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Research paper

A modified tacho-less order tracking method for the surveillance and diagnosis of machine under sharp speed variation

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ABSTRACT

Tacho-less order tracking (TLOT) is an effective technique to address the surveillance and diagnosis of mechanical fault on speed variation conditions without tachometers. Nevertheless, fault diagnosis with sharp speed fluctuations is still a challenging task, since the accurate instantaneous frequency (IF) cannot be obtained from the acquired condition signals. In this work, a modified TLOT method based on nonlinear compensating demodulation transform (NCDT) is proposed for fault diagnostics in extreme condition monitoring of machinery. During NCDT, the demodulation functions based on opposite cubic polynomial are investigated and performed to improve IF estimation. Then, a regression filter (RF) is employed to extract the interested harmonic component according to the estimated IF and instantaneous bandwidth for signal resampling. Finally, order spectrum analysis is used to analyze the resampled signal for mechanical fault diagnosis. Simulations, experiments and industrial cases are given to verify the effectiveness and efficiency of the proposed method. The results are as effective as those obtained by tacho-based method under sharp speed fluctuation.

1. Introduction

Tachometers are the important hardware to obtain the shaft speed in mechanical engineering applications [1]. In particular, they are fundamental and crucial for surveillance and diagnosis of mechanical equipment under speed variation condition. Tachometer can provide a reference signal to perform order tracking (OT) for overcoming the frequency modulation and spectral smearing caused by speed variation. Thus, they are indispensable devices for traditional OT technique. However, in many circumstances, tachometers cannot be installed due to the space restriction and cost reasons. And therefore, the application of OT technique has been seriously hampered in industrial applications.

To deal with this limitation, a tacho-less OT (TLOT) method was proposed by Bonnardot et al. [2]. In that approach, the instantaneous frequency (IF) is estimated by time-frequency representation (TFR) method using vibration signal rather than tachometers. Based on that, Combet and Gelman proposed a more advanced method, in which the IF can be detected in an automatic way by tracking the meshing frequency of a gearbox [3]. In those approaches, band-pass filtering is commonly used for harmonic extraction, thus they are only suitable to small speed variations, where the harmonics are not overlapped

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List of notations

A_i	amplitude of the ith impulse
B_n	amplitude of the nth harmonic
B_k	instantaneous bandwidth of regression filter
E	complex number form of demodulated operator $e^{-j2\pi S(t)}$
E	unity matrix
$f(t)$	instantaneous frequency
f_0	rotation frequency
f_k	instantaneous frequency of the kth harmonic component
f_{final}	refined instantaneous frequency
f_s	sampling frequency
$f'(\tau)$	first order derivative
$f''(\tau)$	second order derivative
$f^{(n)}(\tau)$	nth order derivative
$h_T(t)$	window function of width T centered at time τ
$n(t)$	noise interference
O_k	order distance between the kth harmonic and closest harmonics
$R_n(t)$	remainder item of Taylor formula
r	weighting factor
$S(t)$	flexible demodulation function
$s(t)$	fault impulse signal
T_i	occurring time of the ith impulse
${t_n}^k$	time information of kth harmonic
$x(t)$	finite energy signal
$\tilde{x}(t)$	function after demodulating
$x(n)$	waveform of the kth interested harmonic component
$\tilde{x}(n)$	Hilbert transform of $x(n)$
x	vector form of $x(n)$
$y(n)$	vibration signal containing noise
y	vector form of $y(n)$
$\varepsilon(n)$	non-homogeneous term
$\boldsymbol{\varepsilon}$	vector form of $\varepsilon(n)$
$\eta(n)$	noise and other uninterested harmonic components
$\boldsymbol{\eta}$	vector form of $\eta(n)$
$\varphi(n)$	instantaneous phase of the reference shaft
$\varphi_k(n)$	instantaneous phase of kth harmonic component
$\varphi_s(n)$	phase shifting
$\tilde{\varphi}(n)$	revised instantaneous phase of reference shaft
$\Delta\theta$	constant angular increment

List of nomenclatures

BCFS	bearing characteristic frequencies
BPFI	ball pass frequency of inner race
BPFO	ball pass frequency of outer race
BSF	ball spin frequency
CT	chirplet transform
IF	instantaneous frequency
IFCF	instantaneous fault characteristic frequency
NCDT	nonlinear compensating demodulation transform
OT	order tracking
RF	regression filter
STFT	short-time Fourier transform
TFR	time–frequency representation
TLOT	tacho-less order tracking

in frequency domain. After that, Randall et al. have extracted the IF of harmonic by an iterative method to achieve TLOT [4]. This method can be applied to the cases where the speed fluctuations are less than 30%. Furthermore, Urbanek et al. proposed a two-step procedure for IF estimation when dealing with relatively large speed fluctuation [5]. Along this line, TLOT