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Recent progress on decoupling diagnosis of hybrid failures in gear transmission systems using vibration sensor signal: A review

Zhixiong Li [a,b,c,*], Yu Jiang [a,c], Chao Hu [d], Z. Peng [c]

[a] School of Mechatronic Engineering & Jiangsu Key Laboratory of Mine Mechanical and Electrical Equipment, China University of Mining & Technology, Xuzhou 221116, China
[b] State Key Laboratory of Tribology, Tsinghua University, Beijing 100000, China
[c] School of Mechanical & Manufacturing Engineering, University of New South Wales, Sydney, NSW 2052, Australia
[d] Department of Mechanical Engineering, Iowa State University, Ames, IA 50011, USA

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ABSTRACT

Reliable recognition of fault type and assessment of fault severity is essential for decision making in condition-based maintenance of gear transmission systems. In engineering practice, the gear systems are often subject to hybrid faults on the same component or different components. The concurrence of multiple faults makes the fault detection, in particular, the examination of both the fault types and severities, more challenging. Recently, this research area has been recognized as an important direction. A logic solution is to decouple the hybrid faults. This paper reviews various aspects of recent research in decoupling diagnosis of hybrid faults in gear transmission systems, and discusses the techniques used for gearbox hybrid faults decoupling. The general fault detection technologies for gearboxes are also briefly summarized. A potential methodology based on the bounded component analysis (BCA) for hybrid faults decoupling is discussed. Possible future research trends of gearbox hybrid faults decoupling diagnosis are suggested.

Contents

1. Introduction

Gear transmission systems are widely used in a variety of applications in many industries, including aerospace, mining, railway, automobile, manufacturing, agriculture and wind energy. A gearbox breakdown may result in catastrophic failures and significant economic losses [1]. For example, a bearing failure led to the damage of a thermal generator set in Japan in 1992 [2], a broken gear tooth resulted in the destruction of a helicopter in UK in 1986 [3], and a gearbox fault caused the damage of a propulsion system in the ‘Zhouying 4’ ship in China in 2006 [3]. According to the

* Corresponding author at: High Street 20, Sydney, NSW 2052, Australia.
E-mail address: zhixiong.li@unsw.edu.au (Z. Li).

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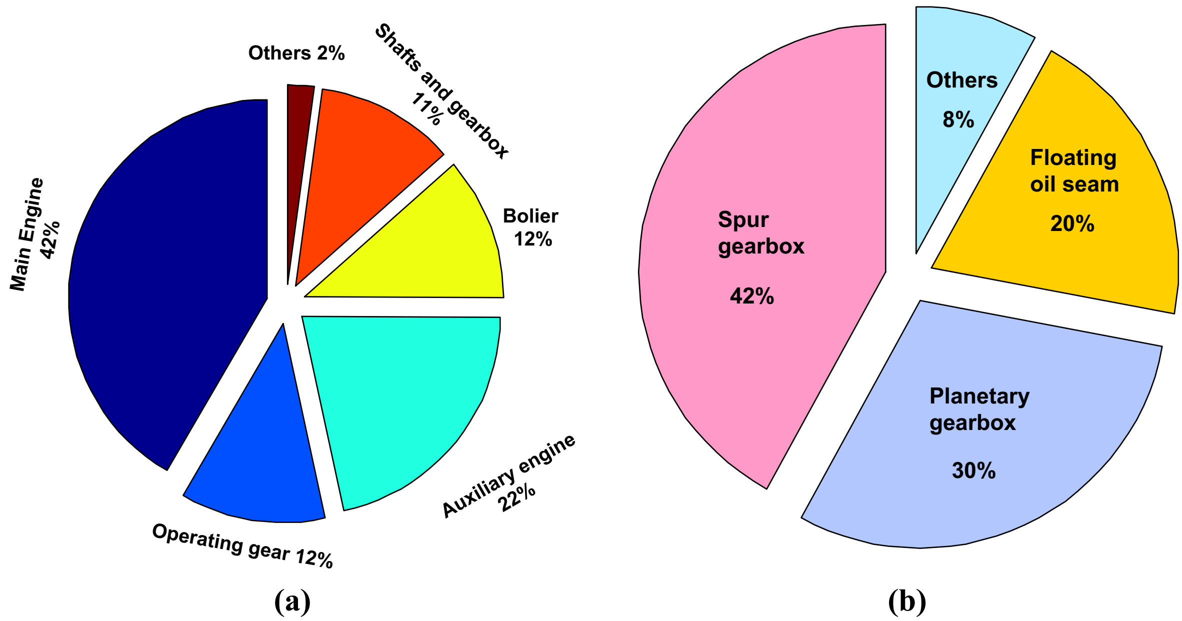

Fig. 1. (a) Settlement of claims in marine propulsions; (b) typical faults in shearer cutting parts in coal cutters.

statistics [3,4], the gearbox faults account for 80% of all the failures in the transmission machinery, and in the gearbox, the gear faults account for 60%. Moreover, according to Swedish Club Highlights [5], the most frequent failure part of a ship is the marine propulsion system (including the diesel engines), in which the gearboxes are identified as one of the most vulnerable components. In the coal mining industry, according to the latest report [6], the gear transmission components of coal cutters have the highest failure rate among other components in the machine. Fig. 1(a) shows the settlement of claims in marine propulsions [5], and Fig. 1(b) shows the fault types of the shearer cutting parts in the coal cutters [6]. The percentage of settlement of claims for the gearbox and operating gear is more than 12% in the marine propulsions (see Fig. 1(a)), and the gear and bearing failures in both the spur and planetary gearboxes account for 72% of all the faults in the shearer cutting parts (see Fig. 1(b)). In addition, in rotorcraft drive systems, the breakdown of the rotorcraft gearboxes is also a critical issue and much research has been devoted to analyzing the reliability of these gearboxes over the past 25 years [7–9]. Hence, in order to ensure safe operation of machinery, improve maintenance efficiency, save time and reduce costs, industries require the maintenance strategies be transformed from the traditional breakdown maintenance (failure and repair model) to condition-based maintenance (CBM), and toward predictive maintenance (PM) [10]. Condition monitoring and fault diagnosis (CMFD) technology provides the solid foundation for the implementation of CBM and PM [11].

2. Brief review of vibration based CMDF techniques

The fault detection is a longstanding research topic, dating back to the early stage of last century [20,21]. Over past decades, it has been widely recognized that vibration analysis can be used effectively for mechanical fault diagnosis. In the early 1940s, pioneering investigation on mechanical damage detection using vibration analysis was conducted by Collacott [12]. A milestone was reached in 1970s when the frequency analysis technologies were firstly introduced into condition monitoring of mechanical systems [13–15]. Representative work includes discrete frequency [13], cepstrum analysis [14] and signature analysis [15]. Then in the 1980–90s, some classical methodologies, including order tracking [16], time domain averaging [17], time–frequency analysis [18] (such as wavelet transform [19] and Wigner–Ville analysis [20]), and fault tree analysis [21], were developed and applied to machinery defects detection. To date, many useful techniques have been developed for gearboxes CMFD (including gears and bearings) [22–31]. Existing vibration signal analysis methodologies applied to gearbox CMFD can mainly be classified into three categories: (1) the statistical analysis, (2) the filter models, and (3) the time and/or frequency domain analysis approaches. Table 1 lists the state-of-the-art presentations of the statistical analysis approach and Table 2 provides the state-of-the-art presentations of the filter models and time/frequency approaches in the gearbox CMFD. Some researchers utilized intelligent pattern recognition techniques (namely, artificial neural network (ANN) [32], fuzzy infer-

Table 1
Representative work using the statistical analysis approach.

Category	Representative approach
Hypothesis testing	Kolmogorov–Smirnov test [38], Satterthwaite's t'-test [39], Wilcoxon rank-sum test [40]
Statistical index	Kurtosis [41], Euclidean distance [42], Mahalanobis distance [43], Kullback–Leibler distance [44], Bayesian distance [23]
Statistical learning	Principal component analysis (PCA) [45], Fisher discriminant analysis (FDA) [45], partial least squares (PLS) [46], multidimensional scaling (MDS) [47], Isomap [48], Laplacian eigenmaps (LE) [49], locally linear embedding (LLE) [50], local tangent space alignment (LTSA) [51], locality preserving projections (LPP) [52], neighborhood preserving embedding (NPE) [53], maximum variance unfolding (MVU) [54], common vector approach (CVA) [55], diffusion maps (DM) [56]
Statistical modeling	Time series model [57], Dempster–Shafer evidence theory [58], hidden Markov model (HMM) [59], proportional hazards model (PHM) [60], proportional covariate model (PCM) [61]