Abstract

Condition-based maintenance (CBM) is an important strategy for reducing the maintenance cost and for operating critical machines throughout their expected life span. Since 1939, when the first paper on machine condition monitoring was published, CBM has been attracting researchers from various fields including sensor design, signal processing and decision making. Rolling element bearings are essential components of rotating machine applications. According to two separate surveys, by United States Department of Energy, 2015 and by IEEE-IAS, 2011, majority of faults in wind turbines and induction machines occur in bearings. Rising market demands and lower time-to-market have increased the risk of failure, and thus for improved system reliability, it is imperative that bearing faults are detected early and preventive maintenance activities are carried out. A continuous monitoring and evaluation of machine health is thus gaining traction and is steadily being preferred over the reactive maintenance. Technological developments in different fields also helped the machine condition monitoring to evolve and flourish as a discipline of academic and industrial research.

The literature in the field has an increasing trend and consists of research on the data acquisition, signal processing and decision making. The data acquisition mainly includes vibration, sound, acoustic emission, temperature and current signature. Various signal processing algorithms, including wavelet transform (WT), empirical mode decomposition (EMD), variational mode decomposition (VMD), cyclostationarity analysis, higher order spectra and different spectral representations, are found in the literature. A review of several research articles focusing on signal processing algorithms is carried out as a part of this thesis. Standard methods, like Kurtogram, WT, EMD and VMD, are implemented and studied to investigate their advantages and drawbacks. The review of related literature also suggests that fractional domain processing can be explored further because of its ability to enhance the fault features. The cyclostationarity of the bearing signal can also be further exploited to improve the performance of existing methods.

The objective of the thesis is to design and develop a signal processing framework for improved bearing fault diagnosis under constant as well as varying operating speed conditions. Modified enveloping techniques - the fractional enveloping and the cumulative distribution sharpness profiling - are proposed to process the vibration and acoustic signals. As signal enveloping is an essential component of bearing fault diagnosis, its generalisation - fractional enveloping - is particularly of interest for this application. This generalisation is defined mainly in three ways - using fractional Fourier transform, modified Hilbert filter and chirp multiplication. These methods are analysed using kurtosis and spectral feature maximisation and fractional Fourier transform based method is found to be effective in enhancing the fault features. The second approach proposes the cumulative distribution sharpness profiling. It is based on the fact that bearing faults, particularly the inner race and outer race faults, follow sharper Laplace distribution. Because of the cyclostationary nature of bearing signal, it is proposed that the sharpness of the cumulative distribution function be calculated locally and a profile of such sharpness values be created. It is observed that the frequency spectrum of such a profile gives a prominent peak at the bearing fault frequency.

Based on the validation of the proposed algorithms on public datasets, a diagnosis framework is developed around the time-frequency ridge curves extraction method and two features - prominence and compliance - are proposed for diagnosing the faults. Under the proposed framework, it is observed that while the fractional enveloping method provides improvements, the cumulative distribution sharpness profiling outperforms other methods in each dataset with an average accuracy of 95%. Whereas the average accuracies of Hilbert transform, Wavelet transform, Variational Mode Decomposition and Fractional Enveloping are 64.25%, 76%, 70.7% and 79.88% respectively.

Although the fractional enveloping method enhances fault features, it does not provide noise filtering and has to be accompanied by a wavelet based or EMD based filtering. Thus the limitations of these methods also apply to the proposed fractional enveloping. Whereas, the cumulative distribution sharpness (CDS) profiling is like an order filter and thus performs better than the fractional enveloping. However, basic assumption of quantifying the fault and non-fault regions using CDS is not satisfied for rolling element faults because the distribution of such cases is closer to Normal distribution. Thus CDSP is not applicable to these faults. In future, CDSP can be modified with the help of appropriate local feature for separating fault and non-fault regions in the rolling element fault cases. Implementing the proposed algorithms on embedded platforms for on-line fault diagnosis can also be an interesting future research avenue.

Keywords: Fault Diagnosis, Signal Processing, Fractional Enveloping, Cumulative Distribution, Variable Speed