MODELS CONCERNING PREVENTIVE VERIFICATION OF TECHNICAL EQUIPMENT

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Abstract – The paper presents three operative models whose purpose is to improve the practice of preventive maintenance to a wide range of technical installations.
Although the calculation criteria are different, the goal is the same: to determine the optimum time between two consecutive preventive interventions.
The optimum criteria of these models are:
- the maximum share of technical entity operating probabilities, in the case of the Ackoff - Sasieni [1] method;
-the optimum time interval for preventive verification depending on the preventive-corrective maintenance costs imposed by the deciding factor, for the Asturio-Baldin [2] model;
- the minimum number of renewals – preventive and/or corrective maintenance operations [3].

Keywords: share of operating probability, reliability protection system, preventive maintenance costs and costs for the corrective option, ERP and RBM maintenance strategies, electro-pump.

1. INTRODUCTION

The optimum techniques presented take into account those technical entities showing an exponential temporal evolution. For the equipment whose operational exponent is Weibull type, Kelly [2] method is recommended.
Note that the optimum time interval expressions for preventive verification according to the first two methods are similar, although the criteria considered are different. Thus, in the case of Ackoff- Sasieni model, the optimum time of the preventive action depends on the falls rate (λ) and on the length of the verification operation (θ), in the case of Asturio-Baldin method the time depends on the same size λ and the duration of the verification is replaced by the ratio between the cost of a preventive operation and the hourly cost for the liquidation of the non-operational status. Referring to this report (economic increment), one can see that, dimensionally, it is equal to θ parameter.

Indeed, in the case of Ackoff-Sasieni model, from a dimensional point of view, θ parameter is expressed as follows:

$\theta[\frac{time\,units\text{(hours)}}{preventive\,action}]$. Thus, in the Asturio-Baldin model, the economic report k is expressed depending on the costs associated to the two preventive (C_p) and corrective maintenance (C_d) categories as follows:

$$k = \frac{C_p}{C_d} \Rightarrow \frac{C_p[\text{m.u.(monetary}\,units)]}{C_d[\text{m.u/ unit time (hour)}]}$$

or

$k = \frac{C_p}{C_d}[\text{hours/ activity}]$. Therefore, this report, from a dimensional point of view, is equivalent to size θ but not numerically equal, because the optimum criteria are different.

2. THE ACKOFF-SASIENI MODEL

Be the sum of operating probabilities in the case of a technical equipment whose temporal evolution on the $[0;\text{t}-1]$ time interval is exponential:

$$\sum_i P_i = e^{-\lambda\cdot 0} + e^{-\lambda\cdot 1} + +..+ e^{-\lambda\cdot k} + ..+ e^{-\lambda(\text{t}-1)} \quad (1)$$

Where:
λ - the failure rate of the technical entity and $0,1,2,...,k,...,t-1$ are the moments of the time interval.
Relation (1) can also be described as:

$$\sum_i P_i = 1 + (e^{-\lambda})^1 + (e^{-\lambda})^2 + +..+ (e^{-\lambda})^k + ..+ (e^{-\lambda})^{t-1} \quad (1')$$

or

$$\sum_i P_i = \frac{[1+(e^{-\lambda})^1 + ..+ (e^{-\lambda})^{t-1}][1-(e^{-\lambda})^1]}{[1-(\text{e}^{-\lambda})^1]} . \quad (1")$$

The numerator of the expression being $(1-\text{e}^{-\lambda t})$, the sum of operating probabilities becomes:

$$\sum_i P_i = \frac{1-e^{-\lambda t}}{1-e^{-\lambda}} . \quad (1''')$$

The share of the sum of these probabilities associated to [0; t] time interval is expressed by the ratio:

$$\Pi = \frac{\sum_i P_i}{[t+\theta+\tau(1-e^{-\lambda t})]} \qquad (2)$$

Where:
t - the operating time interval;
θ - the duration of the preventive intervention;
τ - the average duration of work occurred following a possible state of unavailability of the installation concerned.
Preventive verification can be completed with maintenance works, if necessary.
The calculation imposed by the maximization of the operating probabilities share for the technical equipment is confirmed by the two authors, based on economic criteria.
Next, we intend to obtain the maximization operation of size Π depending on the optimum level of the time interval for the preventive verification of the technical equipment concerned.
The optimum condition is:

$$\frac{d\Pi}{dt} = 0 . \qquad (3)$$

From it, the following results:

$$\frac{d}{dt}(\Pi(t)) = \frac{1}{1-e^{-\lambda}}\frac{d}{dt}[\frac{1-e^{-\lambda t}}{t+\theta+\tau(1-e^{-\lambda t})}] = 0 .$$

By making this calculation, one can deduce the optimum values of the type of preventive verification:

$$t_0 = \sqrt{\frac{2\theta}{\lambda}} . \qquad (4)$$

Thus, one can notice that the optimum time interval depends on the average duration of a preventive verification and on the rhythm of falls.
Be an electro pump of the cooling water system of a steam turbine having the power of P=50 MW.
Knowing parameter $\lambda = 0,00023\, failures/\text{hour}$ [4] and a preventive verification duration, θ= 8 hours, one can deduce the optimum time interval between two preventive verification actions of the installation. According to relation (4),

$$t_0 = \sqrt{\frac{2\cdot 8}{0,00023}} \simeq 264\, hours .$$

The daily operating duration being 8 hours, one can obtain the optimum interval t_0= 33 days, namely around one month of this operating regime.

3. ASTURIO-BALDIN MODEL

This calculation technique takes into account all costs associated to preventive and corrective maintenance and the optimum time interval for periodical verification results from the relation:

$$e^{\lambda t_0} - \lambda t_0 = 1 + \lambda\frac{C_p}{C_d} , \qquad (5)$$

Where:
λ, t_0 and C_p have the meanings specified.
By approximating the Mac-Laurin series development in the first member of relation (4), we obtain:

$$1+\lambda t_0 + \frac{\lambda^2 t_0^2}{2!} - \lambda t_0 = 1+\lambda\frac{C_p}{C_d} \qquad (5')$$

or,

$$\lambda^2 t_0^2 = \frac{C_p}{C_d} . \qquad (5'')$$

It results:

$$t_0 = \sqrt{\frac{2C_p}{\lambda C_d}} . \qquad (6)$$

According to the French documentation, this economic increment [6]:

$$k = \frac{C_p}{C_d} \cong 0,05 \div 0,15 , \qquad (7)$$

the upper limit is adopted to cover the quantum of expenses owed to corrective interventions, more numerous in the case of our country.
Obviously, the optimum value of the time interval for preventive verification obtained from this model is different because of the different optimum criterion adopted in the previous model.

Thus, for the same fall rate $\lambda = 0,00023 h^{-1}$, $C_p = 120$ /preventive verification and $C_d = 1500$ um/flaw (um= monetary units) and the report $k = 0,8$. Then $t_0 = \sqrt{\frac{2\cdot 0,8}{0,00023}} \Rightarrow t_0 = 84$ hours preventive verification interval, which means approximately ten days in the case of the operating regime adopted daily.

4. ERB-RBM MODEL

ERP and RBM represent two preventive maintenance strategies:
- ERP (Eventual Replacement Policy) aims to verify periodically the installations according to the program set and to remedy all non-compliances, if necessary [3];
- RBM (Reliability Based to Maintenance) mainly aims to detect non-compliances that generate flaws, as well as to prevent and liquidate the technical equipment's states of wear [6].
The optimum criterion is the minimum number operating interruptions for the renewal of the installation concerned.
According to an in-depth study, based on the theory of Markov chains [7], the authors of the paper [3] set the expression of a technical equipment renewal function (Fig. 1).

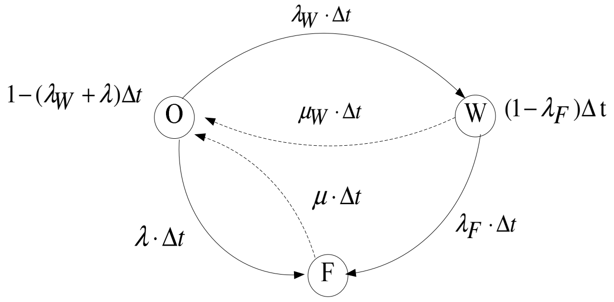

Fig. 1 The graph of state transitions of a used technical system

In the above figure,

λ_W - is the wear intensity of the technical equipment, h^{-1};

λ_F - the dysfunction (failure) intensity of the technical equipment, h^{-1};

μ_W - the rhythm of returning from the wear status;

μ - the rhythm of returning from the failure status.

The calculation does not take into account the dotted arches as well: $\mu_W \cdot \Delta t$ and $\mu \cdot \Delta t$ (the probabilities of returning to state O of the system). Obviously, the return from state F to state W does not make any sense. The renewal function of a technical system is given by the following relation:

$$H(\mathrm{t}) = \frac{\lambda_F(\lambda_W+\lambda)\,\mathrm{t}}{\lambda_W+\lambda_F} + \frac{\lambda_W(\lambda_F+\lambda)}{(\lambda_W+\lambda_F)^2} \cdot e^{-(\lambda_W+\lambda_F)\,\mathrm{t}} - \frac{\lambda_W(\lambda_F-\lambda_F)}{(\lambda_W+\lambda_F)^2}. \quad (7)$$

But to minimize the number of renewals equals to the optimum preventive maintenance strategy. For this reason, we proposed to determine the optimum time interval for practicing regular verifications according to criterion:

$$\frac{d}{dt}(\mathrm{H(t)}) = 0. \quad (8)$$

It results:

$$\frac{\lambda_F(\lambda_W+\lambda)}{\lambda_W+\lambda_F} - \frac{\lambda_W(\lambda_F-\lambda)}{\lambda_W+\lambda_F} e^{-(\lambda_W+\lambda_F)} = 0$$

or

$$\frac{\lambda_W(\lambda_F-\lambda)}{\lambda_F(\lambda_W+\lambda)} = e^{(\lambda_W+\lambda_F)\,\mathrm{t}}. \quad (9)$$

Therefore,

$$t_0 = \frac{1}{\lambda_W+\lambda_F} + \ln\frac{\lambda_W(\lambda_F-\lambda)}{\lambda_F(\lambda_W+\lambda)}. \quad (10)$$

If we exclusively refer to the faulty states caused by use ($\lambda = 0$), the previous expression becomes:

$$t_0 = \frac{1}{\lambda_W+\lambda_F}\ln 1 = 0. \quad (11)$$

Therefore a null time interval which means adopting a continuous monitoring regime of the equipment concerned.

Depending on the pertinent technical and economical motivations, the decision factor imposes the practicing of a quasi-continuous preventive verification regime of certain modules that are part of the technical equipment concerned.

Boston-Edison Company, the author of the RBM maintenance concept, recommends:

- The judiciously grounded approach of the two types of preventive and corrective works or the mixed procedure;
- The correct management of stocks of sub-assemblies, spare parts, materials, supplemented by a preferential selection of suppliers of such products;
- Optimizing the use of human potential;
- Introducing diagnosis to recognize the technical state and the operating time evolution of the (monitoring) equipment.

5. CONCLUSION

The models presented in this paper aimed to highlight the major role of preventive maintenance in maintaining/improving the operational capacity of technical equipment.

The problem of setting the optimal time interval between two consecutive preventive actions constituted the objective of these three methods, obviously depending on the criteria considered:

- Maximizing the sum of operating probabilities;
- Costs of preventive/corrective maintenance;
- The number of interruptions caused by the renewals of the technical equipment state concerned.

Also, the paper aimed to highlight the major role of preventive maintenance in achieving a high level performance function [8] of the technical equipment, functionality intended to meet the requirements imposed by the deciding factor.

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