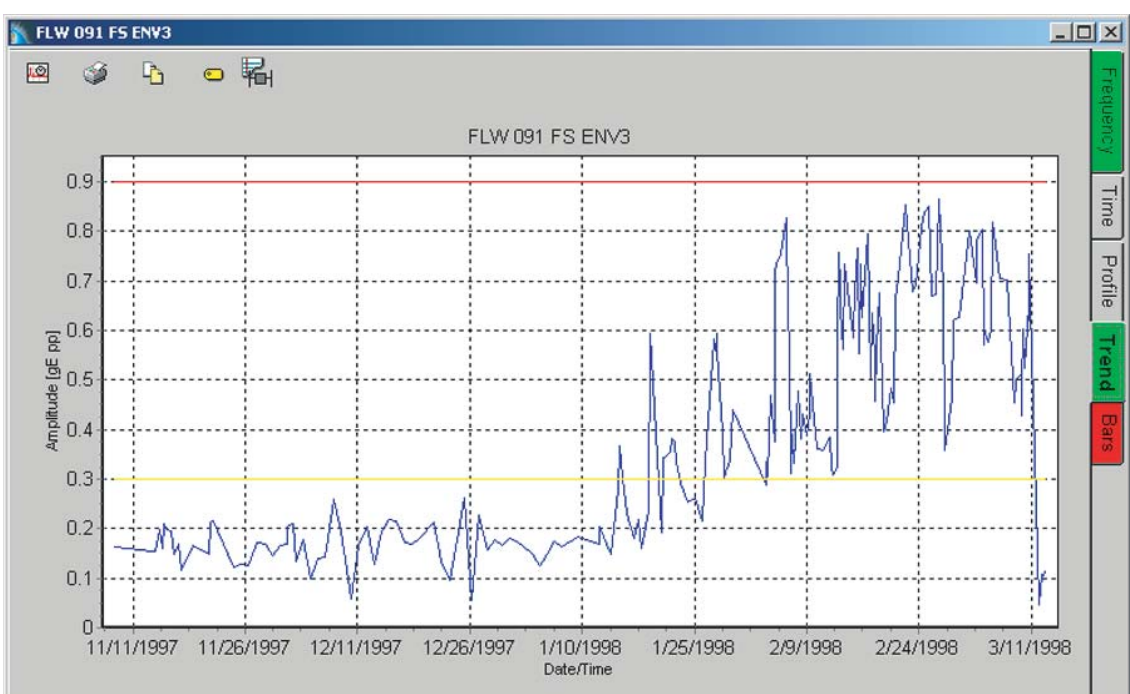

Fig. 6. Overall envelope 3 trend for BPFI.

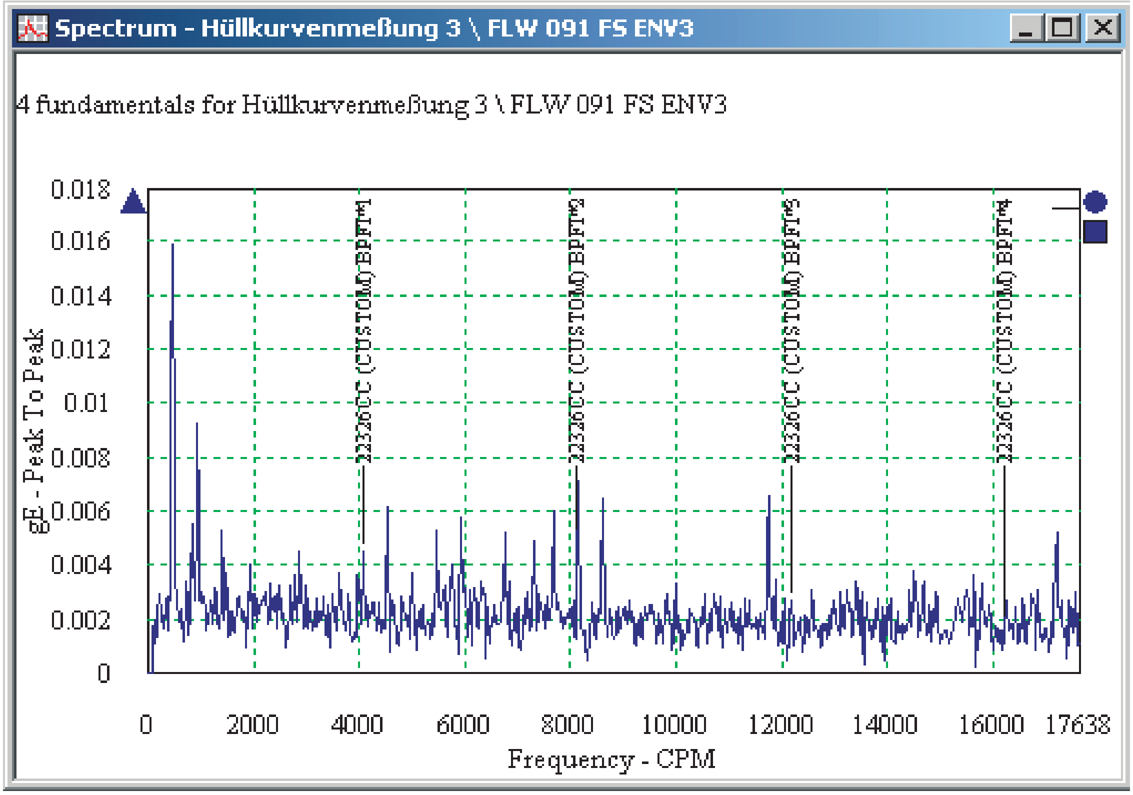

Fig. 7. Envelope 3 spectrum with the HAL index for BPFI at 2,8.

Conclusion

The HAL algorithm is a powerful tool for detecting and confirming harmonic activity in a spectrum. The fact that its alarm threshold has nothing to do with absolute amplitude of the measurement makes it a simple tool to relieve the analyst of the need to page through numerous spectra in search of often difficult to see harmonic activity. The implementation of the HAL algorithm in the SKF Machine Analyst/HMI software provides easy access to this tool for users of SKF Machine Analyst software.

Please contact:

SKF USA Inc.
Condition Monitoring Center – San Diego
5271 Viewridge Court · San Diego, California 92123 USA
Tel: +1 858-496-3400 · Fax: +1 858 496-3531

Web: www.skf.com/cm

PUB CM3070 EN · January 2012