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Condition-based scheduled maintenance optimization of structures based on reliability requirements under continuous degradation and random shocks

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Background

- Engineering structures are often exposed to severe operating conditions during their service lives. Failures may occur due to internal gradual degradation or to external shocks under such circumstances.
- Two dependent failure processes are often identified: 1) soft failures and 2) hard failures.
- Failures of a structure can have catastrophic consequences. In order to avoid such consequences and to prolong the useful lifetime, preventive maintenance (PM) actions are usually executed throughout its operating period.

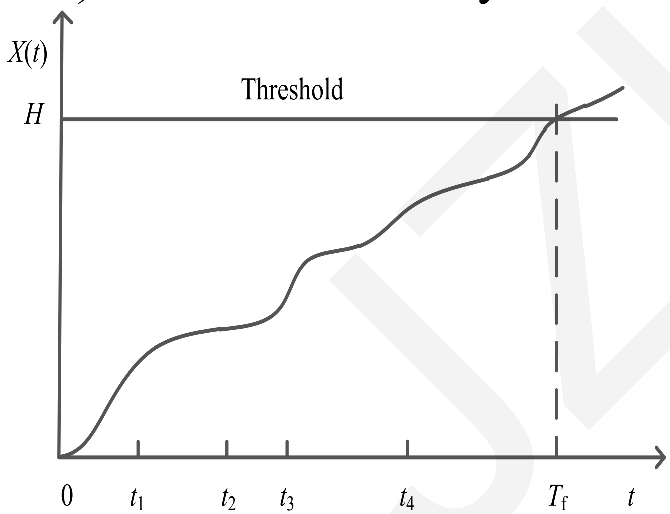

Fig.1 Illustration of gradual degradation

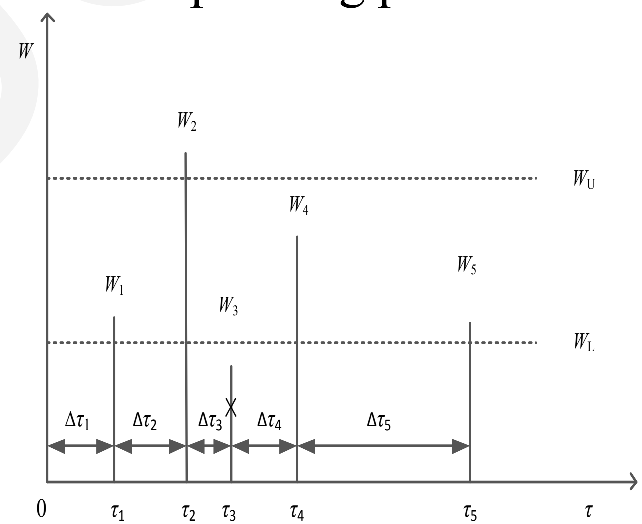

Fig. 2 Illustration of a possible random shock process

Reliability Model

For a system experiencing gradual degradation and shocks, the total damage for the system deterioration is the cumulative effect of both continuous degradation and those moderate shocks, i.e.:

$$X_S(t) = X(t) + S(t) = X(t) + \sum_{j=1}^{N_2(t)} Y_j. \qquad (1)$$

The reliability of the system is evaluated by:

$$R(t) = 1 - P_f = 1 - [\underbrace{\Pr\{N_3(t) \neq 0\}}_{Hard\ \ Failure} + \underbrace{\Pr\{Failure \mid N_3(t) = 0\}}_{Soft\ \ Failure} \cdot \Pr\{N_3(t) = 0\}]$$

$$= \Pr\{N_3(t) = 0\} \cdot \Pr\{X_S(t) < H\}$$

$$= \Pr\{N_3(t) = 0\} \cdot [\Pr\{X(t) < H\} \cdot \Pr\{N_2(t) = 0\}$$

$$+ \sum_{i=1}^{\infty} \Pr\{[X(t) + \sum_{j=1}^{i} Y_j] < H\} \cdot \Pr\{N_2(t) = i\}] \qquad (2)$$

$$= \frac{\gamma(\alpha(t), H/\beta)}{\Gamma(\alpha(t))} \cdot \mathrm{e}^{-\lambda(p_2+p_3)t}$$

$$+ \sum_{i=1}^{\infty} \{[\int_0^H F_{S_i}(H-x) \cdot f_X(x;\alpha(t),\beta)dx - F_{S_i}(0) \cdot \int_0^H f_X(x;\alpha(t),\beta)dx] \cdot e^{-\lambda(p_2+p_3)t} \cdot \frac{(\lambda p_2 t)^i}{i!}\},$$

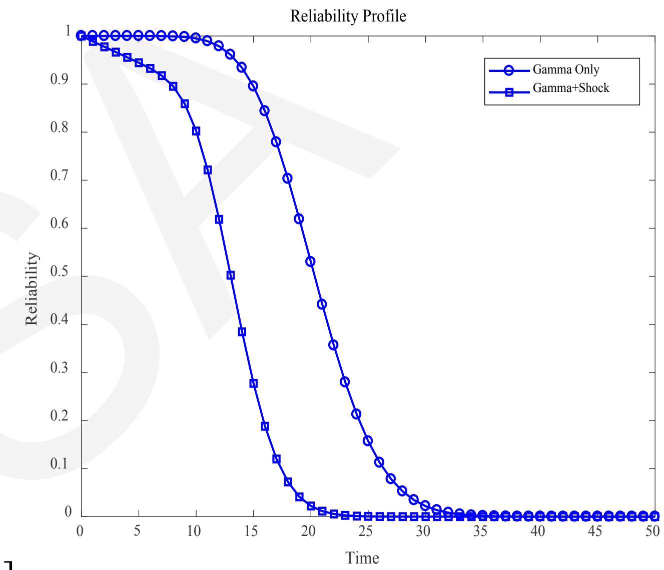

Fig. 3 Plots of reliability function *R*(*t*)

Optimization Model

To avoid severe environmental and/or economic consequences and prolong the useful lifetime of the system, preventive maintenance (PM) actions are usually performed throughout its operating period. In the framework of condition-based maintenance (CBM) optimization, system information is usually employed to make decisions about both the inspection time and maintenance actions. The optimization model for such a problem is as follows:

$$
\begin{aligned}
& Find: \mathrm{MC}^{*} = \min_{M,K} \mathrm{MC}(M, K) \\
& s.t. \;\; M \in (0, H]; \\
& \qquad K \in [1, K_{\max}], \text{ and } K \text{ is integer}; \\
& \qquad R(t) \geq 1 - Q, \; t \in [0, L]; \\
& \qquad \Delta t_{i+1}: \Pr\{X_S^{-}(t_i + \Delta t_{i+1}) \geq H \mid X_S^{+}(t_i)\} = Q, \; i = 0,1,2,3,\ldots, t_0 = 0.
\end{aligned}
\tag{3}
$$

where M is the preventive maintenance threshold, K is the perfect preventive threshold, $K_{\max}$ is the maximum value of K, L is the lifetime and Q is the failure probability threshold.

Results

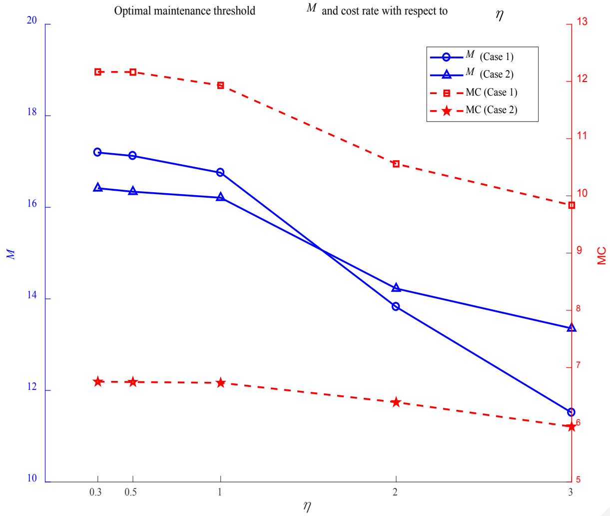

Fig. 4 Optimal maintenance threshold *M* and cost rate with respect to *η* (infinite time span)

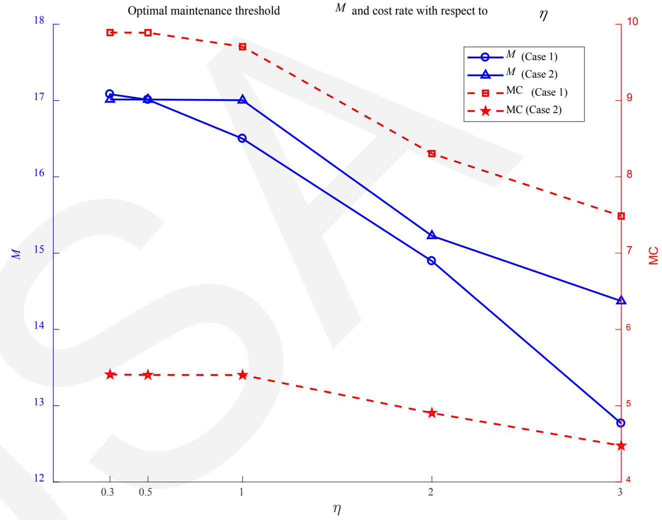

Fig. 5 Optimal maintenance threshold *M* and cost rate with respect to *η* (*T*=50)

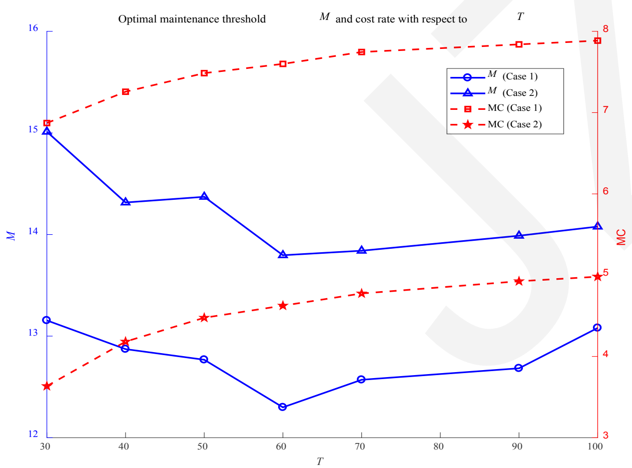

Fig. 6 Optimal maintenance threshold *M* and cost rate with respect to *T*

Case 1: Gamma + Shocks

Case 2: Gamma Only

Conclusions

- The random shock process greatly influences the reliability.
- Systems experiencing a gamma process, as well as a random shock process, are much more vulnerable to failure as compared to the case where only continuous degradation is involved.

- ✓ The shock loads exert notable impacts on the optimal preventive maintenance strategy.
- ✓ Optimal solutions of a finite time span are different greatly from those of an infinite time span. Thus, it is of significance to investigate the optimal condition-based maintenance policy of a system within a finite time horizon.