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On preventive maintenance policy of a critical reliability level for system subject to degradation

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Abstract

Conventional preventive maintenance (PM) policies generally hold same time interval for PM actions and are often applied with known failure modes. The same time interval will give unavoidably decreasing reliabilities at the PM actions for degradation system with imperfect PM effect and the known failure modes may be inaccurate in practice. Therefore, field managers would prefer policy with an acceptable reliability level to keep system often at a good state.

A PM policy with the critical reliability level is presented to address the preference of field managers. Through assuming that system after a PM action starts a new failure process, a parameter so-called degradation ratio is introduced to represent the imperfect effect. The policy holds a law that there is same number of failures in the time intervals of various PM cycles, and same degradation ratio for the system reliability or benefit parameters such as the optimal time intervals and the hazard rates between the neighboring PM cycles. This law is valid to any of the failure modes that could be appropriately referred as a 'general isodegrading model', and the degradation ratio as a 'general isodegrading ratio'. In addition, life cycle availability and cost functions are derived for system with the policy. An analysis of the field data of a loading and unloading machine indicates that the reliability, availability and cost in life cycle might be well modeled by the present theory and approach.

Keywords: Preventive maintenance; Degradation; Critical reliability; Life cycle; Availability; Cost

1. Introduction

Preventive maintenance (PM) is a necessary activity to restore or keep the function of a repairable system in good state. How to assess the effect of this activity and how to arrange it properly for addressing one's satisfactions have been long focused in practice since 1960s [1].

It has been revealed that maintenance effects can be subdivided into a perfect, a non-effect, and an imperfect [2,3]. A perfect effect restores the system to good-as-new, a non-effect to bad-as-old, and an imperfect effect to partly good. For system subjected to age/degradation, the imperfect should be generally for PM, and the perfect and non-effects are extreme. Present paper will discuss the imperfect.

Conventional replacement/PM policies [5–10] are derived using non-decreasing hazard rate functions on a basis of the imperfect effect model by Brown and Proschan [4] or the consideration with minimal repair by Barlow and Hunter [1]. They hold generally a same time interval T for replacement/PM actions and are often applied with known failure modes. The age-T policy will give unavoidably decreasing reliabilities at the PM actions for degradation system with imperfect PM effect and the known failure modes may be inaccurate in practice for complicated system.

An interesting phenomenon worthy to pay attention is that the field managers preferred the PM opportunities being derived from an acceptable specified reliability level [11–13]. This phenomenon is known in our field investigation into the loading and unloading machinery used at Chinese railway terminals. Major causes may be included as:

1. Proper PM actions should be at best derived from the inspection in service. Under this case, unless there is a fine support system for decisions making, the known failure models can be seldom quantified accurately in practice for the complicated repairable system.

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2. Following the management rules with T-age PM policy [14], the machinery exhibit increasing hazard rates at the PM actions due to the imperfect PM effect. Correspondingly, the reliabilities at the PM actions show a gradual decreasing.
3. To keep the machinery operated at a good technical state with reliability above an acceptable reliability level, the field managers took often unconsciously the measurement of shortening the T intervals as the PM action increasing.

However, there is no effort addressing the preference of field managers. Key issues are how to quantify the imperfect effect and how to arrange PM actions properly to address one's satisfactions. These should be very difficult tasks. Some good efforts have made in the proportional hazard (PH) model [15–17] and the work by Soares and Garbatov [18]. The PH model uses the proportional age reduction factor to the baseline of hazard rate or to the operation time. Considering the reliability of the ship hull girder with age failure mechanism after repair smaller than the initial value for new, Soares and Garbatov introduced a reduction factor for piece of time to represent the 'recovered' time of a repair action.

Through assuming that system after PM action starts a new failure process, a parameter so-called degradation ratio should be introduced to represent the imperfect effect of PM on the system reliability, availability, or benefit between neighboring PM cycles. This paper tries to develop a PM policy with a critical reliability level to meet the preference of field managers. Aim is addressed on that the policy is valid to arbitrary failure process/mode. Relative approaches are also explored for predicting the life cycle availability and cost under this policy.

2. Preventive maintenance policy

2.1. Degradation viewpoints

PM cost and effect in general have a non-linear relation. The cost per unit time may increase rapidly when the effect is over a critical level. Therefore, there are few of preferences to cost much more to restore the system good-as-new or well-than-new, i.e. PM effect is generally imperfect.

From viewpoint of the thermodynamics, the components in operation are subject to irreversible energy dissipation due to fatigue, wear, corrosion, etc. up to be replaced. The system in a PM cycle is physically subject to an irreversible degradation due to causes:

1. The components not repaired in PM actions undergo an irreversible, continuous and cumulative damage.
2. Some damaged components are repaired but not replaced in PM actions; the existing cumulative damage cannot be removed.
3. Although some damaged components are replaced in PM actions, the cumulative wear of adjacent and non-replaced components may still exist to worsen the stress conditions of the relative parts.

As shown in Fig. 1, the degradation results in a gradual increase of the hazard rates in the time intervals with the PM cycling.

2.2. Policy

It is here assumed that:

1. The system undergoes relatively constant conditions of stress, environment and maintenance in life cycle.
2. A corrective repair (CR) restores locally the system good-as-before the failure. This implies that the failure process during a PM cycle can be reasonably described as a continuous failure mode.
3. A PM action has an imperfect effect on the system in general. This implies that there is difference between the failure processes before and after the PM action. It is reasonably to consider that after PM action the system begins a new failure process. As shown in Fig. 1, the failure rates at the PM actions exhibit an increase as PM cycling.

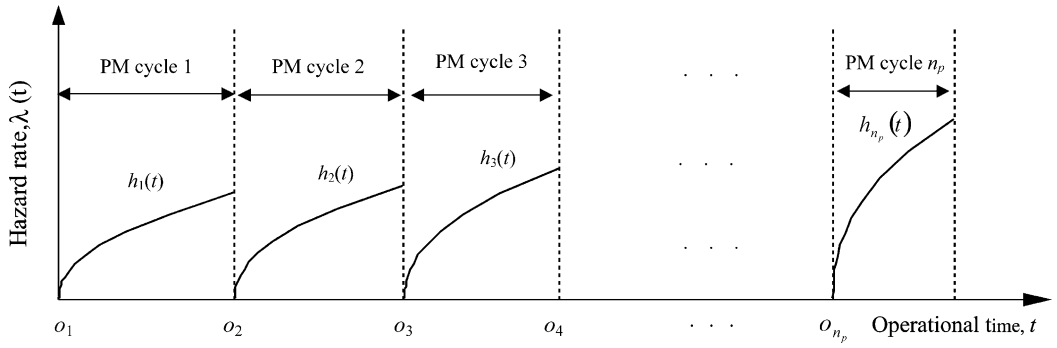

Fig. 1. Hazard rates of PM cycles for the system subject to degradation ($h_i(t)$ is hazard rate function in the PM cycle i; o_i is start point of the PM cycle i; $i = 1, 2, \ldots, n_p$, and n_p is number of PM cycles for the system in life cycle).