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FFT VS. VOLD-KALMAN BASED ORDER ANALYSIS OF A GEARSHIFT EVENT

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ABSTRACT
In this paper a comparison between two order analysis techniques is made, namely a real-time FFT based order analysis using fixed sampling frequency and Vold-Kalman based post-processing order tracking. The measurement was done on a light truck with a V-8 engine and an overdrive automatic transmission, which was run on a dynamometer in a semi anechoic room. A full-throttle run-up was performed under light load condition from 1st to 4th gear through 2nd and 3rd gear. Especially around the gearshift events the results have been compared. The advantages and disadvantages of the two methods are also summarized.

1 - INTRODUCTION
The Vold-Kalman filter allows for the high performance simultaneous tracking of orders in systems with multiple independent shafts. With this new order waveforms, as well as amplitude and phase may be extracted without slew rate limitations as found with conventional methods. See refs [1,2,3,4,5,6].

2 - ANALYSIS OF A GEARSHIFT EVENT
The measurement was done on a light truck with a V-8 engine and an overdrive automatic transmission, which was run on a dynamometer in a semi-anechoic room. For this example a full-throttle run-up was performed under light load condition, using a tractive (drag) force of only 50 lbf (≈222 N). Fig. 1 shows the RPM versus time curves from the tachometers on both the engine and the drive shaft (propeller shaft) for the complete run using a wide frequency and time range pre-analysis. See also ref [6] for more details.

Microphone signals from a binaural recording using a Brüel & Kjær HATS (Head and Torso Simulator) Type 4100 in the passenger seat, as well as accelerometer signals at several locations (pinion gear housing, transmission case at drive shaft side etc.), were recorded. The right ear signal from the HATS was analyzed in order to illustrate the capability of the Vold-Kalman Order Tracking Filter for handling gearshifts. It was decided to focus on the shift from the 2nd gear into the 3rd gear around time 11,5 s shown in Fig. 1. Thus a second PULSE multi-analysis of the recording was performed using a Tachometer Analyzer for triggering and RPM detection and monitoring purposes, an FFT analyzer for real-time FFT-order processing and a Time Capture Analyzer for capturing data for Vold-Kalman order tracking analysis.

For the FFT analysis a 400 Hz baseband, 100 line analysis (T=250 msec. and Δf=4 Hz) with Maximum overlap was performed. Maximum overlap was in this case 99,5% since each FFT calculation including averaging etc. took 1,4 ms. Exponential averaging with 1 average was used. Spectra as well as pre-processed order slices were stored into a multi-buffer, using the 1900 RPM of the drive shaft as a start reference, i.e. used as time zero. Update interval was 10 ms with a total of 551 spectra corresponding to a duration of 5,5 s.

The time Capture Analyzer was also triggered to start at 1900 RPM making a 5 s recording up to approximately 2800 RPM using a frequency range of 1600 Hz corresponding to a total of 20 480 time samples per channel.

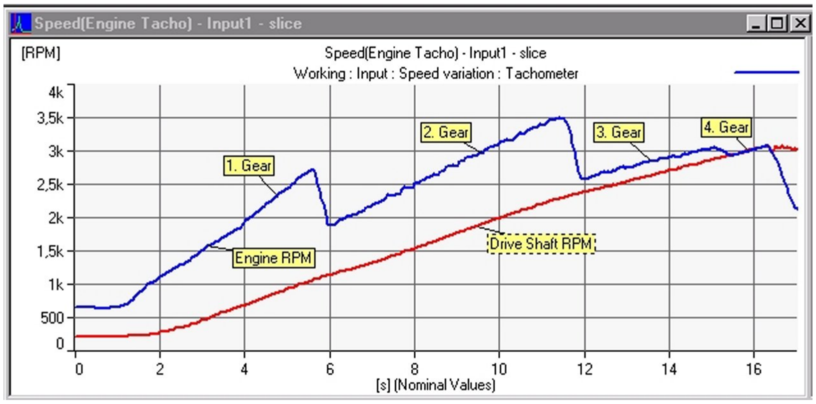

Figure 1: RPM profiles of run-up, with gear shift events.

As expected a contour/waterfall plot indicates that the dominant frequency content is found along the half-order lines of the engine, especially also at orders 4.0, 8.0 and 12.0, the V-8 engine firing harmonics. The 4^{th} order is the dominating order both before and after the gearshift.
The data represents a typical case of high slew rates, especially the engine RPM at the shift points (up to 2800 RPM/s). Fig. 2 displays the engine RPM curve near the shift from 2nd into 3rd gear, showing the curvefit RPM (smoothed) curve overlaid with the raw estimate (RPM table). The hinge point was found from the raw RPM by using the "display zoom" facility and visual inspection as well as the standard cursor readings, Maximum and Minimum Values (in this case found by PULSE at 1,758 s and at 2,280 s respectively). These numbers were then keyed into the Vold-Kalman RPM Curve Fit property page. In the actual calculation the Number of Segments was set to 10 even though fewer segments could have been used successfully.

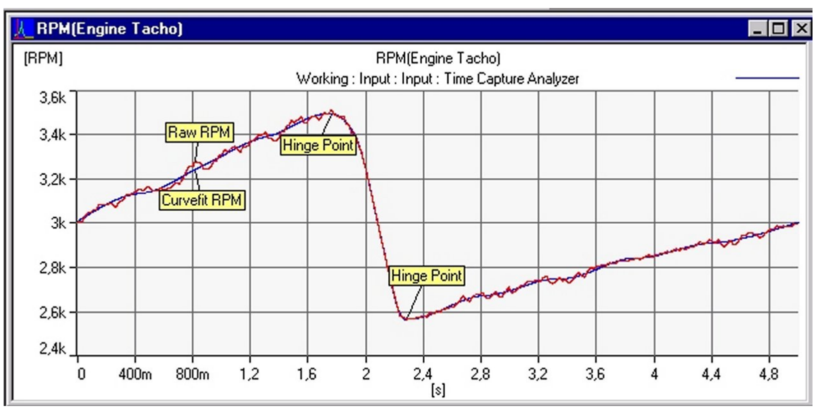

Figure 2: Detail of the Raw RPM (rippled curve) and the Curve Fit RPM (smooth curve) at the shift point.

Fig. 3 shows the magnitude of engine order 4.0, extracted using a three pole Vold-Kalman filter with a relative bandwidth of 20 % ($\approx$ 10 Hz). Fig. 4 shows the magnitude of engine order 4.0 using real-time FFT processing. Also an order slice bandwidth of 20 % corresponding to approximately 2,5 FFT lines was used for comparison purposes. Due to the record length of 250 ms, all FFT based events are displaced, compared to the Vold-Kalman extracted order, with a delay of 125 ms corresponding to 1/2 the FFT record length.
When comparing the two 4th order slices the two methods agree extremely well for the slowly changing amplitudes, but the FFT is not able to accurately track the two rapid level changes which are seen in the Vold-Kalman results around the shift point between time 2,0 s and 2,4 s. One can say that the Vold-Kalman filter yields better dynamic range than the FFT technique in this case. This is due to the fact that the Vold-Kalman filtering has no slew rate limitations although the real-time FFT was actually able to track the RPM changes in this case. On the other hand the Vold-Kalman filtering provides a better time resolution as well as more data points compared to the FFT technique as explained in the following.

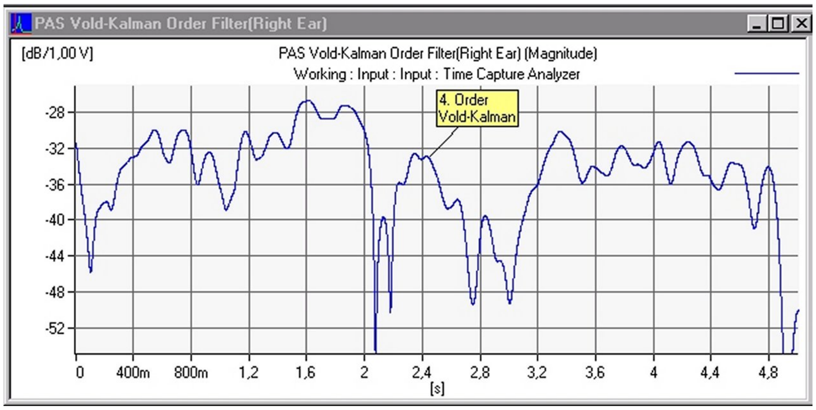

Figure 3: Engine order 4.0 extracted using Vold-Kalman order tracking filtering; X-axis is displayed from 0 s to 5 s.

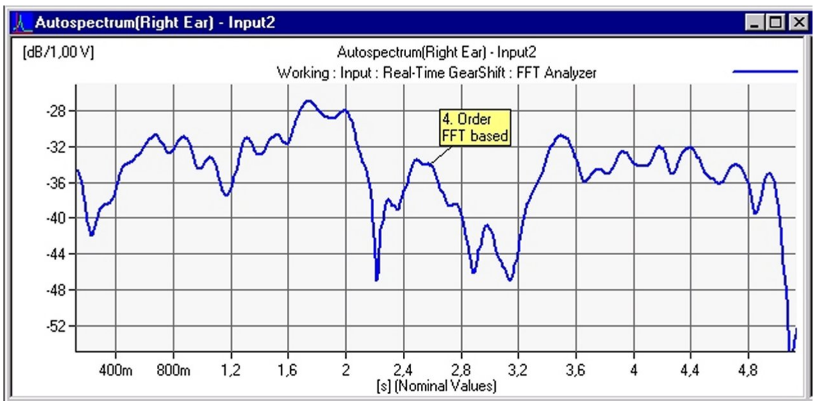

Figure 4: Engine order 4.0 extracted using real-time FFT processing; X-axis is displayed from 0,125 s to 5,125 s.

The FFT multi-buffer settings results in 501 data points along the 5 sec. long Z-axis (25 multibuffer entries per FFT record-length, one entry per 7 FFT calculations). Each FFT record represents approximately 94 ms (= 250 ms x 37,5%) when using a Hanning weighting function. The effective duration of the Hanning weighting is defined in Ref [7]. The Vold-Kalman technique results in this case in 20480 data points (for export purposes decimation of the data is possible). The selected frequency bandwidth of 10 Hz corresponds to a length of the IRF of 2 τ = (0,2 x 2 / 10Hz) = 40 ms.

3 - CONCLUSION

The Vold-Kalman filter allows for order tracking without trackingability slew-rate limitations, only speed limitation is due to the filter response time. Phase assigned orders (shown as real, imaginary, magnitude, phase and Nyquist plots) as well as order time waveforms (playback using soundboards) are available. Abrupt changes of the RPM, such as in gear shifts, and tacho dropouts can be handled and finally decoupling of close and crossing orders are possible. The only disadvantages of the technique is non-real time processing, "longer" calculation time, no information between orders and some a priori knowledge of the contents of the signal is required.

ACKNOWLEDGEMENTS

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REFERENCES

1. **Vold, H., Leuridan, J.**, Order Tracking at Extreme Slew Rates, Using Kalman Tracking Filters, In *SAE Paper*, 1993

2. **Vold, H., Mains, M., Blough, J.**, Theoretical Foundations for High Performance Order Tracking with the Vold-Kalman Tracking Filter, In *SAE Paper*, 1997

3. **Vold, Herlufsen, Mains, Corwin-Renner**, Multiple Axle Order Tracking with the Vold-Kalman Tracking Filter, *Sound and Vibration Magazine*, Vol. May, pp. 30-34, 1997

4. **Brüel & Kjær**, *Vold-Kalman Order Tracking Filter - Type 7703*, Product Data

5. **Gade, S., Herlufsen, H., Konstantin-Hansen, H., Vold, H**, Characteristics of the Vold-Kalman Order Tracking Filter, *Brüel & Kjær Technical Review*, Vol. No. 1, 1999

6. **Vold, H., Deel, J.**, Vold Kalman Order Tracking: New Methods for Vehicle Sound Quality and Drive Train NVH applications, In *SAE Paper*, 1997

7. **Gade, S., Herlufsen, H.**, Use of weighting Functions in DFT/FFT Analysis, *Brüel & Kjær Technical Review*, Vol. Nos. 3 & 4, 1987