Approaches to the improvement of order tracking techniques for vibration based diagnostics in rotating machines

KeSheng Wang

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by

KeSheng Wang

Supervisor: Prof. P. S. Heyns

Department: Mechanical and Aeronautical Engineering

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Summary

Conventional rotating machine vibration monitoring techniques are based on the assumption that changes in the measured structural response are caused by deterioration in the condition of the rotating machine. However, due to variations of the rotational speed, the measured signal may be non-stationary and difficult to interpret. For this reason, the order tracking technique is introduced. One of main advantages of order tracking over traditional vibration monitoring lies in its ability to clearly identify non-stationary vibration data and to a large extent exclude the influences of varying rotational speed.

In recent years, different order tracking techniques have been developed. Each of these has their own pros and cons in analyzing rotating machinery vibration signals. In this research, three existing order tracking techniques are extensively investigated and combined to further explore their abilities in the context of condition monitoring.

Firstly, computed order tracking is examined. This allows non-stationary effects due to the variation of rotational speed to be largely excluded. However, this technique was developed to deal with the entire raw signal and therefore looses the ability to focus on each individual order of interest.

Secondly, Vold-Kalman filter order tracking is considered. It is widely reported that this technique overcomes many of the limitations of other order tracking methods and extracts order signals into the time domain. However because of the adaptive nature of the Vold-Kalman filter, the non-stationary effects due to the rotational speed will remain in the extracted order waveform, which is not ideal for conventional signal processing methods such as Fourier analysis. Yet, the strict mathematical filter (the Vold-Kalman filter is based upon two rigorous mathematical equations, namely the data equation and the structural equation, to realize the filter) gives this technique an excellent ability to focus on the orders of interest.

Thirdly, the empirical mode decomposition method is studied. In the literature, this technique is claimed to be an effective diagnostic tool for various kinds of applications including diagnosis of rotating machinery faults. Its unique empirical way of extracting non-stationary and non-linear signals allows it to capture machine fault information which is intractable by other order tracking methods. But since there is no precise mathematical definition for an intrinsic mode function in empirical mode decomposition and – as far as could be ascertained – no published assessment of the relationship between an order and an intrinsic mode function, this technique has not been properly considered by analysts in terms of order tracking. As a result, its abilities have not really been explored in the context of order related vibrations in rotating machinery. In this research, the relationship between an order and an intrinsic mode function is discussed and it is treated as a special kind of order tracking method.

In stead of focusing individually on each order tracking technique, the current work synthesizes different order tracking techniques. Through combination, exchange and reconciliation of ideas between these order tracking techniques, three improved order tracking techniques are developed for the purpose of enhancing order tracking analysis in condition monitoring. The techniques are Vold-Kalman filter and computed order tracking (VKC-OT), intrinsic mode function and Vold-Kalman filter order tracking (IVK-OT) and intrinsic cycle re-sampling (ICR). Indeed, these improved approaches contribute to current order tracking practice, by providing new order tracking methods with new capabilities for condition monitoring of systems which are intractable by traditional order tracking methods, or which enhances results obtained by these traditional methods.

The work commences with a discussion of the inter-relationship between the order tracking methods which are considered in the thesis, and exposition of the scope of the work and an explanation of the way these independent order tracking techniques are integrated in the thesis.

To demonstrate the abilities of the improved order tracking techniques, two simulation models are established. One is a simple single-degree-of-freedom (SDOF) rotor model with which VKC-OT and IVK-OT techniques are demonstrated. The other is a simplified gear mesh model through which the effectiveness of the ICR technique is proved.

Finally two experimental set-ups in the Sasol Laboratory for Structural Mechanics at the University of Pretoria are used for demonstrating the improved approaches

for real rotating machine signals. One test rig was established to monitor an automotive alternator driven by a variable speed motor. A stator winding inter-turn short was artificially introduced. Advantages of the VKC-OT technique are presented and features clear and clean order components under non-stationary conditions. The diagnostic ability of the IVK-OT technique of further decomposing an intrinsic mode function is also demonstrated via signals from this test rig, so that order signals and vibrations that modulate orders in IMFs can be separated and used for condition monitoring purposes.

The second experimental test rig is a transmission gearbox. Artificially damaged gear teeth were introduced. The ICR technique provides a practical alternative tool for fault diagnosis. It proves to be effective in diagnosing damaged gear teeth.

Keywords: Computed Order Tracking (COT), Empirical Mode Decomposition (EMD), Intrinsic Mode Function (IMF), Order tracking, Rotating machinery, Vold-Kalman filter order tracking (VKF-OT).

List of publications based on this work:

1) K. S. Wang & P. S. Heyns (2008), Inspecting FFT order components through the joint use if computed order tracking and Vold-Kalman filter order tracking. *21st Intentional Congress and Exhibition. Condition Monitoring and Diagnostic Management (Comadem) 2008*, Prague, June 2008.

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2) K. S. Wang & P. S. Heyns (2009), Vold-Kalman filter order tracking in vibration monitoring of electrical machines. *Journal of Vibration and Control.* 15(9), pp 1325-1347.

3) K. S. Wang & P. S. Heyns (2009), A practical vibration signal processing technique for rotating mechanism condition monitoring-(IVK-OT). Presentation at *International Aerospace Symposium of South Africa*, Nov. 2009.

4) K. S. Wang & P. S. Heyns (2011), Application of computed order tracking, Vold-Kalman filtering and EMD in rotating machine vibration, *Mechanical Systems and Signal Processing*, 25(2),pp416-430.

5) K. S. Wang & P. S. Heyns (2011), The combined use of order tracking techniques for enhanced Fourier analysis of order components. *Mechanical Systems and Signal Processing*, 25(3),pp803-811

6) K. S. Wang & P. S. Heyns, An empirical re-sampling method on intrinsic mode function to deal with speed variation in machine fault diagnostics. *Applied Soft Computing*. Under review, 17 Jan. 2011.

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