Mechanical Systems and Signal Processing 25 (2011) 485–520

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/jnlabr/ymssp

Review

Rolling element bearing diagnostics—A tutorial[☆]

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ARTICLE INFO

Article history:
Received 23 July 2010
Accepted 29 July 2010

Keywords:
Rolling element bearings
Diagnostics
Cyclostationarity
Spectral kurtosis
Minimum entropy deconvolution
Envelope analysis

ABSTRACT

This tutorial is intended to guide the reader in the diagnostic analysis of acceleration signals from rolling element bearings, in particular in the presence of strong masking signals from other machine components such as gears. Rather than being a review of all the current literature on bearing diagnostics, its purpose is to explain the background for a very powerful procedure which is successful in the majority of cases. The latter contention is illustrated by the application to a number of very different case histories, from very low speed to very high speed machines. The specific characteristics of rolling element bearing signals are explained in great detail, in particular the fact that they are not periodic, but stochastic, a fact which allows them to be separated from deterministic signals such as from gears. They can be modelled as cyclostationary for some purposes, but are in fact not strictly cyclostationary (at least for localised defects) so the term pseudo-cyclostationary has been coined. An appendix on cyclostationarity is included. A number of techniques are described for the separation, of which the discrete/random separation (DRS) method is usually most efficient. This sometimes requires the effects of small speed fluctuations to be removed in advance, which can be achieved by order tracking, and so this topic is also amplified in an appendix. Signals from localised faults in bearings are impulsive, at least at the source, so techniques are described to identify the frequency bands in which this impulsivity is most marked, using spectral kurtosis. For very high speed bearings, the impulse responses elicited by the sharp impacts in the bearings may have a comparable length to their separation, and the minimum entropy deconvolution technique may be found useful to remove the smearing effects of the (unknown) transmission path. The final diagnosis is based on "envelope analysis" of the optimally filtered signal, but despite the fact that this technique has been used for 40 years in analogue form, the advantages of more recent digital implementations are explained.

Contents

[☆] Some of the material in this tutorial is adapted from related sections in the book *Vibration-based Condition Monitoring: Industrial, Automotive and Aerospace Applications*, by R.B. Randall, to be published by John Wiley and Sons.

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doi:10.1016/j.ymssp.2010.07.017

1. Introduction

Rolling element bearings are one of the most widely used elements in machines and their failure one of the most frequent reasons for machine breakdown. However, the vibration signals generated by faults in them have been widely studied, and very powerful diagnostic techniques are now available as discussed below.

Fig. 1 shows typical acceleration signals produced by localised faults in the various components of a rolling element bearing, and the corresponding envelope signals produced by amplitude demodulation. It will be shown that analysis of the envelope signals gives more diagnostic information than analysis of the raw signals. The diagram illustrates that as the rolling elements strike a local fault on the outer or inner race a shock is introduced that excites high frequency resonances of the whole structure between the bearing and the response transducer. The same happens when a fault on a rolling element strikes either the inner or outer race. As explained in [1], the series of broadband bursts excited by the shocks is further modulated in amplitude by two factors:

- The strength of the bursts depends on the load borne by the rolling element(s), and this is normally modulated by the rate at which the fault is passing through the load zone.
- Where the fault is moving, the transfer function of the transmission path varies with respect to the fixed positions of response transducers.

Fig. 1 illustrates typical modulation patterns for unidirectional (vertical) load on the bearing, at shaft speed for inner race faults, and cage speed for rolling element faults. The formulae for the various frequencies shown in Fig. 1 are as follows:

Ballpass frequency, outer race:

$$\mathrm{BPFO} = \frac{nf_r}{2}\left\{1-\frac{d}{D}\cos\phi\right\} \tag{1}$$

Ballpass frequency, inner race:

$$BPFI = \frac{nf_r}{2}\left\{1+\frac{d}{D}\cos\phi\right\} \tag{2}$$

Fundamental train frequency (cage speed):

$$FTF = \frac{f_r}{2}\left\{1-\frac{d}{D}\cos\phi\right\} \tag{3}$$