MODELS REGARDING THE PREVENTIVE MAINTENANCE FREQUENCY BY ENERGY INSTALLATIONS

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Abstract In the paper are presented two models: the first one refers on the optimal frequency determination, regarding the preventive maintenance to minimize the time due to the failures of preventive and corrective maintenance, as the second model follows the stabilization of the periodical maintenance frequency required to realize a majored level of availability of the technical analyzed equipment. Both models have R ∊ [0.80; 0/95] domain of reliability.

Key words: preventive maintenance, corrective maintenance, frequency of periodical maintenance

1. PRELIMINARIES

In the first part, let to be the total time of unavailability for a technical system given as a variable of: [1÷7]

$$T^{ind} = \begin{pmatrix} T_P^{ind} & T_C^{ind} \\ p_F & p_D \end{pmatrix} \qquad (1)$$

where

T_P^{ind} - is the time necessary to preventive maintenance;

T_C^{ind} - time of unavailability of the equipment;

p_F, p_D – operation / failure states probability;

From the above, results the average time $E(T^{ind})$ of the system unavailability for a period of T; for example, one year is equivalent to estimated annual operating time:

$$E(T^{ind}) = T_P^{ind} \cdot p_F + T_C^{ind} \cdot p_D \qquad (2)$$

where

$$T_P^{ind} = \theta_f \cdot p_F \qquad (3)$$

$$T_C^{ind} = (T - \theta_f) \cdot p_D \qquad (4)$$

where

θ - average time of a preventive maintenance – h / testing;

f – testing frequency in period of T – testing / year;

T – annual time interval of reference.

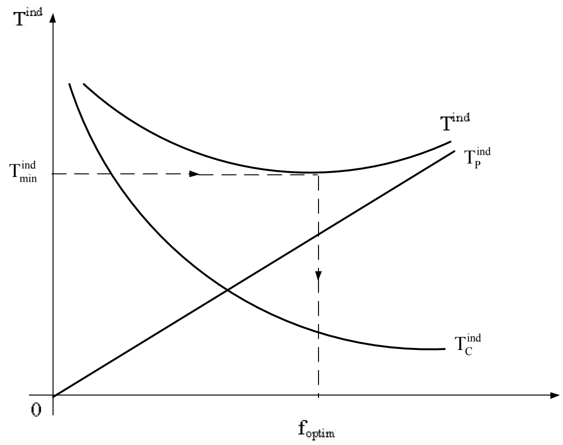

Fig. 1 – The time unavailability dependence on frequency

The expression of average time – mathematical hope – of the time of unavailability in T period is:

$$E(T^{ind}) = \theta_f \cdot p_f + (T - \theta_f) \cdot p_D \qquad (5)$$

or

$$E(T^{ind}) = \theta_f \cdot (p_f - p_D) + T \cdot p_D \qquad (6)$$

This will be deducing the condition of optimum:

$$\frac{d}{df}\left(E\left(T^{ind}\right)\right) = 0 \Rightarrow f_{optimal} \qquad (7)$$

$$\frac{d}{df}\left(E\left(T^{ind}\right)\right) = \theta(p_F - p_D) + \theta_f\left(\frac{dp_F}{d_f} - \frac{dp_D}{d_f}\right) + T\frac{dp_D}{d_f} = 0 \qquad (8)$$

Considering the rate of failure depending on the frequency of preventive maintenance:

$$\lambda* = \lambda e^{-mf} \qquad (9)$$

where

λ* - rate of failure in function with the frequency of testing;

λ - rate of failure of constant equipment;

m – constant of regression (9), experimented.

The expressions of probabilities are:

$$p_F = \frac{\mu}{\lambda e^{-mf} + \mu}; \quad p_D = \frac{\lambda e^{-mf}}{\lambda e^{-mf} + \mu} \tag{10}$$

Solving the relation, results the optimal frequency level f_o.

$$f_o = \frac{1}{m} \ln \frac{m \cdot \lambda (T - 2\theta \cdot f_o)}{\theta \cdot \mu} \tag{11}$$

But

$$2\theta f_o \langle\langle T \tag{12}$$

Deducing:

$$f_o \cong \frac{1}{m} \ln \frac{m\lambda T}{\theta\mu} \tag{13}$$

The values obtained from experiments of m factor take parts of interval:

$$m \in [0{,}4 \div 0{,}8] \tag{14}$$

Relating to duration of θ of preventive maintenance this may be explained by factor of manager, such as:

- $\theta = (2 \div 8)$ hours for preventive maintenance;
- $\theta > 8$ hours in case of corrective – preventive maintenance.

The efficiency of preventive maintenance at equipment becomes concluding if during its operation this has certain remediable level of wear.

In this case, the optimal maintenance strategy is the following:

- The installation is verified in concordance with the required preventive maintenance corresponding to optimal testing frequency;
- If it is justified, it will be executed some works.

Such strategy of maintenance is named as ERP – Eventual Replacement Policy - . The using this optimal model is recommended by "less reliable" installations, as example for range of reliability: R(s) ∈ [0.8; 0.94], to which correspond the percentage increasing - table 1 in descending sense -, for improved reliable level, as example R(s) = 0.98.

Table 1 - Percentage increasing

R(s)	% ΔR(s)
0.80	22.5
0.82	19.5
0.84	16.6
0.86	13.9
0.88	11.4
0.90	8.9
0.92	6.5
0.94	4.3

In the paper it was considered the mean time to repair (MTR), respectively μ, of constant values.

Let to be A(s), A*(s) the initial availabilities/ improving of technical system. The increasingly availability is obtained by decreasing of λ parameter while the testing frequency increases.

Obviously,

$$A^*(s) \rangle A(s) \tag{15}$$

Therefore

$$\frac{A^*(s)}{A(s)} = \alpha \rangle 1 \tag{16}$$

where

$$\alpha = 1 + \frac{\%\Delta A(s)}{100} \tag{17}$$

%ΔA(s) – percentage increases of availability imposed by factor of manager

In function with λ, μ, α and m will be obtained the expression of f frequency:

$$\frac{\dfrac{\mu}{\lambda e^{-mf} + \mu}}{\dfrac{\mu}{\lambda + \mu}} = \alpha$$

Results

$$f = \frac{1}{m} \ln \frac{\alpha\lambda}{\lambda - (\alpha - 1)\mu} \tag{18}$$

Using this frequency of preventive maintenance as consequence has the improving of system availability with percentage value of % ΔA(s).

According to the above mentioned interval, m is chosen randomly.

A condition of compatibility of relation (18) is:

$$\frac{\alpha\lambda}{\lambda - (\alpha - 1)\mu} \rangle 1 \tag{19}$$

Results the inequality:

$$(\alpha - 1)(\lambda + \mu) \rangle 0 \tag{20}$$

2. CASE STUDY

It is considered the energy equipment, for example a fan of burned gases with the following reliability parameters: mean time between failures, MTBF = 2500 hours, as the mean time to repair, MTR = 300 hours, both deduced statistically.

The preventive maintenance operation has approximately an average duration of θ = 5 hours, as the annual average operating time is T = 7000 hours / year.

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It is required:

a. the frequency of optimal testing;
b. minimal time of unavailability;
c. preventive maintenance frequency when the availability increasing is 8%.

Solution

a. The optimal frequency of preventive maintenance is deduced from relation (16):

- according to the interval of (14) it is chosen factor m;
- $MTBF^{-1}$ and MTR^{-1} are converted in parameters of λ, μ.

It is proposed: m = 0.65;

Results: $\lambda = \frac{1}{2500} \Rightarrow \lambda = 0.0004\,h^{-1}$,

$$\mu = \frac{1}{300} \Rightarrow \mu = 0.0033\,h^{-1}$$

From relation (13) is deduced the optimal frequency of testing.

f_o = 7 preventive maintenances, and one time interval between two consecutive testing T_o = 1000 hours, the time of operation is T = 7000 hours / year.

b. According to (2) it will be obtained:

$$T_p^{ind} = \theta \cdot f_o \cdot \frac{\mu}{\lambda^* + \mu}$$

$$T_C^{ind} = (T - \theta f_o)\frac{\lambda^*}{\lambda^* + \mu}$$

where

$$\lambda^* = \lambda e^{-m \cdot fo}$$

Results:

$$\lambda^* = \lambda e^{-0.65 \cdot 7}$$

$$\lambda^* = 0.0004 \cdot e^{-4.55} \Rightarrow \lambda^* = 0.000004226$$

$$T_P^{ind} = 5 \cdot 7 \cdot \frac{0.0033}{0.0004 \cdot e^{-4.55} + 0.0033}$$

$$\Rightarrow T_p^{ind} \cong 34.9\ h/year$$

$$T_C^{ind} = (7000 - 30) \cdot \frac{0.000004226}{0.0004 \cdot e^{-3.9} + 0.0033}$$

$$\Rightarrow T_C^{ind} \cong 8.9\ h/year$$

$$E\left(T_{min}^{ind}\right) \cong 44\ hours/year$$

If the preventive maintenance wouldn't be undertaken the time of unavailability, this would be defined only by corrective maintenance:

$$E\left(T^{ind}\right) = T_C^{ind},$$

$$T_C^{ind} = T \cdot \frac{\lambda}{\lambda + \mu}$$

$$T_C^{ind} = 7000 \cdot \frac{0.0004}{0.0004 + 0.0033} \Rightarrow$$

$$E\left(T^{ind}\right) = T_C^{ind} \Rightarrow E\left(T^{ind}\right) \cong 758\ hours/year$$

c. The frequency of preventive maintenance in this case is in concordance with relation (18):

$$f = \frac{1}{0.65} \ln \frac{1.08 \cdot 0.0004}{0.0004 - (1.08 - 1) \cdot 0.0033}$$

$\Rightarrow f \cong 2$ preventive maintenances / year, as the availability becomes $A^* \cong 0.9623$

3. CONCLUSIONS

The frequency of preventive maintenance determination follows the total time reducing of out of order, first due to prophylactic testing, on the other hand by preventive corrective maintenance testing, in concordance to ERP – Replacement Eventual Policy.

The second presented model may be used to calculate the testing frequency when, it is imposed the improving of an equipment availability with some percentage quantum.

The model offers conclusive solutions for installations with a reliability level of $R \in [0.8; 0.94]$.

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