Engineering Failure Analysis 42 (2014) 210–220

Contents lists available at ScienceDirect

Engineering Failure Analysis

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

Statistical distribution of crankshaft fatigue: Experiment and modeling

Xiaoping Chen [a,*], Xiaoli Yu [b], Rufu Hu [a], Jianfeng Li [c]

[a] School of Mechanical Engineering, Ningbo University of Technology, Ningbo 315016, China
[b] Department of Energy Engineering, Zhejiang University, Hangzhou 310027, China
[c] Hangzhou Branch, Weichai Power Co. Ltd., Hangzhou 310012, China

ARTICLE INFO

Article history:
Received 7 January 2014
Received in revised form 9 April 2014
Accepted 10 April 2014
Available online 19 April 2014

Keywords:
Crankshaft
Fatigue experiment
Distribution function
Data statistics
Weibull distribution

ABSTRACT

Crankshaft fatigue problem has long been a headache and frequent phenomenon in combustion engine which attracts various efforts especially including fundamental fatigue experimental data. In this paper, the rational experimental method is employed to study the crankshaft fatigue phenomenon based on a customized experiment platform, mimicking the real-world crankshaft working condition physically. Then, based on the experiment data, the statistical regression analysis of eight commonly used hypothesis distributions is conducted. The degrees of fitting effects of the chosen statistical model are evaluated individually. Results show that the three-parameter Weibull distribution model fits the data best which may be used as the fundamental model in future analysis. This study provides a solid foundation for better understanding the mechanism of crankshaft fatigue phenomenon.

1. Introduction

The traditional reliability design methods evaluate the safety reliability of components by using the indicator of Safety Factor (SF) [1]. In the case of small distribution range of the material strength and applied stress distribution (shown in Fig. 1 actual line), SF can be defined as:

$$n = \frac{(\sigma_{\text{strength}})_{min}}{(\sigma_{stress})_{max}} \tag{1}$$

where $(\sigma_{stress})_{max}$ means the maximum applied stress and $(\sigma_{strength})_{min}$ indicates the material ultimate strength. When $n \geqslant 1.0$, the failure rate could be equal to zero and the rate of reliability fatigue reliability could reach to 100% by this definition of safety factor.

However, in the case of large distribution range of the material strength and applied stress distribution (shown in Fig. 1 dotted line), the tail sides of the two probability distribution curves of the fatigue limit and the applied stress intersect each other. The failure probability is no longer equal to zero. Therefore, this definition of safety factor by Eq. (1) has lost its meaning. Then, the reliability design must be carried out.

* Corresponding author. Tel.: +86 574 87081274.
E-mail address: cxp@nbut.edu.cn (X. Chen).

http://dx.doi.org/10.1016/j.engfailanal.2014.04.015
1350-6307/

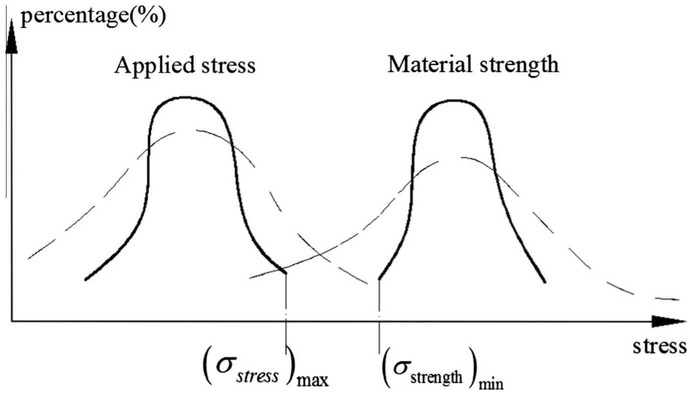

Fig. 1. Illustration of demonstration of safety factor.

As is shown in Fig. 1(dotted line), the distribution of the applied stress and strength of component shows large distribution range. While the applied stress is generally one of the designing parameters, its distribution has been set in the process of designing. Therefore, analyzing the strength limit distribution of materials or components accurately is important to reasonable reliability designing. The research grafting fracture mechanics and reliability engineering to predict the strength limit distribution of materials or components has been pursued by many researchers such as, the research of the variability in the fatigue life of aluminum alloy castings has been modeled by either the lognormal [2] or two-parameter Weibull [3]. The thesis treatise of the distribution of 16Mn [4], Q235 [5] and 1Cr18Ni9Ti [6,7] steel by using a unified linear regression method. And Ref. [8] studied the statistical distribution of the residual stiffness of composite laminates. Ref. [9] studied the statistical distribution of the low cycle fatigue initial life for pressure vessel steel 16MnR. In another study, the fatigue life of the brittle ceramic materials [10] and ceramic matrix composites [11,12] has been modeled by either the normal, lognormal or three-parameter Weibull. The distribution of initial crack by using nondestructive inspection method has been developed [13], the evaluation for the influence of several parameters on the destruction probability or fatigue life distribution has also been studied [14,15]. These researches mainly focus on the analysis of the statistical distribution of material fatigue reliability data. However, for the actual components such as crankshaft where it is the main component of the internal combustion engine, the distribution range of the fatigue limit load distribution is larger. Its fatigue strength assessment is necessary of internal combustion engine design. Therefore the analysis of the statistical distribution of crankshaft fatigue strength has great significance in engineering application which is still unraveled.

To bridge this gap, this paper chooses an appropriate test method for crankshaft fatigue strength test, and the corresponding statistical analysis of test data has been conducted. The commonly used eight kinds of statistical distributions have been carried out for the statistical regression analysis of the fatigue reliability data. The fitting effect is evaluated and the best model to describe the fatigue data is thus recommended.

2. Experimental measurement and data statistics analysis of crankshaft fatigue limit load

2.1. Experimental measurement of crankshaft fatigue limit load

In this study, the test equipment is shown in Fig. 2. The framework of crankshaft bending fatigue test system is shown in Fig. 3 (1-testing crankshaft; 2-strain gauge; 3-compensation strain gauge; 4-bridge box; 5-strain amplifier and signal conditioning circuit; 6-computer; 7-PLC; 8-frequency converter; 9-motor; 10-speed sensor; 11-vibration swing arm; 12-acceleration sensor). PLC and computer are the core of control system. The main measure parameters include the motor speed – n, tension force – F, vibration acceleration – a and crankshaft strain – ε, etc.

The vertical test stand is supported by the spring elasticity. Test excitation is driven by the eccentric rotating motor. The motor rotating speed is determined according to calibration results and the ultimate load enhancement factor. The occurrence of cracks is determined by the control signal of accelerometer. Detailed information about the test equipment could be referred to Refs. [16–18].

The bending fatigue test of crankshaft uses integrated principle of static calibration and dynamic test. The load calibration is divided into two steps: the first step is static calibration for establishing the relationship between the static torque F with strain ε. By applying the static force F at the length of L, we may get the torque $T_1 = FL$, shown in Fig. 4. The relationship between T_1 and ε could be established from the values on the strain gauge on the neck of the crankshaft [19].

The second step is dynamic test to determine the relationship between the dynamic strain of the crankshaft fillet with the testing excitation frequency. In Fig. 4, the motor is used to drive the eccentric wheel to apply loads on the lever. The dynamic