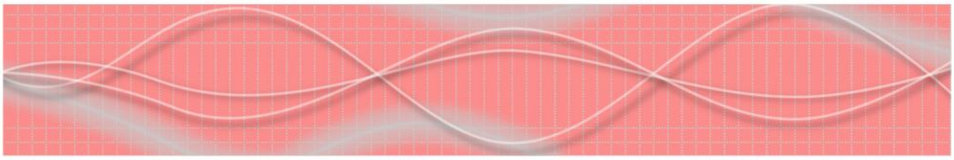
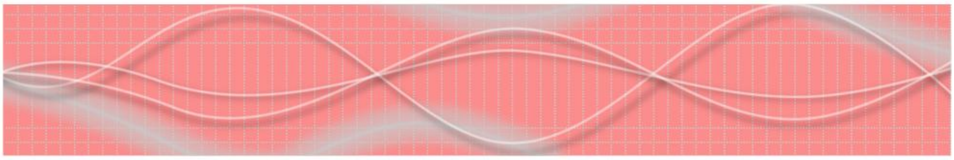
Professional Signal & Spectrum Analysis



WHITE PAPER

Order Tracking Analysis of Variable-Speed Machinery

Decoupling shaft-related faults from structural resonances with SIGVIEW



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SIGVIEW WHITE PAPER

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Decoupling shaft-related faults from structural resonances with SIGVIEW

Overview

A machine running at constant speed produces a clean FFT: every shaft-related fault sits at a fixed multiple of the rotational frequency. When the machine accelerates or decelerates — engine run-up, turbine startup, electric drive ramp — those same lines smear across the spectrum and become invisible. Order tracking resamples the signal against shaft angle rather than time, so a frequency expressed in “orders” (multiples of shaft speed) remains stationary regardless of how the speed varies. SIGVIEW provides this transformation through the Signal Calculator, requiring nothing more than a synchronized Tacho or RPM signal and a few clicks.

Background

The smearing problem

Consider a fan rotor with a slight imbalance accelerating from 600 rpm to 3000 rpm in 10 seconds. The 1× shaft line moves from 10 Hz to 50 Hz; the 2× line from 20 Hz to 100 Hz; the 3.5× component (a common bearing-cage signature) from 35 Hz to 175 Hz. A conventional FFT of the whole record yields no peaks — all the energy is spread across these bands. A spectrogram shows diagonal lines that are hard to interpret quantitatively.

What order tracking does

Given the instantaneous shaft phase $\theta(t)$, order tracking computes $y(\theta)$ by resampling $x(t)$ at constant $\Delta\theta$ intervals (constant angular increments). In the resulting signal, a fault tied to shaft rotation appears at a fixed “order” — order 1 is the shaft itself, order 2 is twice per revolution, order 3.5 is 3.5 events per revolution, and so on. Structural resonances, by contrast, stay at a fixed frequency in Hz and therefore smear across orders, becoming easy to discriminate from rotational defects.

Required Inputs

- **Vibration signal:** accelerometer or velocity transducer recording during the speed change.
- **RPM signal:** a reference signal of shaft speed versus time, expressed in revolutions per minute. Sampling rate can differ from the vibration signal; duration should match within ±10 %.

The RPM signal typically comes from a tachometer (one pulse per revolution) processed into RPM. SIGVIEW includes the Custom tools / Convert Tacho-Signal to RPM tool for exactly this purpose.

Test Signal

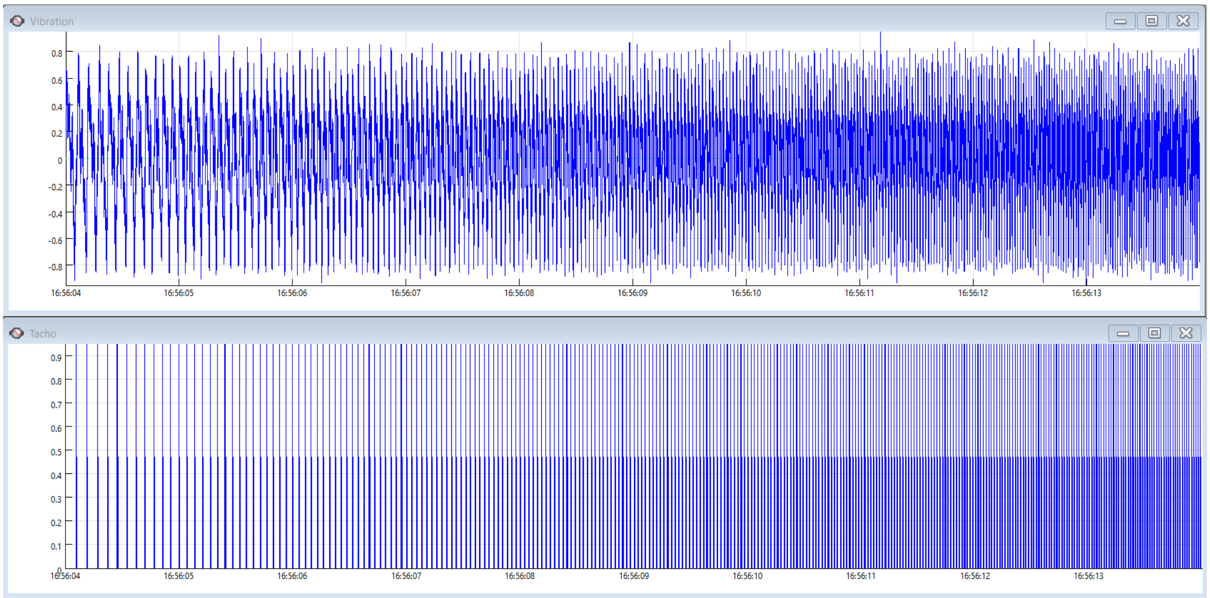
A simulated run-up dataset is provided:

- `runup_2ch.wav` — 10 s, 8000 Hz, 2 channels. Channel 1: vibration of a shaft accelerating from 600 rpm to 3000 rpm, containing order-1 (imbalance), order-2 (misalignment), order-

3.5 (developing bearing-cage fault), and a fixed 320 Hz structural resonance. Channel 2: tachometer pulses, one per shaft revolution.

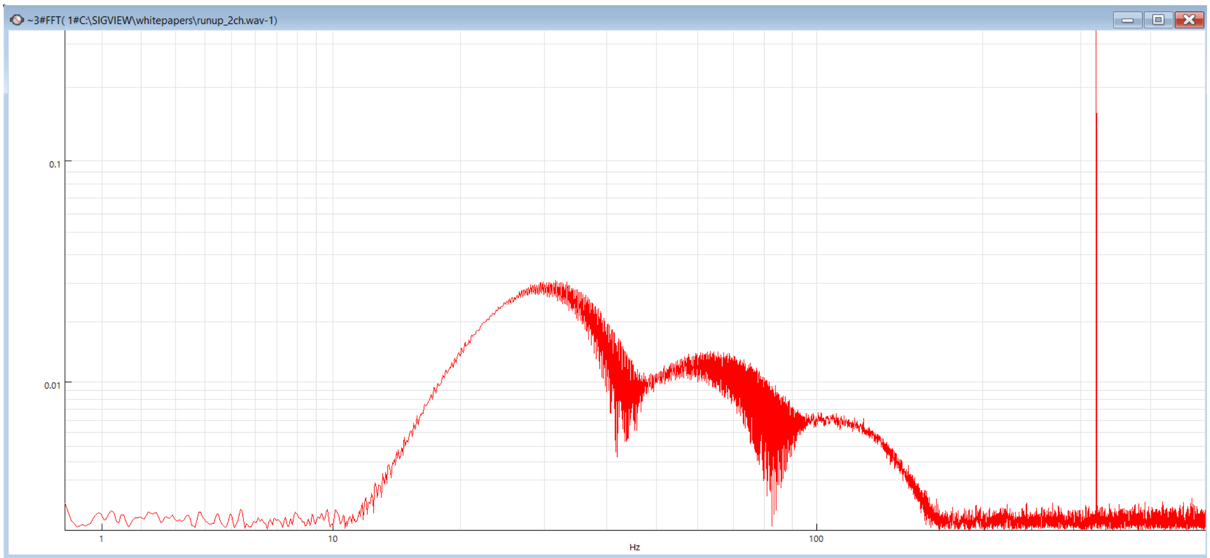
Procedure in SIGVIEW

1. **Load the signal.** Open `runup_2ch.wav` via `File / Open signal...`. SIGVIEW creates two synchronized signal windows: vibration and tacho.



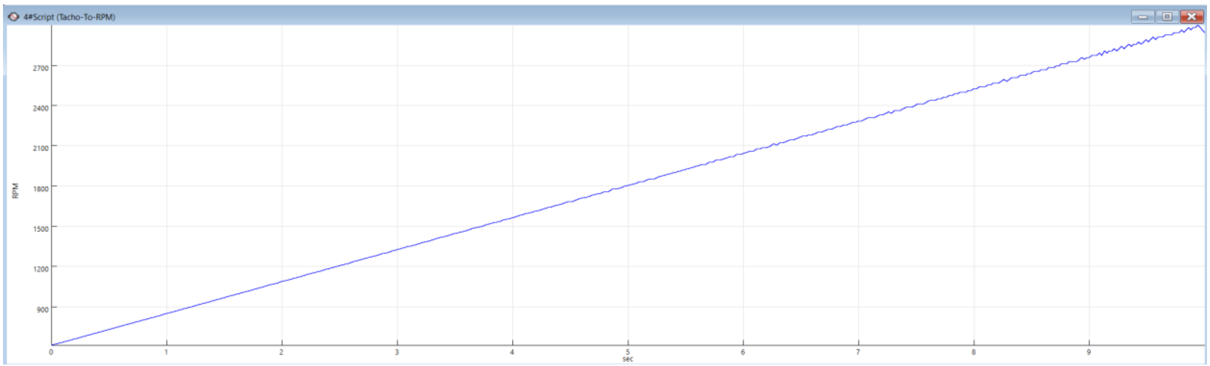
Loaded `runup_2ch.wav` time-domain signal loaded. Top: vibration signal — visibly increasing in frequency content over its 10 s duration. Bottom: tacho pulse train — pulses are widely spaced at the start of the record and densely packed at the end, reflecting the speed-up. Window title changed to describe the content.

2. **Compute the conventional FFT first, to see why it fails.** Click the vibration window and press Ctrl+F. Open the FFT window via Properties... and switch the Y-axis to dB units — or set this globally under `Signal tools / Spectral analysis defaults` so every new spectrum opens in dB. Zoom the X-axis to 0–500 Hz (Edit / Zoom to X samples/values or with the mouse).



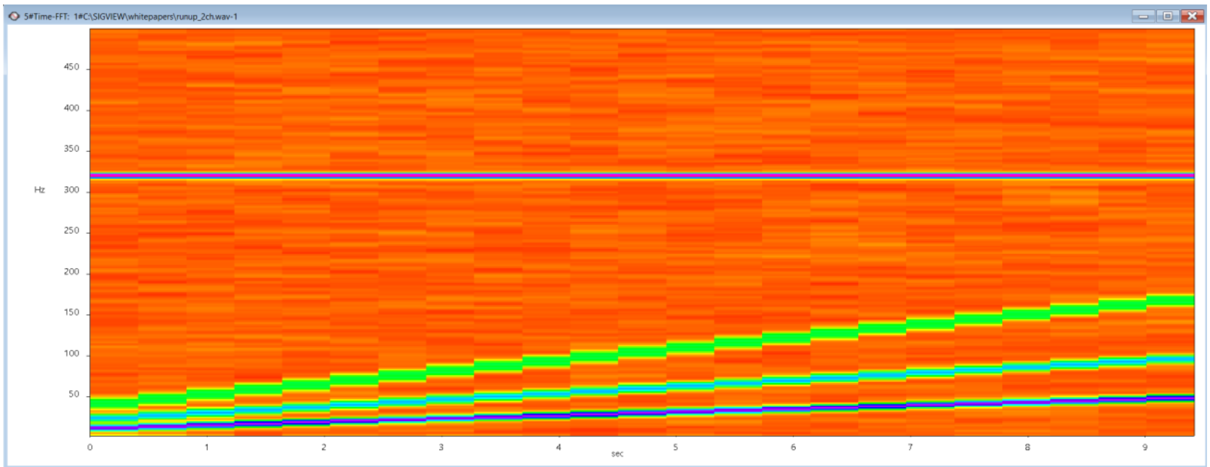
The spectrum tells you very little: a broad, featureless mound of energy fills the 10–200 Hz region with no discrete peaks. The mound is the order-1, order-2, and order-3.5 shaft components — each swept its actual frequency continuously during the record, so the FFT cannot resolve any of them as a line and spreads each one's energy across hundreds of bins. A sharp peak at ~320 Hz is related to the structural resonance frequency.

3. **Convert the tacho pulses into an RPM signal.** Click the tacho window. Choose `Signal tools / Use custom tool / Convert Tacho-Signal to RPM`. A new RPM-signal window is created showing a smooth ramp from 600 to 3000. Change window title to "RPM".



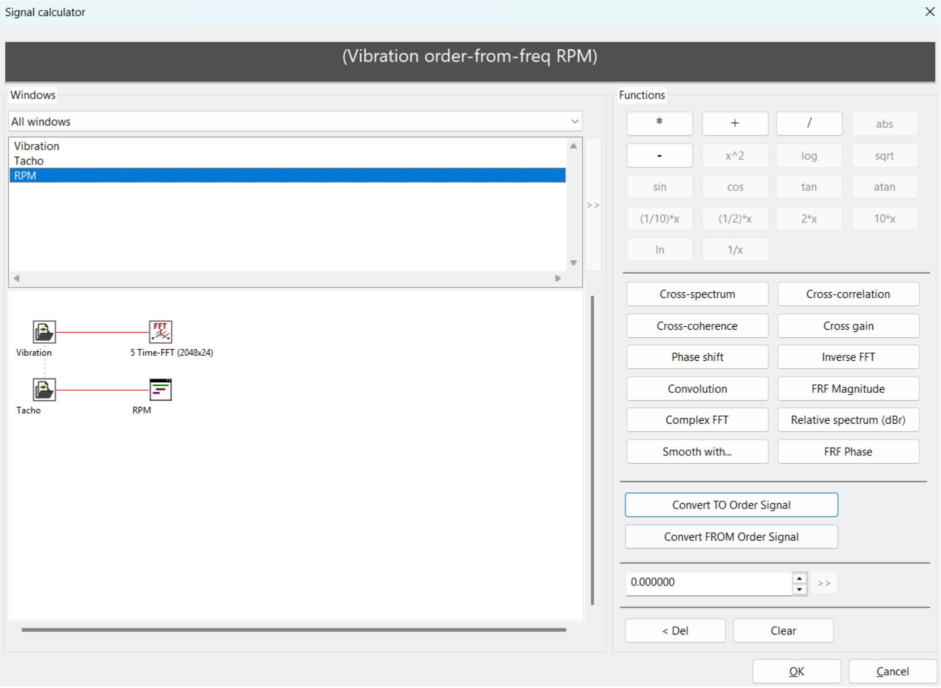
A clean monotonic ramp from 600 rpm at t=0 to 3000 rpm at t=10 s. X-axis in seconds; Y-axis in RPM.

4. **Inspect the time–frequency content first.** Click the vibration window and choose `3D Tools / Spectrogram...`. Select `High frequency resolution` and limit the frequency range to 500Hz.



Time-FFT spectrogram of the raw vibration signal. X-axis: time 0–10 s. Y-axis: frequency 0–500 Hz. Three diagonal ridges sweep upward from low frequency at t=0 to higher frequency at t=10 s: the 1×, 2×, and 3.5× shaft lines. A horizontal bright band sits at ~320 Hz — the fixed structural resonance.

5. **Convert the vibration signal to the order domain.** Choose `Signal tools / Signal calculator...`. Add Vibration signal to the expression. In the function list select `Convert TO Order signal`, then add the RPM signal window as the second window to the expression. Click OK. A new signal window is created with the X-axis in revolutions (or "orders") instead of seconds.

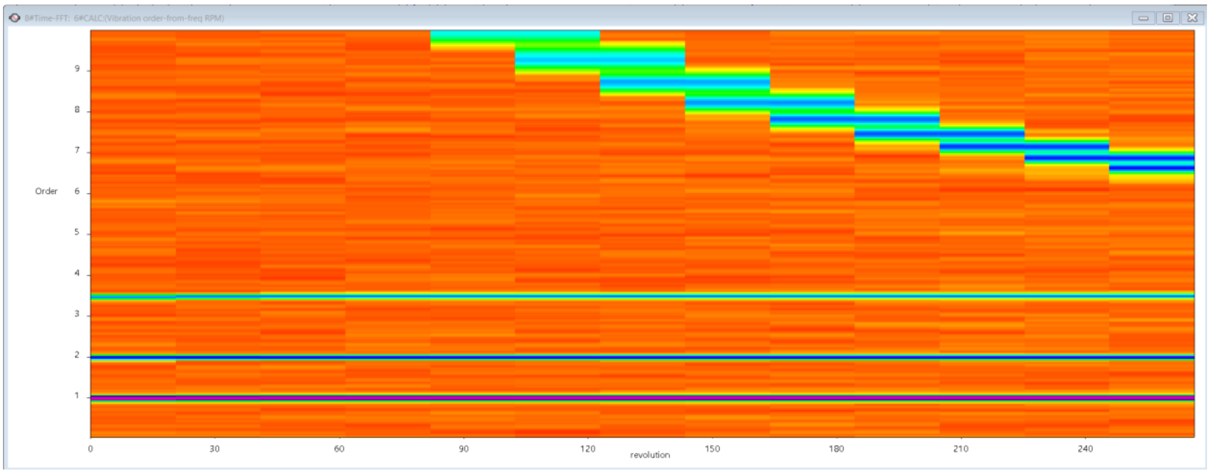


(Vibration order-from-freq RPM)

Signal Calculator dialog. Function: "Convert TO Order signal". Input 1: vibration window. Input 2: RPM signal.

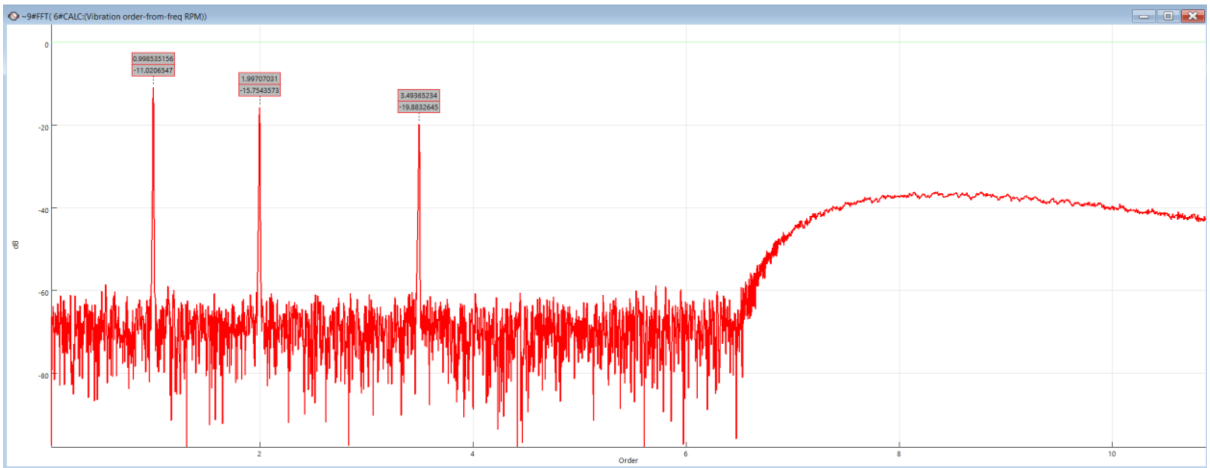
> **Important:** The vibration and RPM signals must overlap in time. Their durations should be within ±10 % of each other. SIGVIEW interpolates the RPM signal to match the vibration sample rate before resampling.

6. **Take the spectrogram of the order signal.** On the new order-domain window choose 3D `Tools / Spectrogram...` Select High frequency resolution and limit the frequency range (now in revolutions/order units) to 10. The result is a spectrogram plot with revolutions on X, order (oscillations per revolution) on Y.



Order-domain spectrogram. X-axis: revolutions (0 to ~300). Y-axis: order (0–10). The three rotational components now appear as straight horizontal lines at orders 1.0, 2.0, and 3.5 — perfectly stationary regardless of speed. The structural resonance at 320 Hz appears as a smeared curve (because at constant 320 Hz the order changes with speed). The two phenomena are now visually separated and easy to identify.

7. **Compute the order spectrum (average across all revolutions).** Click the order-domain signal window and press `Ctrl+F` for FFT. The X-axis of the resulting spectrum is in orders. Each shaft-related fault appears at a discrete value: integer orders point to balance / alignment issues, fractional orders point to specific bearing or cage signatures.



Order spectrum of the converted signal. X-axis: order 0–10. Y-axis: amplitude (dB). Three clear peaks at order 1.0, order 2.0, and order 3.5. The structural resonance contributes a broad low-amplitude smear because it does not align with any fixed order — exactly the opposite of the raw FFT case.

8. **Identify components.** Read the order values directly from the Peak detection markers:

- **Order 1.0:** once-per-revolution → mass imbalance or coupling misalignment.
- **Order 2.0:** twice-per-revolution → angular misalignment, bent shaft, or stiffness asymmetry.
- **Order 3.5:** non-integer → bearing cage frequency, gear-mesh sub-harmonic, or another sub-synchronous defect.

Filtering in the Order Domain

A powerful follow-up step is to filter unwanted order components out of the signal, then convert back to the time domain. With the order-domain window selected, apply `Signal tools / FFT filter` specifying a band-stop around orders 1.0, 2.0, etc. Then use the Signal Calculator function `Convert FROM Order signal` with the same RPM signal as the second input. The result is a time-domain signal with all shaft-locked content removed — useful for isolating structural resonances or bearing impacts that ride on top of a strong rotational background.

Interpretation Cheat-Sheet

Pattern in the order spectrum	Likely diagnosis
Dominant peak at order 1.0, low harmonics	Mass imbalance — common in fans, impellers, machined rotors
Strong order 2.0 with smaller 3.0, 4.0 harmonics	Misalignment (parallel or angular) at a coupling
Half-orders (0.5, 1.5, 2.5)	Mechanical looseness or bearing clearance issues
Non-integer orders with sidebands	Bearing fault — compare against catalogue BPFO/BPFI/BSF multipliers
Integer orders matching tooth count (e.g. order 24 on a 24-tooth gear)	Normal gear mesh — concern only if amplitude grows trend-wise
No peaks at integer orders, only smeared structural lines	No rotational fault — investigate fluid, electrical, or mounting issues instead

Summary

Order tracking turns a smeared run-up FFT into a clean, interpretable spectrum and visually separates rotational faults from structural resonances. SIGVIEW’s Signal Calculator provides the forward and inverse order transformations as single function calls; combined with the spectrogram and FFT tools.