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COST – EFFECTIVE MAINTENANCE WITH PREVENTIVE REPLACEMENT OF OLDEST COMPONENTS

We consider preventive maintenance of a continuously operating system, whose real-life prototype is a rotating chemical reactor for production of phosphorous acid. The drum, in which the reaction takes place, has 42 rollers (elements), which are subjected to a heavy load and to chemical corrosion. The components are organized in a ring-type structure. The system failure is defined either as the failure of 2 adjacent elements, or as a failure of any three elements in a set of 6 adjacent elements. The existing servicing policy prescribes replacing only the failed elements at the instant of system failure occurrence. The operational conditions permit the opportunistic replacement of non-failed components at the instant of system failure.
In this paper, we propose a cost-effective policy of preventive maintenance: at the same time the system fails, several of the oldest non-failed components are replaced by new ones. The application of the above optimal preventive maintenance policy results in a reduction of the average cost per unit time by 15-30%.

Keywords: *preventive maintenance, group replacement, simulation approach*

1. Introduction

Group replacement is one of the strategies that may be employed for the maintenance of technical systems of identical, consecutive components. The aim of the strategy is to replace all or part of the system's components within given time periods, thus minimizing the maintenance costs (Gertsbakh 2000).

It is possible to plan the repair, either on the basis of operational time elapsed since the last repair or when a critical number of elements failed to function. It is natural to replace preventively the oldest elements among the non-failed ones. In order to ensure optimum efficiency in the latter maintenance approach, we introduce two parameters: a threshold of failures, necessary for implementing the repair; and the number of components to be replaced (Dekker et al. 2000).

It is extremely difficult to investigate a problem of this type analytically. Consequently, we propose an approach and a solution based on a simulation study.

2. Problem Description

We consider a system consisting of n independent statistically identical components. It is assumed that 2 adjacent malfunctioning components cause the system to come to a halt. At the instant the system stops, the components that have failed are replaced by new identical ones. We assume that the replacement time is negligible. The cost of the replacement is constant and is C_1, while the cost of the breakdown of the system is C_0. Thus a repair involving the replacement of the malfunctioning component, as well as the r oldest elements, will cost the following sum: $C_0+(r+2)C_1$.

The renewal of the broken elements with the simultaneous replacement of r oldest elements leads both to a decrease in the number of breakdowns when the system is in use, and conversely to an increase in the periods between repairs. The aim of this study is to establish the optimal r, which minimizes the maintenance cost per unit time.

The expected cost of maintenance per time unit is stated as a function of the number of r components and is given by the following formula (Frenkel et al. 2002):

$$\eta(r) = \frac{E[N]\{C_0 + (r+2)C_1\}}{T} \qquad (1)$$

where $E[N]$ represents the mean value of failures occurred in the $[0,T]$ interval.

The simulation algorithm is written in MATLAB.

3. Case Study

The real-life prototype for n-component system is the Phosphor acid filter, using in Rotem/Deshanim Chemical Processing Facility, Arad, Israel, whose base is comprised of 42 identical turning rollers (elements). According to the technical specification, a failure (breakdown) of the system occurs when 2 adjacent rollers stop working. The cost of the system's breakdown is \$100. The cost of replacing an element varies from \$1 to \$99. Time to failure for one roller, according to

Facility data, has Weibull distribution with parameters $\lambda = 3.77*10^{-4}$, $\beta = 2.6$. The time period involved $[0,T]$ is 100 weeks, which is approximately the lifetime of the whole system.

Using the simulation approach, we compare the existing servicing policy with the suggested preventive maintenance policy, when at the same time as the system breaks down, several oldest non-failed components are replaced by new ones, for various values of C_1/C_0.

Fig.1 illustrates the repair cost per unit of time as a function of the number of additionally replaced components for various values of C_1/C_0 calculated for the existing system. The results indicate that when the cost of the replacement is low (i.e. where $C_1/C_0 = 1/100$-$10/100$, see two lower curves), the optimal strategy is to replace all the system's components. On the other hand, when the replacement cost is high (i.e. where $C_1/C_0 = 90/100$ and upwards, see the upper curve), the most effective policy is the replacement of only the failed component. In those instances where C_1/C_0 is greater than 10/100 but less than 90/100, and in particular where $C_1/C_0 = 30/100$, the optimal number of components that should be additionally renewed is 2; and where $C_1/C_0 = 50/100$, the optimal number of components that should be additionally renewed is 1. Thus, if, for example, one component replacement cost is $50, then the replacement of only the broken component would entail a cost of $1,800, whereas replacement of one additional component would entail a cost of $1,516. This represents a saving of 18.7%.

In addition to the above described servicing policy, we suggest two new policies:

(a) replacing 3 failed components in a set of 6 adjacent components;

(b) in addition to (a), several oldest non-failed components are replaced by new ones.

Fig. 2 illustrates the repair cost per unit time as a function of various values of C_1/C_0 for different strategies:

- strategy 1 - replacement of all broken elements after failure of 2 adjacent elements;
- strategy 2 - replacement of all broken elements after failure of 3 elements from 6 adjacent elements;
- strategy 3 - replacement of all broken and one additional oldest element after failure of 2 adjacent elements;
- strategy 4 - replacement of all broken and one additional oldest element after failure of 3 elements from 6 adjacent elements.

As evident in Figure 2, the replacement of one additional oldest element to 2 adjacent failed elements or replacement of an additional oldest element to 3 elements from 6 adjacent elements saves 15-25%. Changing the existing maintenance policy to the best policy saves 23-32% for different values of C_1/C_0.

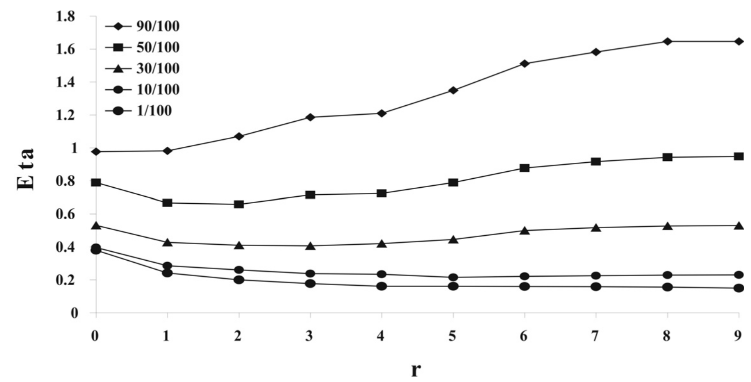

Fig. 1. Repair cost per unit of time as a function of the number of additional replaced components and the ratio C_1/C_0

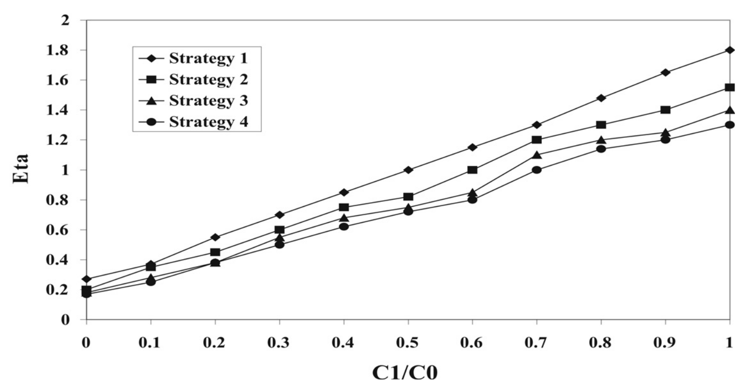

Fig. 2. Repair cost per unit time as a function n of various value of C_1/C_0

4. Conclusion

In summation, it is proposed that an optimal policy of maintenance, for a system consisting of identical and independent components, be based on the replacement of both the failed components and a certain number of the oldest but still functioning components.

It has been demonstrated that this strategy of group replacement compares very favorably with that of simply replacing the failed components and that it guarantees savings in the range of 15-32%.

5. References

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