Engineering Failure Analysis 73 (2017) 57–71

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/engfailanal

Fatigue failure analysis of high speed train gearbox housings

Weigang Hu *, Zhiming Liu, Dekun Liu, Xue Hai

School of Mechanical, Electronic and Control Engineering, Beijing Jiaotong University, China

A R T I C L E I N F O

Article history:
Received 18 July 2016
Received in revised form 16 December 2016
Accepted 16 December 2016
Available online 22 December 2016

Keywords:
Time-frequency analysis
Crack failure
Beat vibration
Wheel-rail excitation

A B S T R A C T

The present work addresses the formation of fatigue cracks in gearbox housings of high speed trains. Systematic studies of fracture analysis, finite element analysis, and field tests under actual stress and acceleration conditions are employed. Time domain, frequency domain, and time-frequency domain analyses indicate that the first two natural vibration modes are excited by out-of-round wheels and rail-track irregularities, and the superposition of these vibration modes results in the occurrence of the beat phenomenon, where the amplitude of the vibration modulates periodically, which increases the likelihood of exceeding fatigue limits, and produces greater structural damage. Analyses reveal that the fatigue strength of the failure region is reduced by the casting process, which eventually leads to the formation of fatigue cracks. Our findings suggest that the gearbox housing casting process should be improved to reduce casting porosity, and the housing structure must be redesigned to avoid the resonance frequencies associated with wheel-rail excitation at operational speeds.

1. Introduction

Modern high speed trains are famous for their safety, speed, and reduced-pollution features. The greatly reduced travel time plays an important role in promoting economic growth. High speed train service is rapidly developing in China. By the end of 2015, the total mileage of dedicated passenger lines in China was greater than 19,000 km, and is expected to exceed 30,000 km by 2020. However, various unexpected problems have been observed during high speed train operation. One recent problem involves the crack failure of gearbox housings during operation, where gearbox housings have failed to reach their designed operating mileage, resulting in diminished operational safety.

A gearbox is a key transmission component of a high speed train traction system, which is supported on the axle with bearings through one end and with the other end connected to the bogie frame by means of a C bracket, and the pinion shaft end is connected with the motor by universal couplings, as shown in Fig. 1. The gearbox is used for transmitting the motor torque to the axle, so its reliability is directly related with the operational safety of a high speed train [1].

Extensive gearbox-related studies have been conducted, although most have focused on rotary machines and gear transmission systems [2,3,4]. Some studies have considered the dynamic response of the gearbox housing. Sonsino [5] employed laboratory proof tests to evaluate the structural durability of train gearbox housings under variable amplitude loading. Morgado [6] analyzed the failure region of locomotive gearbox housings according to the stress spectrum based on data obtained from field testing. Wei [7] simulated the dynamic response of a marine gearbox system subject to internal and external excitation by a modal superposition method based on vibration theory. Huang [8] simulated the dynamic response of a high speed train gearbox system subjected to internal and external excitation by a numerical integral method. Ren and Liu [9] analyzed the vibration

* Corresponding author.
E-mail address: 12116322@bjtu.edu.cn (W. Hu).

http://dx.doi.org/10.1016/j.engfailanal.2016.12.008
1350-6307/

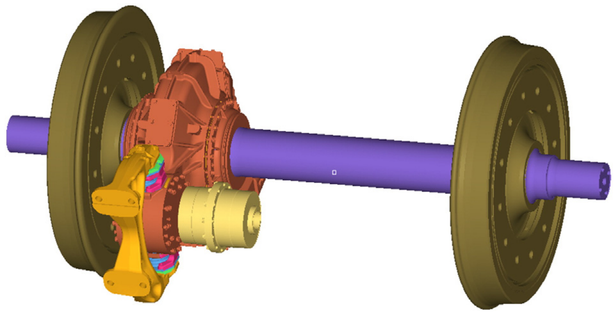

Fig. 1. The gearbox system.

characteristics and the frequency distribution of an axle box, and demonstrated that the vibration excitation frequency under operational conditions was within 1000 Hz. Zhai [10] further verified that the wheel-rail excitation affect the axle box vibration frequency distribution.

However, the dynamic response of the gearbox housing has rarely been investigated via a combination of simulation and experiment. Owing to the constraints of experimental conditions, what can be evaluated experimentally is often limited, and, while simulation offers a much more flexible scheme of study, the results of simulation typically require experimental validation. Therefore, a combined scheme is expected to yield a wider and more reliable evaluation of the phenomenon.

According to fracture mechanics, structure life depends on stress state, stress level, and the manufacturing quality, which is indicated by factors such as the initial defects and geometry of the structure. Therefore, to investigate the ultimate causes of the crack failure of high speed train gearbox housings, fracture analysis, finite element analysis, and field tests were conducted in the present study. Fracture morphology analysis and metallographic analysis were conducted to determine failure modes, and evaluate the casting quality of the failure region. Fatigue strength analysis and modal analysis employing finite element analysis (FEA) techniques were conducted to examine the structural response and structural characteristics of gearbox housings. Based on the FEA results, field testing employed various strain gauges and acceleration sensors mounted in strategic locations on a high speed traction system to obtain the stress response signals and acceleration signals of the gearbox housing and the axle box. From time domain, frequency domain, and time-frequency domain analyses, the underlying causes of crack failure were investigated.

2. Gearbox housing fracture analysis

The gearbox housing is fabricated by the sand casting of an aluminum alloy. Its chemical composition and hardness meet the requirements of related standards and technology agreements. Gearbox housing fractures are mainly located in proximity to the inspection window of the upper box near the thread hole on the wheel-axle side, as shown in Fig. 2(a). It is obvious that a typical casting process produces defects on the inner surface of the viewport, and the inner surface is rough, as shown in Fig. 2(b).

The macroscopic fracture morphology on the rough inner surface of the gearbox housing, as shown in Fig. 3, indicates that crack initiation begins at the inner surface of the upper box, with radial fatigue lines clearly expanding toward the external surface, which is the most conspicuous feature of fatigue failure [11]. The fracture region can be divided into a smooth area and a rough area. The smooth area represents the region of crack initiation and propagation. The rough area represents the terminal region where the propagated crack has attained a critical width.

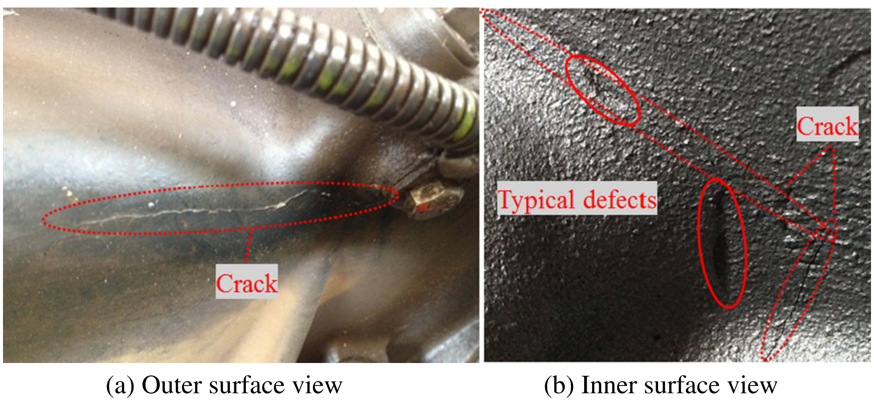

Fig. 2. Crack position of the gearbox upper housing.