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A study of availability-centered preventive maintenance for multi-component systems

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Abstract

This paper studies preventive maintenance (PM) in simultaneously considering three actions, mechanical service, repair and replacement for a multi-components system based on availability. Mechanical service denotes the activities including lubricating, cleaning, checking and adjusting, etc. which is set to alleviate strength degradation. Repair is defined on that not only slow down the degraded velocity but also restore the degraded strength partly. Replacement is settled to recover a component to its original condition. According to the definitions, the degradation of components is analyzed from its failure mechanisms and the improvements of various actions to it in reliability were measured by using two improved factors. Following the proposed model of reliability, the mean-up and mean-down times of each component are also investigated and the replacement intervals of components are determined based on availability maximization. Here, the minimum one among the intervals is chosen as the PM interval of system for programming the periodical PM policy. The selection of action for the components on every PM stage is decided by maximizing system benefit in maintenance. Repeatedly, the scheduling is progressed step by step and is terminated until the system extended life reaching to its expected life. The complete schedule provides the information, the actions adopted for the components, the availability and the total cost of system on each stage. Validly, a multi-components system is used as an example to describe the proposed algorithm.

Keywords: Preventive maintenance; Reliability and availability

1. Introduction

To keep a system in normal condition, taking proper maintenance becomes even more important during its serviced life. According to the studies reported in past, maintenance was classified into two categories, corrective maintenance (CM) and preventive maintenance (PM) [1]. Normally, PM is more effective than CM because it is always to keep a system in an available condition so that the large loss caused by unpredictable fails can be avoided. Aiming to PM policy, preventive replacement is a topic frequently discussed. For example, Jayabalan and Chaudhuri [2] developed a branching algorithm with effective dominance rules to determine the number of maintenance interventions before each replacement. Aven and Dekker [3] presented a general framework including various age and block replacement models for the optimization of replacement times. Zheng [4] proposed an opportunity-triggered replacement model to allow joint replacements for multiple-unit systems. Legat et al. [5] determined the optimal interval for PM/replacement using either an age-based or diagnostic-based renewal strategy. Wang et al. [6] proposed a scheduled method of preventive replacement for the key components of mechanical systems. Moreover, Vaurio [7] investigated the time-dependent unavailability of periodically tested aging components under different testing and repair policies, and then decided the time intervals in periodic testing and scheduled maintenance. In particular, combining the expert judgments with available operating feedback (Bayesian approach) have been reported by Procaccia et al. [8] for taking into account the combination of failure risk and economic consequence (statistical decision theory) to achieve a true optimization of maintenance policy choices.

Reviewing the above papers, most of them always concentrated on the development of mathematical models in

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achieving the optimization of PM policy based on some specific supporting, such as uniform improvement, maintenance activity and cost, etc. For a system which is consisted of many subsystems and/or components (SCs), the effectiveness of maintenance mainly depends on both the improved levels and the maintenance-costs of the SCs. It is similar to imperfect maintenance. Aiming to imperfect maintenance, Whitaker and Samaniego [9] proposed a method of reliability evaluation. Refs. [10,11] below cover different approaches proposed to model imperfect maintenance based on an improvement factor. Considering multi-activities in maintenance, Martorell et al. [12] assumed that the PM activities would affect component age as a function of the maintenance effectiveness, and suggested some age-dependent models to determine the risk and associated economic cost problems. Further, a new reliability model was presented by Martorel et al. [13] in which includes parameters related to surveillance and maintenance effectiveness and working conditions of the equipment, both environmental and operational.

For suitably modeling the effects of maintenance to a multi-component system, this paper combines three typical PM actions as follows.

(1a)-maintenance (mechanical service). This type-action emphasizes on maintaining a system on normal operating condition. It usually involves less techniques and tools, i.e. the improvement is limitary. It just only improves the extrinsic state (the deteriorated environment) so that it can tune the SCs to a more good condition. Several typical activities for this type are, for example, (a) lubricating, (b) adjusting/calibrating the position or load carried to the mating parts, (c) tightening the loose parts, (d) cleaning the dust, jam and rust, etc. to maintain the inherent function of parts, and (e) consuming materials supplement such as oil, waters, etc.

(1b)-maintenance (repair). This type-action is mainly adopted for some SCs which are expensive and/or uneasily to be acquired. It generally includes the activities of (1a) and repairing/replacing for some simple parts such as springs, seals, belts and bearings, etc. It can rightly recover the intrinsic damage except the extrinsic condition improved. Examples for this type are engine overhaul, engineering structure reinforcement and surface treatments to the moving parts, etc. Normally, it usually contains the following activities: (a) disassembly, (b) reassemble of the repaired SCs and/or (c) the whole function calibration.

(2P)-maintenance (replacement). This type-action is to replace the subsystem/component (SC) with a new one. It is frequently adopted for the key SCs to avoid serious damage occurred. In addition, the SCs which undergone several times (1a) and (1b) and were not worthy to go on using, may also take this type-action.

While planning the PM schedule according to the defined activities, the maintenance time and the optimization goal of system would affect the contents of actions adopted. Considering the time of PM taken, PM policies can be classified into two kinds, periodical PM and non-periodical PM. The former is more regular so that it is often executed in a general system. The latter usually is more complex and is mostly adopted for some specific parts, e.g. key components, because its maintenance interval is not constant. Moreover, the commonly used goals on maintenance optimization are based on either costs minimization or profits maximization [14]. A frequent adopted index in representing system performance is the availability, which describes the ratio of up and down times of systems. It is so important as well as costs/profits in many real situations. Therefore, there were many authors to have considered the both criteria in developing approaches for searching the optimized maintenance [15–17]. Typically, Borgonovo et al. [18] presented an approach for the evaluation of plant maintenance strategies and operating procedures under economic constraints.

For a complex system, the shut-down loss could be obviously reduced as well as its effectiveness can be promoted if its availability can be set or maintained at someone level. In this paper, availability maximization is adopted as a criterion for scheduling periodical PM. It is used to determine the PM intervals of SCs for a multi-component system. Three kinds of action mentioned above are concurrently taken on each PM stage. The purpose of PM strategy is not only on maintaining the system life to its expected life but also in obtaining the maximum system benefit by availability optimization. By the example analysis, the results demonstrate that the PM policy which considers more than one action is more advantage than that only single action (replacement) adopted.

2. Reliability under PM

Before scheduling the PM program, the improvements of various PM actions to reliability must be identified at first. From the viewpoint of strength–stress interference theory (SSI), reliability degrading denotes that the strength distribution is moving toward left depending on time. The (1a)-maintenance could slow down the moving velocity of the strength distribution due to the deteriorated environment improved so as to it could delay the degraded time. On the other hand, the (1b)- and (2P)-maintenances could shift the distribution toward right except holding the function of (1a), i.e. uplifting the reliability, because the cumulative damages of system could be solved by the two actions. The effects of various actions to the strength distribution were shown in Fig. 1.

According to the improved mechanisms, the improvements of maintenance to the system can be classified into two parts. The former is the recovery to the failed parts of system which are restored either by repairing or by replacing. The latter is the improvement to the survival parts which are restored by anyone of the three actions. Ideally, the reliability of surviving parts can be modeled by using the age reduction model [1,2]. This model proposed the system reliability