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Envelope analysis – the key to rolling-element bearing diagnosis

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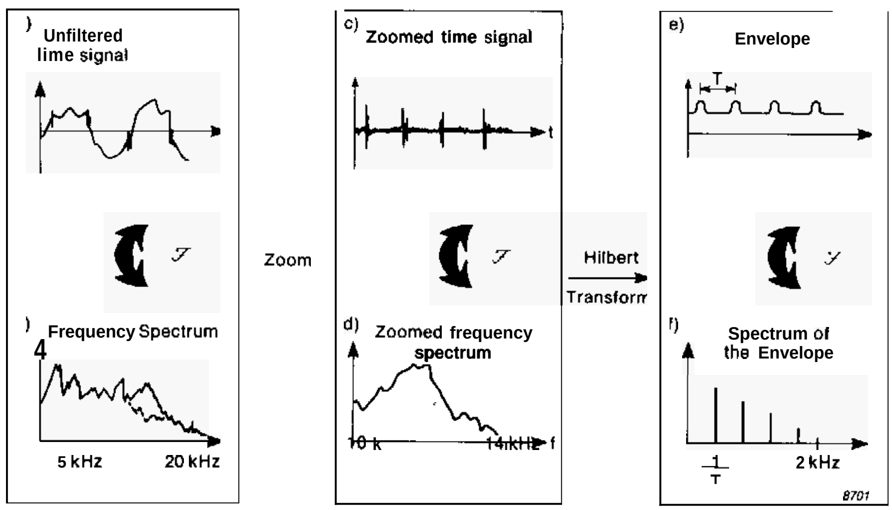
Envelope-analysis of a band-pass-filtered signal is an established technique for indentifying faults in rolling-element bearings. The traditional method uses an analogue handpass-filter plus a rectifier and smoothing circuit. The filter extracts the resonance excited by the hearing fault from the frequency spectrum; the detector detects the envelope of the corresponding time-signal.

The Dual-Channel Signal Analyzer Type 2032/34 offers an alternative way of implementing envelope-analysis, which is faster and more accurate. Zoom extracts the resonance of interest from the frequency spectrum, replacing the handpass filtering. The Hilbert transform generates the envelope of the time-signal by calculating the magnitude of the time function. The envelope's frequency spectrum is computed in the 2032/34 controlled by a computer or the Graphics **Re**corder Type 2313.



The **2032/34** uses zoom lo extract the region of **the** resonance excited **by** the hearing-fault, from the frequency spectrum. Then lhe Hilhert transform is used to produce the envelope **of thc** filtered lime signal.

Rolling-element bearing vibration

Local faults in rolling-element hearings produce a series of impacts which repeat periodically at a rate dependent on hearing geometry. These repetition rates are known as the bearing frequencies. More specifically: the ball-passing frequency outer-race (RPFO) or the hall-passing frequency inner-race (BPFI) for a fault on the outer- or inner-race, the ball-spin frequency (BSF) for a fault on the hall, and the fundamental train frequency (FTF) for a fault on the cage.

Figure 1 illustrates the result of analyzing an impactive fault exciting only one resonance. The dotted line represents the energy spectrum of one pulse, that is the frequency response of a single-degree-of-freedom system. If the pulses are identical and are uniformly spaced hy T, the spectrum of the impact series would be a line spectrum comprizing all harmonics of the repetition frequency $1/T$, with the largest, amplitudes in the vicinity of the resonance frequency. The repetition frequency could be determined by zooming in this region and establishing the harmonic separation. In practice, there are small differences between the pulses and in their spacing; as a consequence the higher order harmonics hroaden and eventually merge. As an example, a speed fluctuation of 0,1% would cause merging around the thousandth harmonic. At low frequencies the influence of speed fluctuations is very small. However, the harmonic pattern of the hearing fault(s) is obscured by the background vibration from rotating elements.

Figure 2 illustrates the differcncc between the signal produced by a fault on the stationary race and a fault on the rotating race. In the first case, the fault will always he subject to the same load and the resulting impacts will have equal amplitudes. In the second case, the fault will rotate in and out of the loaded region, causing modulation of the impact amplitudes by the rotation speed of the shaft.

In cunclusion. the first sign of rolling-clement hearing deterioration will be an increase in the amplitude level of the frequency spectrum somewhere in the 5 kHz to 20 kHz region This is because each time a hall passes the fault. the resulting impact cxcitcs the resonances in the structure. It is difficult to diagnose the fault hy examining thr frequency spectrum. But it is simple to diagnose the fault by using the envelopc-analysis technique.

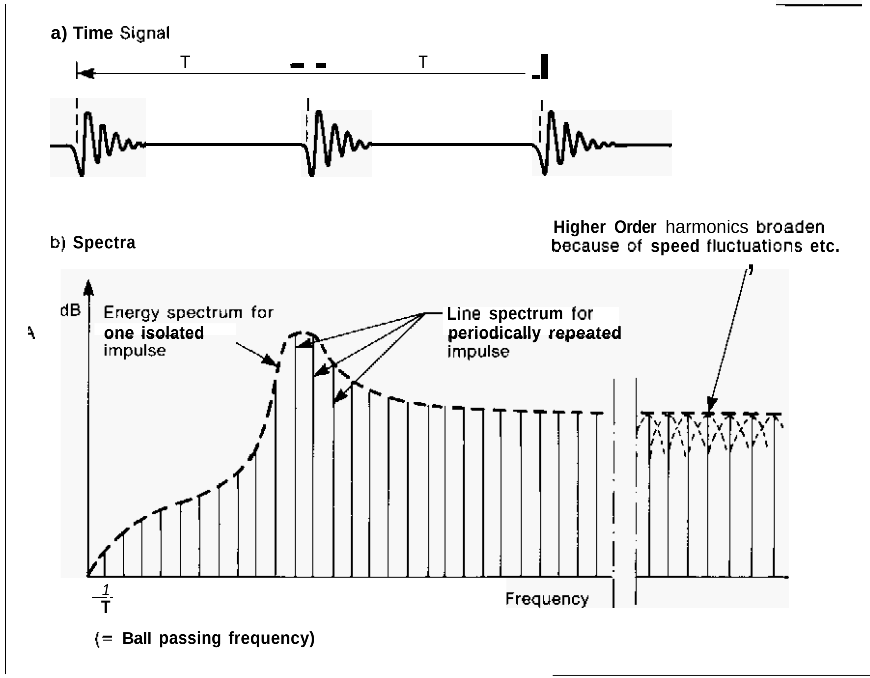


Fig. 1. Frequency spectrum for an idealized impact fault.

Principle of envelope analysis

The envelope-analysis principle of the 2032/34-based system is shown on the previous page:

(a) is the time signal of the vibration measurement, from the bearing housing.

(h) is the corresponding frequency spectrum, which is related to the time signal by the Fourier transform. An increase in level in a particular frequency range (as indicated by the dotted line) is detected when a structural resonance has been excited hy a fault.

(d) is the frequency spectrum extracted by zooming around this particular frequency range. It contains the structural resonances which have been excited hy the impacts produced by the fault(s).

(c) is the corresponding time signal, which contains only the resonance frequency which is modulated by the impact frequency.

(e) In the analogue process, the time signal is then rectified and smoothed by a detector to produce the envelope of the time signal. Consequently, the envelope contains only the low modulation-frequency cnmponent relating to the impact rate(s). The 2032/34 produces a very accurate representation of the time signal, which is free from the limitations of a smoothing circuit, by using the Hilhert transform to calculate the magnitude of the time signal.

(f) The time envelope is then frequency analyzed to establish the impact frequencies. This reveals the presence of a bearing fault. The Dual-Channel **Analyzer** Type 2032/34 computes the frequency spectrum of the envelope of the zoomed time signal, when controlled either by a computer with the Envelope Analysis Program for the 2032134 or by Graphics Recorder Type 2313 with Application Package BZ7006.

The type of fault is indicated by the impact rates present in the frequency spectrum of the envelope. The number of faults is determined by examining the envelope of the Lime signal, and this is described in the following case story

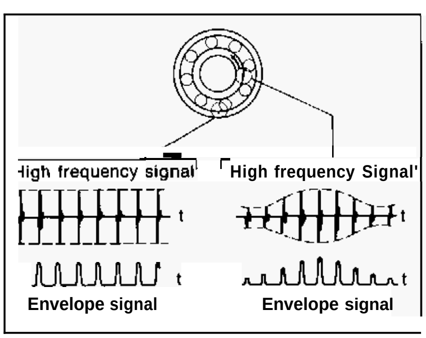


Fig 2. The modulation effect **caused** *by a fault on thr stationary and on the rotating* race.

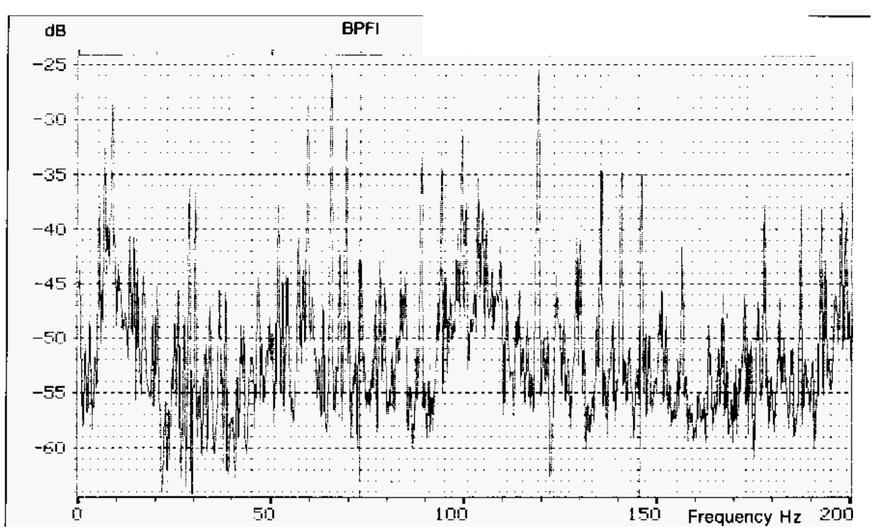


Fig. 3. Baseband vibration spectrum up to 200 Hz for a faulty ball-bearing. It is very difficult to detect any of the bearing characteristic frequencies.

Case study

The following case study describes an envelope analysis of a hall hearing from a paper-drier. The roller-rotation frequency was 5,3 Hz and the bearing characteristic frequencies were: RPFO 59,4 Hz, BPFI 73,0 Hz, BSF 51,0 Hz, and FTF 2,4 Hz.

The frequency spectrnm of the acceleration signal for the ball bearing is shown in Fig. 3. This is the region in which we would expect to detect the hearing characteristic frequencies for a faulty hearing. It's very difficult to detect any of the bearing frequencies in the baseband measurement because other vibration sources have produced more dominant frequency components.

Consequently. 2032/34-based envelope analysis was used to produce the envelope of the zoomed time signal. The corresponding frequency spectrum was calculated using the Graphics Recorder Type 2313 together with the BZ 7006 Application Package. and this is shown in Fig. 4. This clearly shows the RPFI at 73 Hz and the second harmonic at 146 Hz; the sidehands are caused by modulation due to the rotation speed which is 5,3 Hz. This modulation occurs as the fault mores through the loaded area of the hearing.

The envelope of the zoomed time-signal is shown in Fig. 5. This reveals a series of peaks repeating with a period equal to 1/BPFI. Each time a hall passes a crack, an impulse is produced, which results in a peak. On examining Fig. 5 more closely, three more-narrowly spaced peaks are evident. These **peaks** originate from three transverse cracks on the inner race. The three-peak pattern is repeated as balls pass over the three cracks. These impacts are clearly amplitude modulated with a period equal to 1/roller-rotation frequency.

As nn reference spectra were available for the paper-drier, a hammer test was used to produce the frequency response to an impact. This reveals the structural resonances of the hearing, which are shown in Fig. ti. The structural resonances are concentrat**ed** in the 8 kHz to 10 kHz region, which is the region most suitable for zoom analysis as it offers the greatest signal-to-noise ratio.

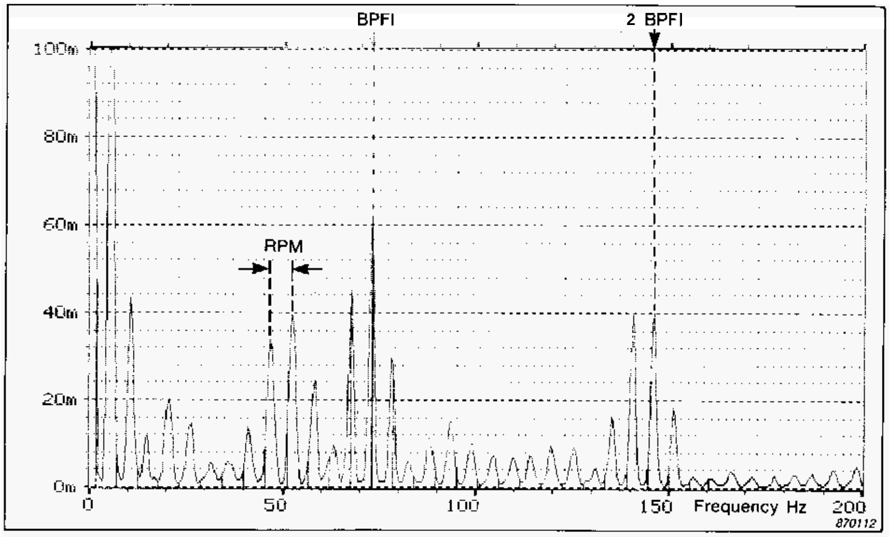


Fig. 4. Envelope of the frequency analysis (zoomed around 9 kHz) of the faulty ball-bearing. The BPFI and sidebands modulated by the RPM are clearly evident.

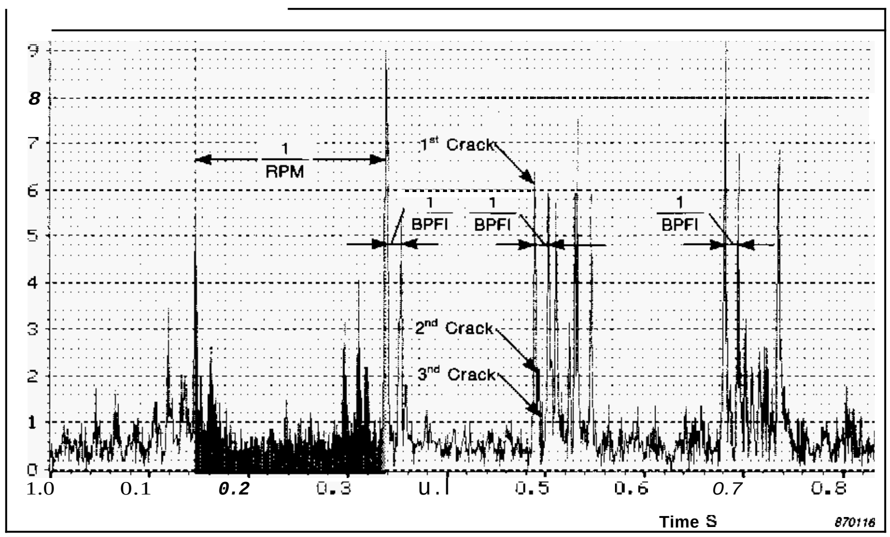


Fig. 5. The envelope's time-signal showing a series of impacts repeating at the rotation frequency. Close inspection reveals three closely-spaced peaks, relating to three transverse cracks on the inner race.

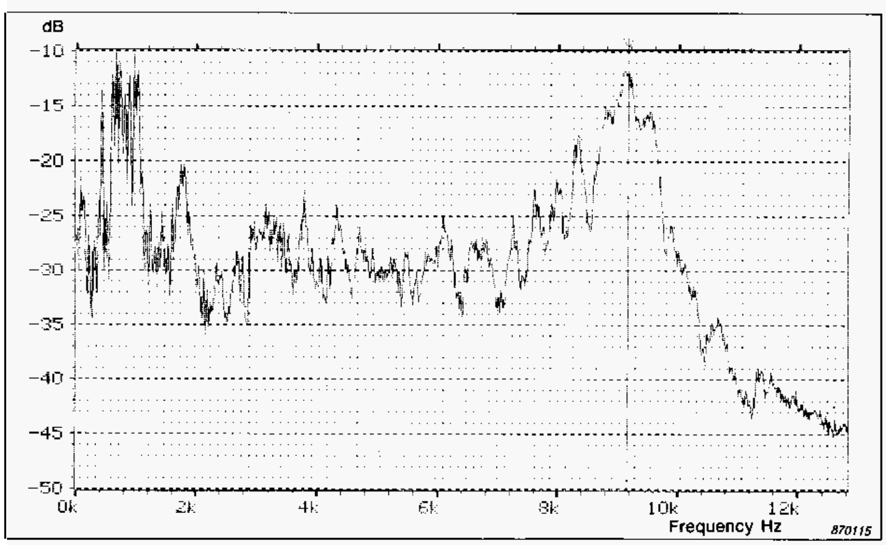


Fig. 6. Response function (0-12,5 kHz) produced by a hammer test, showing the structural resonances for the bearing housing. The resonance at 9 kHz was used for the zoom analysis.

To perform a hammer test on the hearing housing, the machine has Lo be stopped. Often, this is impossible (for example: in the continuous process industry) and in this case the vibration spectrum must be used to establish the must suitable zoom region. The vihration spectrum up to 12,5 kHz is shown in Fig. 7; the same structural resonance region is evident in the 8 kHz to 10 kHz region.

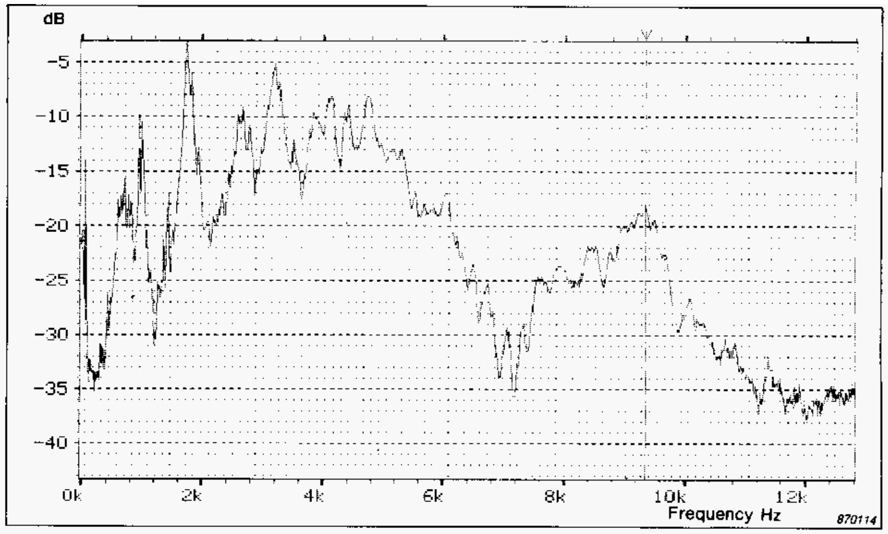


Fig. 7 Vibration spectrum up to 12,5 kHz showing the same resonance region as the hammer-test response.

Conclusion

Envelope analysis is a technique for studying the amplitude modulation of machine vibration signals.

It is a powerful simplification technique – zoom analysis separates the effects of specific faults from hackgmnnd vibration. and the Hilbert transform isolates the amplitude modulation.

Impactive faults excite the high frequency bearing and structural resonances nf the rolling-element bearing. The diagnostic information of interest is contained in the repetition frequency of the impact series, and not in the frequency spectrum resulting from the impacts, as this would usually be a sum of the resonance frequencies excited. The envelope-analysis technique reduces the high frequency problem to a low Srequency problem by isolating the impact-repetition rates. This is important when the impact-repetitinn rates are unstable because of fluctuating rotation speeds, as the periodicity of the harmonics goes undetected because the harmonics are smeared at the higher frequencies hut not at the fundemental.

Further frequency analysis of the envelope signal enables easier diagnosis of multiple defects in rolling-element bearings, as the periodicity of the impacts can be difficult to recognize in the envelope itself.

Furthermore, this final analysis enables identification and separation of the many modulation sources often found in complex machinery. This allows, for example, precise diagnosis of the following: hall-hearing faults, cracked gear teeth, eccentricity in gears, turhine blade deterioration etc., even if one or more of these faults are present at the same time.

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