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Reliability modeling for systems subject to multiple dependent competing failure processes with shock loads above a certain level

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A B S T R A C T

Considering that products with high reliability have ability to resist small shock loads, a new reliability model is proposed for system experiencing dependent competing failure processes(DCFP) with shock loads above a certain level. Such shock loads are separated by the shock threshold, beyond which are fatal shocks causing sudden failure of systems. The remaining part between the certain level and shock threshold are general shock loads causing sudden degradation increments (SDI). Moreover, an explicit relationship between SDI and the magnitude of shock loads is established for reliability assessment. In this study, we consider two kinds of DCFP: (1) a shock process and a degradation process; (2) a shock process and multiple degradation processes. In case (1), we consider the dependence between shock process and degradation process with conditional probability. In case (2), we not only consider the dependence between shock process and degradation processes with conditional probability, but also the dependence between multiple degradation processes with Copulas. Finally, the effectiveness of proposed models is demonstrated by reliability analysis of the microengine developed by Sandia National Laboratories and an extended numerical example. Besides, sensitivity analysis is performed to assess the effects of model parameters on the system reliability.

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1. Introduction

A complex system can fail due to multiple failure mechanisms induced by internal degradation or external shocks, such as corrosion, erosion, fatigue, wear, overload, etc., that will lead to multiple failure processes. These failure processes are dependent and competing with each other. For example, if a device experiences a shock process and a degradation process, these processes are dependent because the arrival of each shock affects both failure processes. They also compete with each other because any of the failure processes occur will cause the failure of systems.

The dependence among multiple failure processes creates a unique and challenging problem to build the system reliability model. In the available literature, extensive research has been devoted to predict the reliability of systems experiencing multiple dependent competing failure processes with a shock process and a degradation process. Peng et al. [1] developed reliability models for systems subject to multiple dependent competing failure processes, where two dependent failure processes are considered: soft failures caused jointly by continuous smooth degradation and additional sudden degradation increments due to a shock process and sudden failures caused by fatal shock loads from the same shock process. Wang et al. [2] conducted reliability analysis involving degradation and shocks considering two kinds of shock effect on degradation: 1) a sudden random increase in the degradation after a shock; 2) a sudden increase in the failure rate after a shock. Wang et al. [3] took two types of shocks into consideration: fatal shocks that cause the sudden failure of system, and general shock loads that increase the system degradation level, without considering shock loads below a certain level when assessing the system reliability. Huynh et al. [4] established the reliability model of DCFP considering that there is an interaction between the shock arrival time modeled by a nonhomogeneous Poisson process and the degradation level caused by both internal degradation and external shock. Fan et al. [5] considered the system that suffered from nonhomogeneous Poisson process shocks, where degradation would increase the magnitude of shock loads. Jiang et al. [6] established a new reliability model of MDCFP considering that shock threshold for hard failure can shift due to exposure to various shock patterns. Rafiee et al. [7] developed reliability models for system experiencing MDCFP by considering the changing degradation rate due to exposure to a particular pattern of shocks. Wang et al. [8] considered the influences of two types of shock processes, periodic shock process and shock process with arrival time following Poisson process, on the degradation process when modeling the system reliability. In Refs. [1,6,7], there is an implicit assumption that the arrival of each shock will cause sudden

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degradation increases, which is not suitable for the reliability modeling of systems with high reliability and long life because they have ability to resist small shock loads owing to material strength. The microengine is such a device showing no sudden degradation increases under the shock loads below a certain level when they are tested at different levels of shocks at Sandia National Laboratories [9]. In addition, despite there is a relationship between sudden degradation increments caused by shock loads and the magnitude of shock loads, no explicit model has been proposed to describe such relationship but a relationship between the mean values of these two random variables [10]. Jiang et al. [11] has done some research, in which the small shock loads has no effect on the degradation process based on gamma process. But sometimes it is not proper for us to describe the degradation process with gamma process and they did not consider the component facing one shock process and two degradation processes.

In addition, there are many literatures about reliability evaluation of system experiencing two dependent degradation processes. Pan et al. [12] described the dependence of two degradation characteristics from the perspective of degradation increments by Copulas with the degradation paths governed by a Wiener process. Pan et al. [13] adopted bivariate Birnbaum-Saunders distribution and its marginal distributions to approximate the reliability function of systems with two degradation paths modeled by gamma processes. Zhang et al. [14] applied Copulas to combine the time to failure distribution of the multiple degradation processes of products. Liu et al. [15] built a reliability model for systems with multiple degradation processes using Inverse Gaussian process and copulas. Peng et al. [16] proposed a new type of bivariate degradation model based on inverse Gaussian processes, where the dependence between the degradation processes was considered with copulas. Eryilmaz [17] modeled the dependence between two multi-state components via Copulas, where degradation process in both components follows a Markov process. In these researches, they only considered the dependence of two degradation processes without shock process, which has great influence on the degradation process. Only a few researchers studied the reliability of system experiencing one shock process and two degradation processes. Song et al. [18] developed a new multi-component system reliability model subject to multiple dependent competing failure processes. But the system was assumed to be a serial system, parallel system and series-parallel system respectively, which did not consider the complicated dependence between components. Li et al. [19] investigated the reliability of systems experiencing a shock process and two degradation processes. But they assumed that the three failure processes are independent. Li et al. [20] developed a generalized multi-state degraded system reliability model subject to multiple competing failure processes, including two degradation processes, and random shocks. But these failure processes were assumed to be independent. However, dynamics of the dependent structure between these processes are of importance, and should not be neglected. On the one hand, random shocks will accelerate the system degradation processes with sudden degradation increments. On the other hand, multiple performance degradation processes are dependent on each other because they are influenced by the same shock process. Wang *et al*. [21] modeled the dependent competing risks with multiple degradation processes and random shock using time-varying copulas. But they did not consider that the material with high reliability and long life has the ability to resist against small shock loads.

In this paper, we establish a new reliability model of system experiencing MDCFP with shock loads above a certain level. During the process of reliability modeling, we propose a simple relationship between sudden degradation increments caused by shock loads and the magnitude of shock loads. Here, we not only assess the reliability of systems experiencing a shock process and a degradation process but also the reliability of systems experiencing a shock process and multiple degradation processes. The dependence between a shock process and multiple degradation processes is considered with conditional probability and Copulas.

The remainder of this paper is organized as follows. Section 2 describes the system of interest. Section 3 discusses the reliability modeling of systems under a shock process and a degradation process. Section 4 discusses the reliability modeling of systems under a shock process and multiple degradation processes, where only shock loads above a certain level can cause sudden degradation increases. In Section 5, an application example and an extended example are presented to implement our models and sensitivity analysis. Section 6 summarizes this paper with concluding remarks.

2. System Description

The degradation process of the system is a continuous stochastic process when the system does not experience random shock loads, as shown in Fig. 1(a). If the system suffers random shock loads, as shown in Fig. 1(c), then the degradation process of the system will be changed, as shown in Fig. 1(b), which represents the total degradation process of the system. It is obvious that the system experiences two dependent competing failure processes: 1) soft failure caused by degradation, see Fig. 1(b); 2) hard failure caused by random shock loads. These two failure processes are dependent because they share the same random

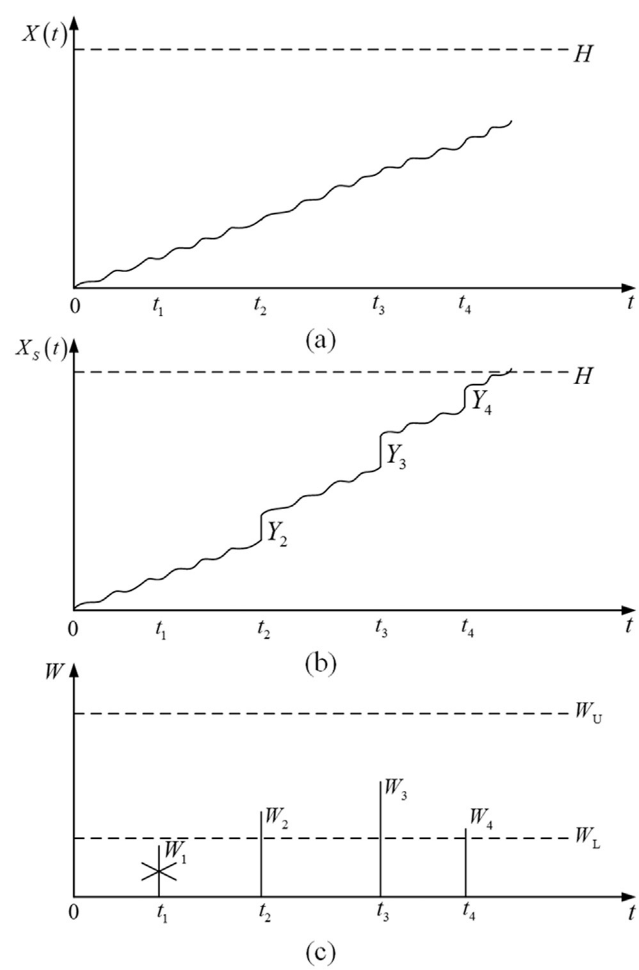

Fig. 1. Two dependent competing failure processes: (a) Continuous degradation (b) Total degradation process (c) Random shock process.

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