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Optimizing preventive maintenance for mechanical components using genetic algorithms

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Abstract

This paper presents periodic preventive maintenance (PM) of a system with deteriorated components. Two activities, simple preventive maintenance and preventive replacement, are simultaneously considered to arrange the PM schedule of a system. A simple PM is to recover the degraded component to some level of the original condition according to an improvement factor which is determined by a quantitative assessment process. A preventive replacement is to restore the aged component by a new one. The degraded behavior of components is modeled by a dynamic reliability equation, and the effect of PM activities to reliability and failure rate of components is formulated based on age reduction model. While scheduling the PM policy, the PM components within a system are first identified. The maintenance cost and the extended life of the system under any activities-combination, which represents what kind of activities taken for these chosen components, are analyzed for evaluating the unit-cost life of the system. The optimal activities-combination at each PM stage is decided by using genetic algorithm in maximizing the system unit-cost life. Repeatedly, the PM scheduling is progressed to the next stage until the system's unit-cost life is less than its discarded life. Appropriately a mechatronic system is used as an example to demonstrate the proposed algorithm. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Reliability; Preventive maintenance; Improvement factor; Genetic algorithms

1. Introduction

Reliability is an index representing the system performance. For a system, the reliability usually degrades depending on the increase of system service time. To maintain the expected performance of a system, taking proper maintenance during its life cycle is necessary. According to the time of maintenance-executed, maintenance is usually classified into two major categories, corrective maintenance (CM) and preventive maintenance (PM). The former corresponds to the actions that occur after the system breaks down. The latter corresponds to the actions that come about when the system is operating. The advantage of PM is that the system can always be kept in an available condition when needed and the serious loss incurred by the unpredicted fails can be avoided. According to the definition reported by Lie and Chun [1], CM activities are categorized into minimal repair (1C) and corrective replacement (2C). 1C-maintenance makes no change in system time and restores the system reliability to it when it had failed. 2C-maintenance renews the system time to zero and the reliability curve is that of a new system. PM activities are also grouped into simple preventive maintenance (1P) and preventive replacement (2P). 1P-maintenance changes the system reliability to some newer time. 2P-maintenance likes corrective replacement that restores the reliability curve to new one, but only occurs in the system state. Fig. 1 shows the reliability behavior of a system on various maintenance types. This classification in maintenance was already quoted and a branching algorithm with effective dominance rules was also developed by Jayaband and Chaudhuri [2] to determine the number of maintenance interventions before each replacement. However, the PM policy of a system owning many components have not yet discussed. Thus, this paper simultaneously considers the activities of 1P and 2P for some important components enclosed in a system to arrange the PM schedule. Moreover, genetic algorithms (GAs) is used as a tool for deciding what kind of activities to be performed on every PM stage.

In past, many PM policies concentrated on the problem of 2P. For instance, Aven and Dekker [3] presented a general framework including various age and block replacement models for the optimization of replacement times. Zheng

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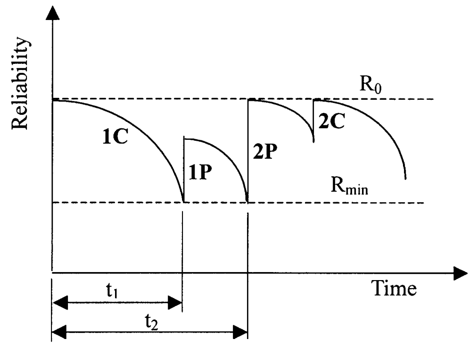

Fig. 1. Reliability change of system under various maintenance types.

[4] proposed an opportunity-triggered replacement model to allow joint replacements for multiple-unit systems. Legat et al. [5] determined the optimal interval for preventive maintenance/replacement using either an age-based or diagnostic-based renewal strategy. Wang et al. [6] proposed a method of preventive replacement scheduling for the key components of a mechanical system by pursuing the system profit maximum. 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. Procaccia [8] combined expert judgments with available operating feedback (Bayesian approach) and took into account the combination of failure risk and economic consequence (statistical decision theory) to achieve a true optimization of maintenance policy choices. In these papers, most of them always endeavored to the development of mathematical models in achieving the optimal maintenance policy under some specific supporting, such as uniform maintenance activity and cost, etc. They always assumed that the system after each PM intervention is restored as new. However, this assumption does not hold true in most situations as the state of the system after PM is somewhere between as good as new and as bad as old.

Customarily, PM which does not return the system to its original condition just like 1P is known as an imperfect repair. Considering the imperfect repair, the maintained system usually was treated as though it is being renewed partly. Concerning the prior published work, Refs. [9–11] below cover different approaches proposed to model imperfect maintenance based on an improvement factor (named factor 'm' here). Typically, Wang [12] explored the optimal maintenance-level of system for planning the repair policy of a mechanical system. To quantify the effect of surveillance and maintenance to component-reliability, some age-dependent models to determine risks and associated economic costs were reported by Martorell et al. [13], which explicitly consider how activities affect the component age as a function of the maintenance effectiveness. Further, Martorell et al. [14] presented two general models named PAR (Proportional Age Reduction) and PAS (Proportional Age Setback), the former being similar to the one proposed by the authors in this paper (see Eq. (5)). It is worthy to demonstrate (or provide appropriate reference to previous work) that the mechanical equipment fits the PAR model proposed here better than others, as for example the PAS model.

For convenience in maintenance a system is usually decomposed into many individual components or/and units. However, the maintenance-activities for these components at each PM stage may be different due to the degraded difference and the cost or risk considerations. Considering the effects of system cost and life, the arrangement of PM activity becomes an optimization problem in deciding what is the optimal activities-combination for the maintained components. Although the optimization problem can be resolved by completely enumerating the possible answers to the search space, it is exhaust in time and is inefficient for a large space. In the last years, an increasing number of GAs was used to treat the optimization problems in system reliability [15,16] and in maintenance strategy [17,18]. Aiming to a complex system, the component's maintenance period and process can usually be solved quickly by GAs [18,19]. The tendency reveals that GAs is an efficient tool to rapidly obtain the optimal solution of PM policy. Thus, GAs is used as a tool here to find out the optimal activities-combination for the maintained components.

In this paper, two kind of PM activities, 1P and 2P, are concurrently taken into account at every PM stage for a mechanical system. The degraded behavior of the maintained components is modeled by a dynamic reliability equation and the improved levels of 1P to these components are evaluated by a quantitative assessment procedure. No sooner than the PM components established, the extended life and the maintenance cost of the system in any activities-combination are investigated to calculate the unit-cost life of system. Ideally, the optimal activities-combination which maximizes system unit-cost life at each PM stage is decided by using GAs. Continually, the PM scheduling is terminated until the unit-cost life with maintenance is less than its discarded life.

2. Effect of 1P-maintenance to reliability

System performance can be kept as good as possible if great care in maintenance is taken during its operation. Meanwhile, the life cycle of the system is extended and the efficiency is also promoted. To decrease the potential risk of the system or to avoid great economic loss occurrance, taking periodic PM for some important components is needed. Since PM is classified into 1P and 2P, either 1P or 2P is adopted for these components. Combining the effects of PM to these components, the performance promotion of the system can be calculated.