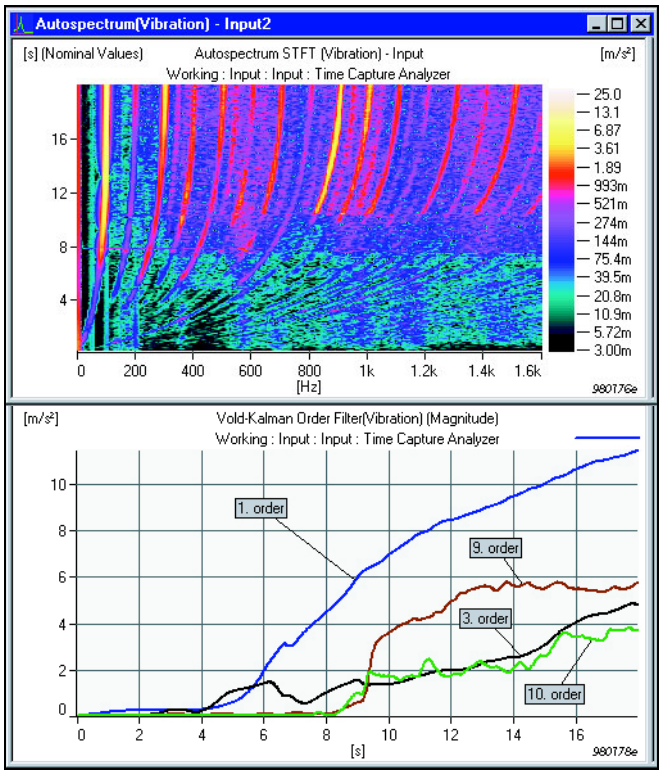
PRODUCT DATA

Vold-Kalman Order Tracking Filter — Type 7703 for PULSE, the Multi-analyzer System Type 3560

Vold-Kalman Order Tracking Filter Type 7703 allows high-performance tracking of harmonic responses, or orders, of periodic loads in mechanical and acoustical systems. This method allows the beat-free extraction of close and crossing orders in systems with multiple axles, and possesses a finer frequency and order resolution than conventional techniques. The tracking capabilities are independent of the rate of change of the rotational speed (slew rate).



Uses and Features

USES

- Amplitude and phase of first order for multiplane balancing and foundation diagnoses of industrial rotors
- Amplitude and phase for operating deflection shapes per order
- Separation of drive shaft orders from wheel orders in suspension tuning
- Isolation of order interaction phenomena in subjective sound quality studies
- Separation of sinusoids from broadband noise

FEATURES

- Post-processing operations on any number of channels at any sampling rate
- Order extraction as phase assigned order or order waveform as a function of time
- Order extraction independent of the rate of change of rotational speed (slew rate)
- No phase bias in time domain waveform extraction
- Separation of interacting orders in multi-shaft systems overcoming beat phenomena
- Ultra-fine tracking resolution in absolute bandwidth or constant percentage bandwidth
- 1-, 2- and 3-pole filter shapes
- RPM profile (RPM versus time) estimation using least squares cubic splines giving accurate instantaneous RPM
- Repair of RPM profile in cases of tacho signal drop-outs
- Hinge points in RPM profile allowing for, for example, gear shifts
- Playback of order waveform through a sound card

Brüel & Kjær

Fundamentals of Order Tracking

Mechanical systems under periodic excitation, such as machines with one or more rotating shafts or reciprocating components, will, in vibration and noise measurements, respond with a superposition of sine waves. The frequencies of these sine waves are integer multiples of the fundamental of the involved excitation frequencies. The sine waves are called harmonics, or orders, of the respective excitations. As the frequencies of the periodic excitations change, the frequencies of the orders will accordingly.

From the excitation "point" in the machine to the measurement point, the sine waves are subjected to the transfer characteristics, the Frequency Response Function (FRF), of the structure, meaning that all the sine waves or orders have their amplitude and phase changed in accordance with the FRFs.

When the excitation frequencies change, the responses will still be harmonics of the excitations for non-linear structures, but the non-linearity will generate higher harmonics. Mechanical looseness or rattling may generate subharmonics. Some machinery may have inherent modulation mechanisms giving rise to orders that are not integers of the excitation frequencies but rather modulation products of the excitations.

The art of order tracking is to extract selected orders in terms of amplitude and phase, the phase assigned order, and the waveform it self, the order waveform. The order waveform and the phase assigned order are given as functions of time.

Phase Assigned Orders and Order Waveforms

A harmonic is a sine waveform whose instantaneous frequency is a constant multiple of that of an underlying periodic load. The amplitude and phase of the harmonic is a function of the load and the transfer characteristics of the system, and is called the phase assigned order. The output of the Vold-Kalman filter is the order waveform as a function of time. The filter is symmetric in time, such that there is no phase bias. The phase assigned order, i.e., amplitude and phase as a function of time, may also be generated from order waveform.

Capabilities

The Vold-Kalman tracking filter provides a very sharp single-pole filter shape for compatibility with first generation Kalman filtering, and 2- and 3-pole filters with flatter passband and improved selectivity of orders. Filter bandwidth is specified in absolute bandwidth or in constant percentage bandwidth.

The method allows for the simultaneous extraction of orders, also with respect to multiple shafts, such that even close and crossing orders may be extracted without beating interactions.

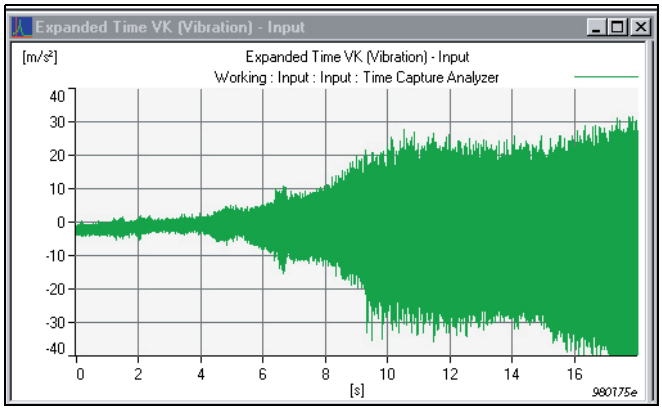
The RPM estimation is performed with a least squares cubic spline curve fit with the possibility of automatic repair of RPM profiles in cases of tacho signal drop-outs. The algorithm allows for sudden RPM changes experienced, for example, in engaging and disengaging the clutch and in gear shifts.

Operation

The steps in a Vold-Kalman order analysis procedure are as follows:

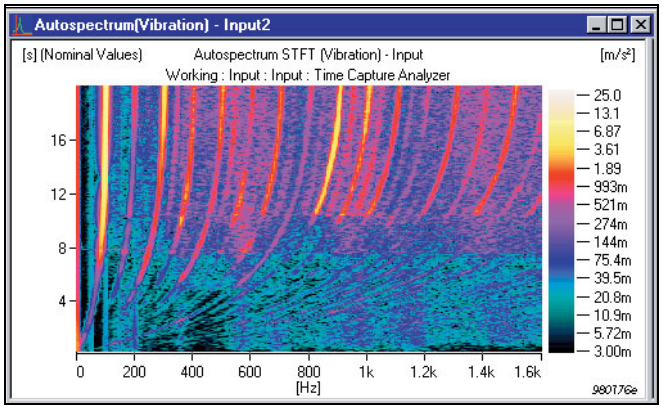
- Depending on the length of the time signal (see Requirements in the Specifications), use an FFT analyzer in Type 7700 or Type 7770, Time Capture Type 7705 (Fig. 1) or Data Recorder Type 7701 to acquire the tacho signals and the response signals.

Fig. 1
The time history record of a vibration response from a fast run-up using Time Capture Type 7705



- Make waterfall and contour plots of the acquired data using FFT analysis. This gives an overview of the event to be analysed (Fig. 2)

Fig. 2
Short-time Fourier Transform of the vibration signal of the run-up



- Select the part of the acquired time signal to be analysed
- Estimate the RPM profile (Fig. 4)
- Use the Vold-Kalman filter to extract the selected phase assigned orders (Fig. 5) or the order waveforms (Fig. 6)

Fig. 3
Recorded tacho signal

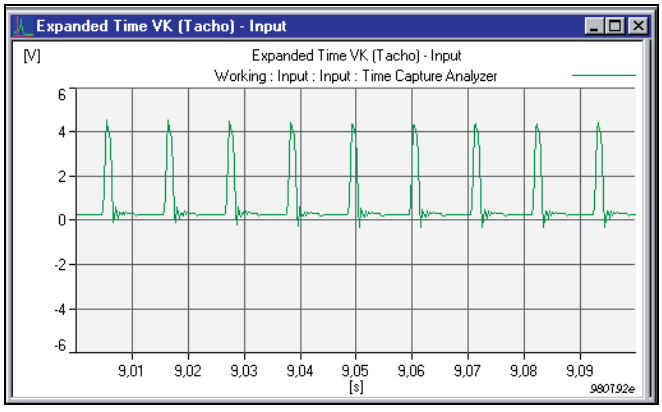


Fig. 4
RPM Profile (RPM as a function of time) estimated from a recorded tacho signal

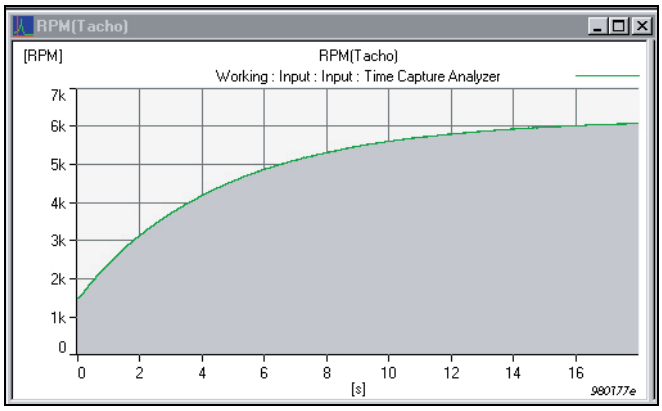
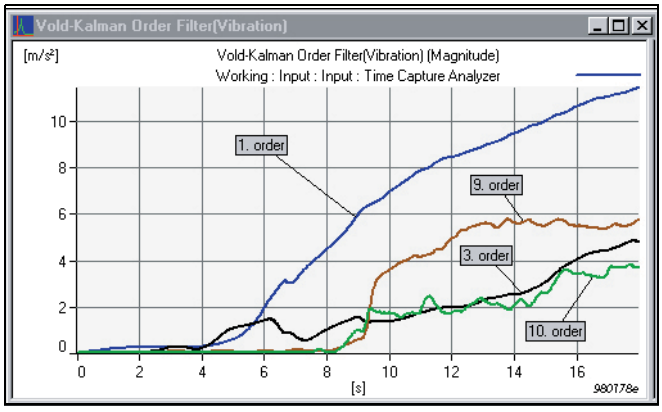


Fig. 5
Magnitude of selected (phase assigned) orders extracted using the Vold-Kalman Order Tracking Filter Type 7703



Comparison of Methods

Compared to other order analysis methods, Vold-Kalman Order Tracking Filtering offers a number of unique advantages

General advantages

- Beat-free decoupling of close and crossing orders
- Advanced tachometer signal processing including automatic wild point rejection

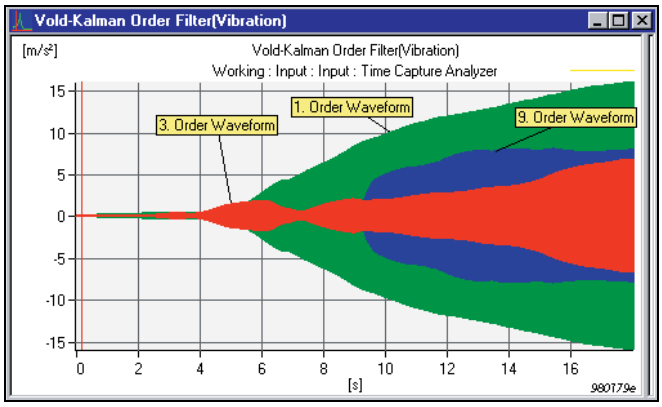
Advantages compared to FFT-based Order Analysis

- Fine resolution in both the time and the frequency domain
- No slew rate limitation
- Order waveform
- No picket fence effect error (amplitude error)

Advantages compared to Order Tracking

- Fine resolution in both the time and the frequency domain
- No slew rate limitation
- Order waveform

Fig. 6
Three order waveforms extracted by Vold-Kalman filtering of the run-up response signal



Advantages compared to Digital Tracking Filters

- Much shorter transients
- No phase bias (for most digital filters)
- Order waveform and phase assigned orders
- No slew rate limitation

Advantages compared to 1st Generation Kalman Tracking Filters

- Filter bandwidth specified in Hz or %
- Multipole filters for flat passband and improved selectivity

Specifications – Vold-Kalman Order Tracking Filter Type 7703

Type 7703 is software for use with PULSE, the Multi-analyzer System Type 3560

Requirements

- The PC Requirements for Multi-analyzer System Type 3560 must be fulfilled
- FFT & CPB Analysis Type 7700 or FFT Analysis Type 7770 must be installed
- The max. time record is 16 k samples (e.g., T = 2 s for 3.2 kHz span) for Types 7700 and 7770.
  Hence, Time Capture Type 7705 is strongly recommended for capturing of and selection in long time records
- The Time Capture real-time channel × bandwidth product (ChBW) depends very much on the PC and the amount of graphics displayed. Time Capture ChBW products above 200 kHz are obtainable, but for high ChBW products (high frequency range and/or many channels), the use of the Data Recorder Type 7701 is typically required

Processing Functions

Type 7703 includes the following processes:

- Vold-Kalman RPM profile estimation from tacho signals – spline curve fit of RPM profile overcoming tacho signal drop-outs
- Vold-Kalman Order filtering (phase-bias-free filtering conserving the phase properties of the signals)

Processing Control

Type 7703 allows control of calculations as follows:

- Tacho pulse detection controlled by tacho level, slope and hysteresis and number (real) of tacho pulses per revolution
- RPM profile curve fitting controlled by segmentation of, and allowance for, hinge or bend points in the profile. The RPM profile may be decimated to reduce the amount of output data
- Vold-Kalman order filtering based on one or more RPM profiles. The filtering is controlled by single-pole filters and 2- and 3-pole filters (flat response and better selectivity). For all filter types, the bandwidth (BW) can be set as a constant BW [Hz] or as a constant percentage BW [%] (of the order)

The outputs are one or more orders (order no. being an integer or real) in terms of: order waveforms as function of time or phase assigned orders (amplitude and phase) as function of time. The phase assigned order output may be decimated to reduce the amount of output data

Display

Specifications are the same as for FFT & CPB Analysis Type 7700 with the following additions:

RPM TYPES:

- Raw RPM and spline fitted RPM profiles for verification of the correctness of the fit

ORDER TYPES:

- Order waveform as function of time
- Phase assigned order as a function of time

Vold-Kalman Order Tracking Properties

ORDER EXTRACTION:

Tracking: Tracks non-progressive RPM profiles including sudden RPM changes (e.g., gear shifts). Unlimited RPM change rate, acceleration

Filtering: Phase-bias-free filtering conserving the phase properties of the analysed signals

Order Decoupling: If more orders are extracted jointly, coupled – i.e., crossing or close orders – will be extracted decoupled and beat-free

RPM PROFILE SPLINE FITTING:

Segmentation and Hinge Points: The spline fit may be segmented and equipped with hinge points. Each segment accounts for a local RPM maximum or minimum; for a progressive RPM profile 8 – 10 segments yields a god fit. The hinge points allow for sudden RPM changes as introduced, for example, by a gear shift

Tacho RPM Repair: Tacho signal drop-outs may be rejected still obtaining a good RPM profile.

Ordering Information

Type 7703-X[1] PULSE Vold-Kalman Order Tracking Filter

Type 7703 requires FFT & CPB Analysis Type 7700 or FFT Analysis Type 7770

Optional Accessories

For long time records and/or high channel × bandwidth products:
Type 7701-X[1] PULSE Data Recorder
Type 7705-X[1] PULSE Time Capture

1. X indicates the license model, either N: node locked, or F: floating

Standard Configurations

Type 7703 is also available as part of pre-defined standard configurations. For further details see the “PULSE Analyzers & Solutions” Catalogue (BF 0209)

Services

M1-7703-X[1] Software Maintenance and Support Agreement
M2-7703-X[1] Software Maintenance and Upgrade Agreement

See the Software Maintenance and Upgrade Product Data (BP 1800) for further details of M1 and M2 Agreements

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