ARTICLE IN PRESS
Applied Mathematical Modelling xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Mathematical Modelling

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

Dynamic fuzzy reliability models of degraded hold-down structures for folded solar array

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ARTICLE INFO

Article history:
Received 15 February 2012
Received in revised form 26 January 2014
Accepted 11 February 2014
Available online xxxx

Keywords:
Solar array
Fuzzy reliability
Fuzzy failure rate
Material probabilistic property

ABSTRACT

The hold-down structures are of considerable importance to the launch of solar array. Due to the difficulties in obtaining sufficient load specimen, it is imprecise to construct the stress as random variables. Therefore, dynamic fuzzy reliability models are developed in this paper, which resolve the problems in dealing with the interaction between the fuzzy stress process and the stochastic strength process. Even for a deterministic fuzzy stress process, the influences of material statistical properties on reliability can be affected by the level α of fuzzy stress. Meanwhile, the level α relates to investment in the collection of information about the fuzzy stress on hold-down bar. Hence, the models can be used for the economic analysis and optimal design of hold-down bar. Finally, key fuzzy parameters of stress, which have significant influences on both the reliability behavior and the effects of material statistical properties on reliability, are identified and some suggestions for the reliability enhancement of hold-down bar are provided in this paper.

1. Introduction

Solar arrays are of considerable importance to the successful operation of satellites, which provide reliable power to satellites during the mission period [1]. The solar array of the satellite is mainly composed of yoke, outer-panel, mid-panel, inner-panel and closed cable loop as shown in Fig. 1.Over the last ten years, 10.26% of the solar array anomalies directly result in the total satellite failure according to the Airclaim's Ascend SpaceTrak database [2]. Moreover, solar array claims are more costly than any other power system element [3]. The designers and the manufacturers are greatly interested in any improvement in the reliability of the solar array. Therefore, it is worthwhile to develop reliability models of the solar array to facilitate engineers in understanding the variation in reliability with the parameters involved in the design and manufacture of the solar array.

During the last two decades, many novel methods are proposed for reliability assessment of solar array. Castet and Saleh conducted the nonparametric reliability analysis of 1584 Earth-orbiting satellites launched between January 1990 and October 2008 under the assumption of binary-state components and the assumption of multi-state components, respectively [2]. Wu and Yan proposed the reliability analysis method of the solar array by combining the fault tree analysis with the

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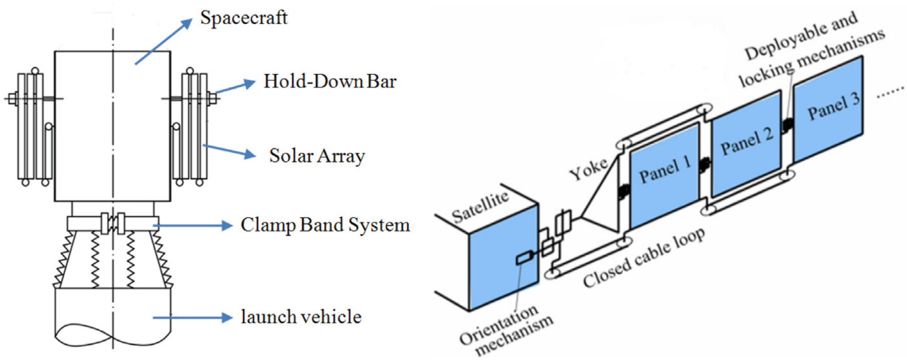
http://dx.doi.org/10.1016/j.apm.2014.02.011
0307-904X/



(a) Solar array in folded state **(b)** Solar array in deployed state

Fig. 1. Structure of the solar array.

fuzzy petri net [3]. In these models, the solar array is modeled as a one-shot subsystem, whose failure is caused by its deployment in a short duration.

The hold-down structures are composed of mechanical components, whose failure accounts for a large proportion of solar array anomalies [3–5].Over the last few decades, reliability analysis of mechanical components has been well reported. Jensen et al. presents an approach for solving reliability-based optimization problems under stochastic loading [6]. Guilleminot et al. proposeda probabilistic model for bounded elasticity tensor random fields, which is applied for polycrystalline microstructures [7]. Moller et al. provides a review of various non-traditional uncertainty models for engineering computation [8]. Taflanidis et al. developed a framework for optimal robust stochastic system design by means of stochastic simulation [9].

When developing reliability models of hold-down structures, there exist several problems to directly use these existing models, which are listed as follows.

(1) The models proposed by the authors in [10] are constructed by the probability theory. However, due to the difficulties in obtaining sufficient load specimen, it is imprecise to construct the stress on hold-down structures as a random variable. In this case, the stress could be modeled as a fuzzy variable [11–17]. Conventional fuzzy reliability models of mechanical components are always static. However, in the launch of rocket, strength deterioration of hold-down structures occurs due to the repetitious action of load. The difficulty in developing dynamic fuzzy reliability models of mechanical components lies in how to mathematically deal with the interaction between the fuzzy stress process and the stochastic strength process. In this paper, dynamic reliability models of components are developed by integrating the decomposition theorem and the properties of strength deterioration of components.
(2) In Ref. [18], the authors proposed a fuzzy reliability model of a series system. However, Ref. [18] is aimed at analyzing the systemic reliability behavior. In Ref. [17], the models are only focused on the influences of component dependency on the systemic reliability without any investigation about how the reliability behavior of a component is affected by the material characteristics and fuzzy stress. In addition, for a component, engineers are more interested in the impact of statistical properties of component parameter on reliability. In conventional dynamic reliability models, stress process and strength process are mathematically expressed as two different stochastic processes. Thus, the influences of material statistical properties on reliability are deterministic for a deterministic stochastic stress process. However, even for a deterministic fuzzy stress process, the influences of material statistical properties on reliability may be different owing to the fuzzy properties of stress, such as the level α of fuzzy stress.

As a matter of fact, the level α of fuzzy stress is determined by the requirement of engineers and the amount of available information. The level of α affects both the reliability and the impacts of the statistical property of component parameters on reliability, which has not been reported in current literatures. The elevation of the level α requires more investment in the collection of information about the fuzzy stress on HDB. In this paper, the proposed models provide an approach to quantitatively establish the relationship between the level α and reliability, which can offer guidance in the decision-making of the economic analysis and design of HDB.

In addition, it should be noted that the impacts of the statistical property of component parameters on reliability are also affected by the fuzzy properties of stress. The proposed dynamic models can be used to analytically analyze the effects of the fuzzy properties of stress on the impacts of statistical property of component parameters on reliability in different period of working time, which will be demonstrated in this paper.

The remainder of this paper is organized as follows: A brief introduction of hold-down structures is given in Section 2. In Section 3, dynamic fuzzy reliability models of HDB in terms of action times of load are developed. In Section 4, dynamic reliability models of HDB in terms of time are constructed based on the models developed in Section 3. In Section 5, numerical

Please cite this article in press as: P. Gao et al., Dynamic fuzzy reliability models of degraded hold-down structures for folded solar array, Appl. Math. Modell. (2014), http://dx.doi.org/10.1016/j.apm.2014.02.011