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Detection of Combined Gear-Bearing Fault in Single Stage Spur Gear Box Using Artificial Neural Network

Laxmikant S. Dhamande[a,]*, Mangesh B. Chaudhari[b]

[a]*Asst. Professor, SRES, College of Engineering, Kopargaon, 423603, (SPPU, Pune) India*
[b]*Professor, Vishwakarma Institute of Technology, Bibwewadi, Pune, 444001, India*

Abstract

Gears and bearings are important components of almost every machines used in industrial environment. Hence detection of defect in any of these must be detected in advance to avoid catastrophic failure. This paper aims to address the effect of bearing defect on gear vibration signature and effect gear defect on bearing vibration signature. Also its purpose is to make vibration analysis of single stage spur gear box, when both gear and bearing are defective. A condition monitoring set up is designed for analyzing the defect in outer race of bearing and damaged tooth of gear. MATLAB is used for feature extraction and neural network is used for diagnosis. In the literature, many authors have analyzed defects in bearings and gears separately. But it is found that the real situation may be more complex. The work presents a laboratory investigation carried out through an experimental set-up for the study of combined gear –bearing fault. This paper proposes a novel approach of damage detection in which defects in multiple components are analyzed using vibration signal.

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Keywords: Vibration; Combined gear-bearing fault; Feature extraction; Artificial neural network.

1. Introduction

Rotating machinery plays an important role in any industry while bearings and gears are inevitable part of any rotating machinery. So detection of defects in gears and bearings is the most important task for maintenance engineer using condition based maintenance in their plant. A lot of research has been done on defect detection of gears and bearings but all the researchers focused on single or multiple defects in a gear or bearing. D.J. Ewins [1] have presented an overview of the vibration problems which are experienced in gas turbines such as resonance, instability from aerodynamic forces or from rotor dynamics. By tune design the vibrations can be managed so as to

* Corresponding author. Tel.: +91-940-431-9427; fax: +91-242-322-2682
E-mail address: laxmikantdhamandemech@sanjivanicoe.org.in

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avoid the most serious resonance which is done by ensuring the critical frequency crossings do not exist in the running speed range. N. Tandon et al [2] have reviewed the vibration and acoustic measurement methods for the detection of both localized and distributed defects in rolling element bearings in time domain and frequency domain. V. N. Patel et al [3] worked on the detection of defects existing on races of deep groove ball bearing in the presence of external vibrations using envelope analysis and Duffing oscillator. Xiaoyuan Zhang and Jianzhong Zhou [4] have proposed a novel procedure based on ensemble empirical mode decomposition (EEMD) and optimized support vector machine (SVM) for multi-fault diagnosis of rolling element bearings. Sait et al. [5] summarized the different methods of defect detection in gears using condition monitoring by vibration analysis. Loutas et al [6] utilized acoustic emission (AE) and vibration measurements for single stage gear box and different conventional as well as advanced features are compared for its diagnostics capacity. Daming Lina et al [7] used an approach to extract useful condition indicators (covariates) from raw vibration signals and developed optimal maintenance policies for the gearboxes. Mohit Lal and Rajiv Tiwari [8] developed an identification algorithm to estimate parameters of multiple faults in a turbine-generator system model based on the forced response information. D.J. Bordoloi and Rajiv Tiwari [9] have used statistical features in frequency domain for the multi-fault classification of gears using support vector machine (SVM). D.P. Jena, et al. [10] established a robust technique of acoustic signal processing for detection and localization of multiple teeth defect in geared systems using features extracted from wavelet transform and artificial neural network (ANN) for diagnosis. N. Saravanan and K.I. Ramachandran [11] have analysed the gear defects such as face wear, tooth breakage by extracting features using discrete wavelet transform and ANN is used as classifier. N. Sawalhi and R. B. Randall [12] have studied the combined gear /bearing simulation model to understand the interaction between them.

In this work a novel thing is that, the more complex but real situation is considered where the combined defect in gear and bearing i.e. defects in multiple components are analyzed using vibration signal. The literature provides the analysis in time domain, frequency domain and time-frequency domain. Here an attempt is made to make use of the important and most significant features of gear and bearings in each domain. These features extracted from vibration signals are used by a classifier called artificial neural network for fault diagnosis.

2. Methodology

Any vibration signal measured by accelerometer is a mixture of bearing and gear signal. Since the first aim of this work is to find the effect of gear defect on bearing signature and bearing defect on gear signature. Hence it is necessary to understand how these signals are generated. The vibration signal generated by a bearing fault can be described by combining Braun's and McFadden's models [13]. The vibration induced by shaft rotation & gear mesh is denoted by s (t), and the vibration by a bearing fault is b(t),

$$s(t) = \sum_j A_j \cos\left(j\omega_s t + \phi_j\right), \tag{1}$$

$$b(t) = \sum_k B_k \{ e^{-\left(\frac{t-kT}{\alpha}\right)} . \cos[\omega_n (t - kT)] . U(t - kT) \} \tag{2}$$

Where, j is the shaft order number, A_j and ϕ_j are amplitude and phase, respectively, at j^{th} order and ω_s is the shaft rotation frequency (in rad /sec). In the bearing signal shown in Eq. (2), T is the characteristic fault period (i.e., the reciprocal of the fault frequency 2p /ω), and ω_n the structure resonant frequency exited by bearing fault, α denotes the time constant for the exponential decay of the resonant oscillations, which is determined by system damping, and U(t) is a unit step function. B_k represents the peak amplitude of k^{th} impulse produced by the bearing fault. When the bearing fault is small, the amplitude of b(t) can be much less than that of s(t). The shaft synchronous signal s(t) and bearing fault induced signal b(t) can be mixed together in both additive and multiplicative (by a factor of s = 0~1) forms, resulting a signal

$$x(t) = s(t) + b(t) + s \times s(t)b(t) = s(t) + [1 + s.s(t)] \times b(t) \tag{3}$$

In practice, the actual measured signal will be the convolution of signal *x(t)* with the system's transmission path