**SKF Reliability Systems**

# Acceleration Enveloping in Paper Machines

## *An Approach To Extracting Very Low Frequency Impact Signals*

## Abstract

Recent advancements in envelope enhancement techniques (as applied to acceleration and acoustics emissions signals) have led to new measurement solutions for many vibration problems. This paper discusses the basics of enveloping and how it is implemented in practice. It presents a paper machine case study that illustrates how a roll defect grows when it is related to a felt joint discontinuity.

## Enveloping Basics

Enveloping addresses the problem of isolating small but significant impulse perturbations that are summed, during measurement, with larger, low frequency, stationary vibration signals, such as imbalance and misalignment. These small impulse signals come from the accelerometer response to impulsive forces from bearing race defects, from roll flat spots, and even from felt joint connectivity.

Figure 1 shows a time domain plot of a typical raw transducer signal which includes small impulsive defect signals.

Figure 2 illustrates the separation of the small repetitive impulses from the complete large signal (which is dominated by low frequency machine synchronous components).

Although normal FFT spectrum analysis separates these signals into their fundamental and harmonics, the amplitudes are often too small to be seen above the instrumentation noise level.

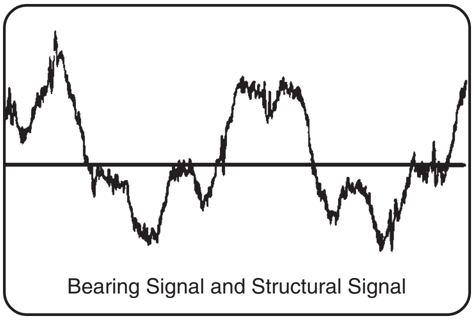


*Figure 1. A time domain plot which includes small impulsive defect signals.*

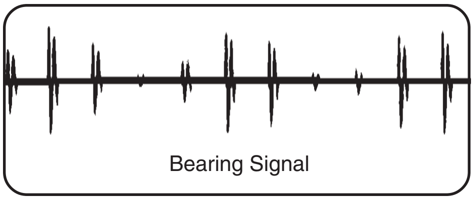


*Figure 2. Bearing signal.*

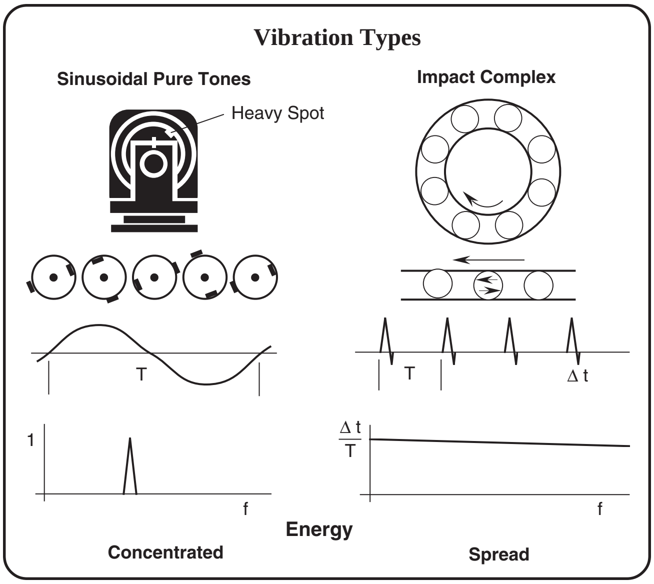


*Figure 3. Impact and machine vibration time frequency displays.*

**Application Note**

**CM3024**

Because of this low signal-to-noise ratio, these small spectral components are not generally measurable in the early onset of a bearing fault.

A small, narrow, repetitive impact signal, when converted to the frequency domain, results in a plot of small harmonic amplitudes with a frequency separation equal to the repetitive rate. Figure 3 compares the different amplitude/frequency relationships between a sinusoidal pure tone signal and a repetitive impulse.

The impulse signal amplitude is proportional to the pulse width ($\Delta t$) and pulse cycle interval (T).

The smaller this ratio is – that is, the narrower the pulse width – the smaller are the spectrum amplitudes. This ratio is, of course, related to the width of the bearing defect.

Initially, an accelerometer response signal is small in amplitude and narrow in time as each ball rolls over a newly developing fault. An acceleration spectrum plot at this early stage of defect growth would probably not show the defect as its amplitude is below the dynamic range of the measuring instrument. Vibration components identifying an incipient bearing failure are then not seen in an acceleration spectrum plot. However, enveloping technology, now implemented in many data loggers that incorporate FFT analysis, has proven to be an effective measurement tool because it modifies the raw vibration signal so as to enhance the rolling element bearing defect signal.

## The Basics of Enveloping

The envelope method separates a repetitive impulse from a complex vibration signal by using a band pass filter that rejects low frequency components that are synchronous with vibration. Figure 4 shows the optional filter selection from the SKF Condition Monitoring Microlog.

Although there are signal enhancements that result from structural resonances, the envelope method is not solely dependent on local resonance to isolate rolling element defect signals. Filter criteria selection is based on suitable rejection of the low frequency sinusoids while optimizing the passband of the defect harmonics. Figure 5 provides a table of filter selections based on rotational speeds in an analysis range.

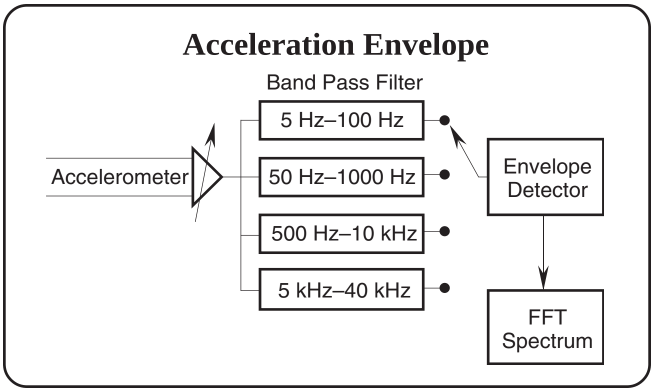


*Figure 4. Optimum filter options.*

After filtering the vibration signal, the resultant signal is enveloped by means of a circuit that approximately squares the signal.

Figure 6 shows the relationship between a time domain repetitive impulse signal and its FFT spectrum conversion. The peak component is the exponentially decayed signal modulated by the repetition frequency. The sidebands are spaced at the repetition rate frequency.

The enveloping process demodulates the signal which approximates a squaring function. This translates the signal in the frequency domain to a baseband display of the repetition rate harmonic components, where the component amplitude vs. frequency is equivalent to the

$$\frac{\sin x}{x} \text{ distribution } x = \frac{x = (\Delta t)}{T} \text{ radians}$$

These displays would only be seen if there are repetitive impulse components in a part of the overall raw vibration signal.

**Enveloping Settings Microlog**

| Filters | Frequency Band | Speed Range | Analyzing Range |
|---|---|---|---|
| 1 | 5 – 100 Hz | 0 – 50 RPM | 0 – 10 Hz |
| 2 | 50 – 1,000 Hz | 25 – 500 RPM | 0 – 100 Hz |
| 3 | 500 – 10,000 Hz | 250 – 5,000 RPM | 0 – 1,000 Hz |
| 4 | 5,000 – 40,000 Hz | 2,500 – … RPM | 0 – 10,000 Hz |

*Figure 5. Filter selection vs. speed/analysis range.*

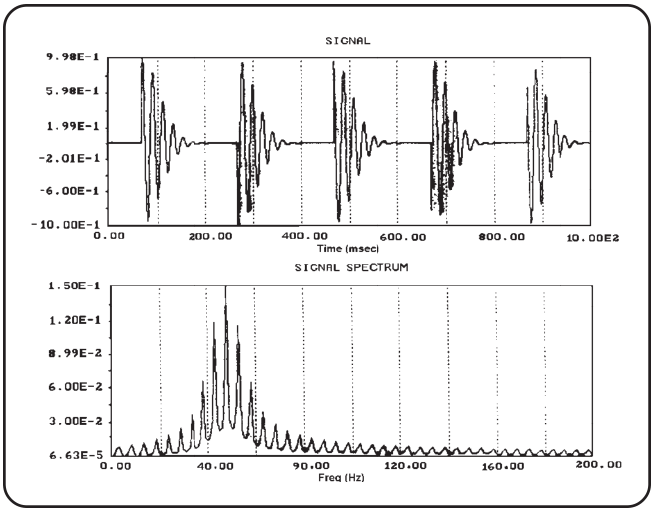


*Figure 6. An impulse/time spectrum display.*

Another way of understanding this translation to baseband is to consider the bandpass filtered signal as only comprising the higher frequency harmonic components of the repetitive impulse.

When this harmonic series is squared, sum and difference components are created. The difference components fold back into the analysis range while most of the summed components are outside analysis range.

An example of this process is discussed in the appendix where the filtered harmonic series is assumed to start at the 51st harmonic. Squaring this signal produces a vectored sum of each 1X, 2X, 3X, etc. difference components resulting in the (Figure 7) time spectrum display.

Again, this time spectral display of Figure 7 occurs only if a repetitive impulse signal is filtered from the raw composite vibration signal.

## A Paper Machine Case Study

A major problem associated with the wet section of a paper machine is the identification of improper (faulty) felt operation. Felt velocity is very slow which aggravates measurement analysis options.

A recent vibration monitoring interval at a paper machine at the KNP MAASTRICHT facility used acceleration enveloping methods to trend the felt operation in the wet section of a fine paper machine. An accelerometer was mounted on the granite roll bearing housing whose roll presses the felt and the paper against the crowned control roll. Figure 8 displays the overall acceleration envelope trend from 29 April to 13 May which shows a 3 to 1 upward trend of the overall level.

The instrumentation for Figure 8 was set up with a filter selection of 5 to 100 Hz, Fmax at 200 Hz, FFT lines: 400.

Another measurement was made on 19 May with 6,400 line resolution in both acceleration (Figure 9) and acceleration enveloping (Figure 10) which gave the first indication that the worn felt malfunction was dominating the spectrum plot.

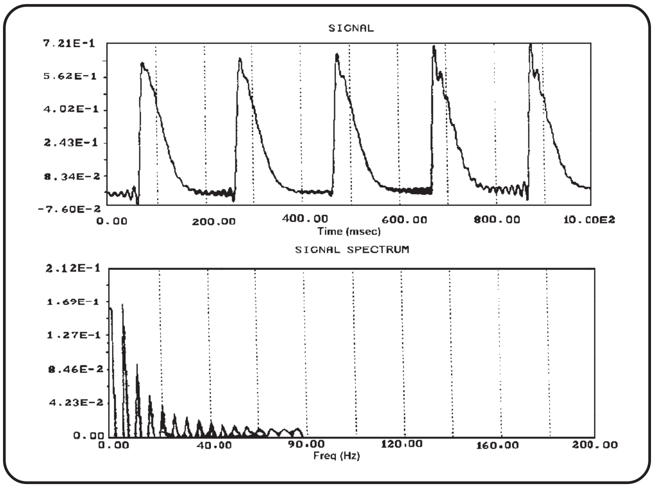
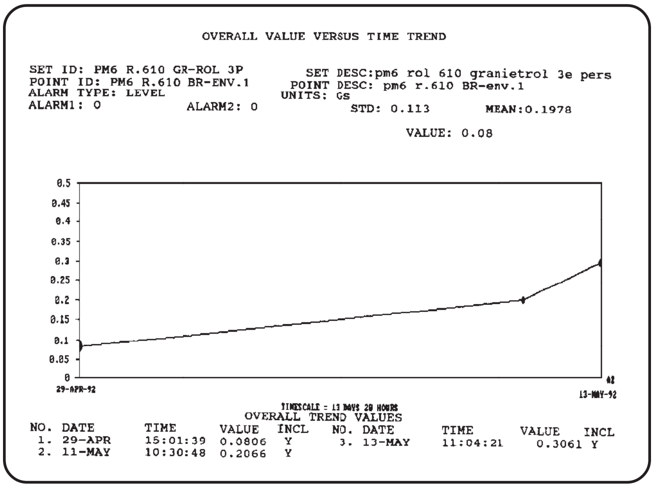


*Figure 7. An envelope/time spectrum display.*



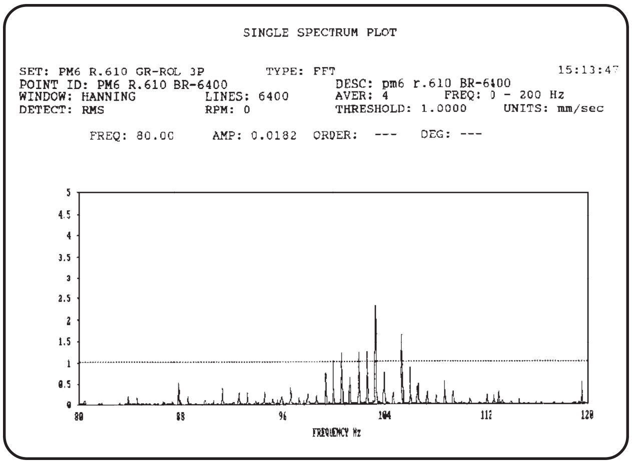
```
                OVERALL VALUE VERSUS TIME TREND

SET ID: PM6 R.610 GR-ROL 3P          SET DESC:pm6 rol 610 granietrol 3e pers
POINT ID: PM6 R.610 BR-ENV.1        POINT DESC: pm6 r.610 BR-env.1
ALARM TYPE: LEVEL                  UNITS: Gs
ALARM1: 0            ALARM2: 0            STD: 0.113       MEAN:0.1978

                                             VALUE: 0.08
```

```
                        OVERALL TREND VALUES
NO. DATE      TIME      VALUE  INCL   NO. DATE      TIME       VALUE   INCL
 1. 29-APR    15:01:39  0.0806  Y      3. 13-MAY    11:04:21    0.3061 Y
 2. 11-MAY    10:30:48  0.2066  Y
```

*Figure 8. An impulse/time spectrum display.*

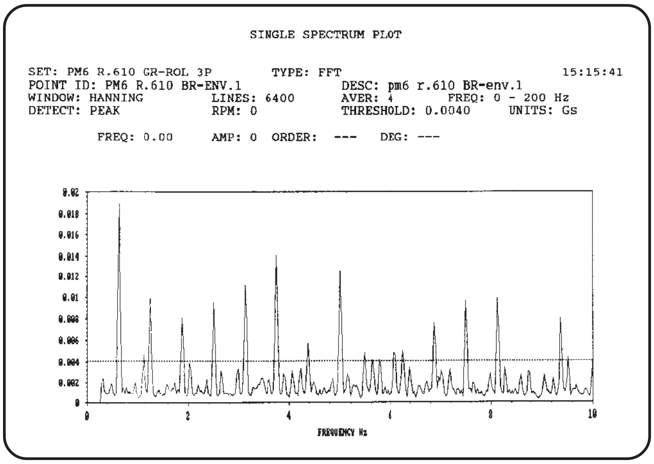


```
                     SINGLE SPECTRUM PLOT

SET: PM6 R.610 GR-ROL 3P       TYPE: FFT                           15:13:47
POINT ID: PM6 R.610 BR-6400              DESC: pm6 r.610 BR-6400
WINDOW: HANNING          LINES: 6400     AVER: 4       FREQ: 0 - 200 Hz
DETECT: RMS              RPM: 0          THRESHOLD: 1.0000    UNITS: mm/sec

       FREQ: 80.00     AMP: 0.0182  ORDER:  ---   DEG: ---
```

*Figure 9. An acceleration spectrum indicating felt rotation sidebands.*



```
                     SINGLE SPECTRUM PLOT

SET: PM6 R.610 GR-ROL 3P       TYPE: FFT                          15:15:41
POINT ID: PM6 R.610 BR-ENV.1             DESC: pm6 r.610 BR-env.1
WINDOW: HANNING          LINES: 6400     AVER: 4       FREQ: 0 - 200 Hz
DETECT: PEAK             RPM: 0          THRESHOLD: 0.0040    UNITS: Gs

       FREQ: 0.00     AMP: 0  ORDER:  ---   DEG: ---
```

*Figure 10. An enveloped spectrum indicating felt anomalies.*

The felt was changed and a new spectrum was obtained in acceleration enveloping on 27 May. It became apparent that the crown control roll was out of round (Figure 11) which showed up as rotational harmonic components.

Another measurement was made on 1 June and again the worn felt symptom appeared as a dominant vibration component (Figure 11).

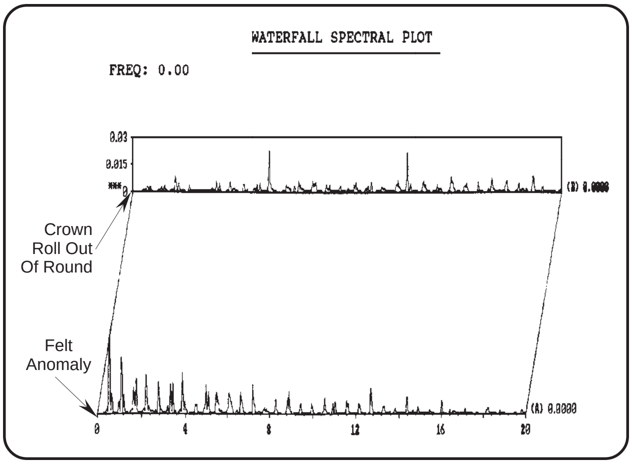


*Figure 11. Development of a crown roll defect into a felt anomaly.*

This time both the felt and the crown control roll were changed. In the monitoring sequence that followed, neither felt nor crown roll have given indication of further operational problems.

## Conclusion

The acceleration enveloping technique is emerging as a very practical measurement tool for assessing initial problems associated with bearings, rollers, and felt rotation. The very low speeds at which these measurements occur are often at sensitivity limits of transducers and electronics. In the past, synchronous time averaging over very long intervals was required to isolate problems to a particular roller by establishing external trigger references.

In this case study enveloping has proven to be a very effective method to diagnose impact forces developed by roll eccentricity, flat spots, and rolling element bearing defects. Although enveloping is not the panacea for diagnosing all machine problems, it has become an adaptable and effective measurement in the tool box of analysis techniques.

### Appendix:

Because: $(\sin \alpha)(\sin \beta) = \frac{1}{2}\cos(\alpha - \beta) - \frac{1}{2}\cos(\alpha + \beta)$,

Assume an acceleration signal is filtered to pass only the higher orders of a bearing defect frequency greater than the 50th harmonic. When a harmonic series is multiplied by itself, the resultant series is a summation of all the sum and difference components that are developed during the multiplication process.

$$
\begin{aligned}
&f(A) \times f(A) = \\
&\quad f(A) = \sin(51A) + \sin(52A) + \sin(53A) \ldots + \sin(99A) + \sin(100A) \\
&\quad \times \\
&\quad f(A) = \sin(51A) + \sin(52A) + \sin(53A) \ldots + \sin(99A) + \sin(100A) \\
&\quad = \sin(51A)\sin(51A) + 2\sin(51A)\sin(52A) + 2\sin(51A)\sin(53A) \ldots \\
&\quad + 2\sin(51A)\sin(100A) + 2\sin(52A)\sin(51A) + \sin(100A)\sin(100A)
\end{aligned}
$$

Since the sum components $(\alpha + \beta)$ are generally outside the analysis measurement range, we are interested only in the difference components.

The products which are one unit apart (such as 52A and 51A) produce a 1X component according to:

$$1X\ component = \sum_{n=51}^{n=100} \sin[(n+1) - n]A = \sum_{n=51}^{n=100} \sin A$$

Similarly, any mX component produces:

$$mX\ component = \sum_{n=51}^{n=100} \sin[(n+m) - n]A = \sum_{n=51}^{n=100} \sin mA$$

These 1X, 2X, 3X, etc., components, produce FFT peaks at the 1X, 2X, 3X, etc., frequencies, thus permitting normal FFT analysis.

**SKF Reliability Systems**
4141 Ruffin Road
San Diego, California 92123
USA
Telephone (+1) 858-496-3400
FAX (+1) 858-496-3531

***Web: www.skfreliability.com***

**CM3024 (Revised 8-00)**