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ANALITIČKI POSTUPAK ODREĐIVANJA MOMENATA I INTERVALA VREMENA IZMEĐU PREVENTIVNIH PREGLEDA STROJEVA

ANALYTICAL PROCEDURE FOR DETERMINING MOMENTS AND TIME INTERVALS BETWEEN PREVENTIVE CHECKS OF DEVICES

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Stručni članak

Sažetak: *U članku je prikazan jedan analitički postupak određivanja momenata, odnosno intervala vremena između mjerenja vitalnih karakteristika uređaja u cilju utvrđivanja momenta nastupanja kvara, tako da maksimalna relativna greška, učinjena pri tom, bude konstantna pri bilo kojem mjerenju. Ovaj postupak odnosi se na slučaj kada se mjerenja na uređaju ne obavljaju kontinuirano, već se vrše povremeno.*

Ključne riječi: *održavanje, kvar, preventivni pregled*

Professional paper

Abstract: *This paper presents an analytical procedure for determining moments, i.e. time intervals between measuring vital characteristics of devices for the purpose of determining the moment at which a malfunction occurred, so that the maximum relative error remains constant during every measurement. This procedure is related to situations when measurements are not carried out continually, but occasionally.*

Keywords: *maintenance, malfunction, preventive check*

1. INTRODUCTION

Preventive checks are planned and prepared in advance, but according to prescribed technology for their completion. They are carried out for the purpose of timely detection of temporal malfunctions. In technical systems they are in practice mostly carried out on the basis of a defined work period or according to a defined date.

Upon the completion of a preventive check data are obtained, which are significant for carrying out timely maintenance activities. According to previous experiences [2], preventive checks result in up to 50 % less malfunctions in technical systems.

During every preventive check the question arises on when it is to be carried out and how to determine the moment of carrying it out. These are relevant questions from the aspect of assuring that the check is carried out before a malfunction occurs.

In practice this is usually defined on the basis of prior experience in maintaining similar systems, but frequently it is determined randomly [1, 2].

In recent years several procedures for determining periodicity of such checks have been developed. This paper describes an analytical procedure for determining the moment, i.e. time interval between preventive checks (measuring vital parameters of a technical system) for the purpose of determining the moment at which a malfunction occurred, so that the maximum relative error remains constant during every measurement. This procedure is related to situations when measurements are not carried out continually, but occasionally.

2. DEFINING THE MOMENT AND TIME INTERVAL BETWEEN PREVENTIVE CHECKS

The method involves defining the moment and time interval between preventive checks for the purpose of determining the moment at which a malfunction occurred, so that the maximum relative error remains constant during every check. Periodicity is defined against the most critical assembly or unit, with no significant error.

A malfunction of a critical unit assumes an event that occurs when any element leaves predefined domains of operating characteristics (Fig. 1).

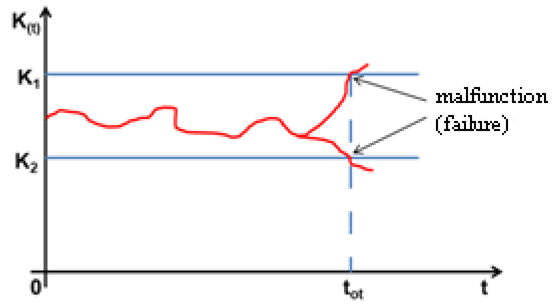

Figure 1. Key assembly characteristic leaving the specified limits

Indications in Fig. 1 refer to:
t – operating time of the system,
t_{ot} – the moment of malfunction occurrence,
K – vital characteristic of the most critical unit, as time-of-use function,
K_1 and K_2 – minimum and maximum tolerance value respectively.

Fig. 1 shows that it is necessary to constantly measure the vital characteristic of the most critical unit of the system in order for the moment at which the malfunction occurs to be determined as precisely as possible. However, in practice this is done very rarely. It is much more common that the critical unit is controlled from time to time, during which it is determined whether a malfunction exists in the critical unit.

In this case the actual moment at which the malfunction occurred is transformed into the moment of carrying out a preventive check. It is self-evident that such procedure of determining the moment of carrying out a preventive check involves an error of a greater or a lesser extent, as the malfunction in the critical unit may have occurred directly after the check, but also much earlier, i.e. right after the last check.

The essence of the method involves temporal scheduling of these checks in the way that the maximum relative error of determining the precise moment at which the malfunction occurred remains constant during every check.

Let's assume that a malfunction in the critical unit was detected during the i^th^ preventive check (Fig. 2). It means that it will be declared that the critical unit had failed at the moment t_i. However, the moment t_{ot} when the malfunction had actually occurred lies somewhere between t_{i-1} and t_i.

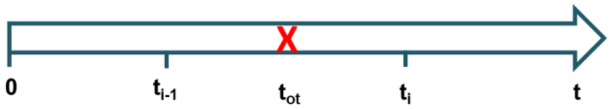

Figure 2. Determining a malfunction during the i^{th} preventive check

Therefore, the absolute error made thereat amounts to:

$$\Delta t_{ot} = t_i - t_{ot} \tag{1}$$

The maximum absolute error is:

$$\Delta t_{ot,max} = t_i - t_{i-1} = \Delta t_i \tag{2}$$

The maximum relative error may be expressed as:

$$\varepsilon = \frac{t_i - t_{i-1}}{t_i} \tag{3}$$

If values of the maximum relative error are adopted, based on the previous expression the following relation between t_i and t_{i-1} may be made:

$$t_i = \frac{1}{1-\varepsilon} \cdot t_{i-1} \tag{4}$$

Mathematical induction leads to the following expression:

$$t_i = \left(\frac{1}{1-\varepsilon}\right)^i \cdot t_o \tag{5}$$

In order to determine t_0 for t_i, time of the first preventive check t_i is to be adopted:

$$t_i = \varepsilon \cdot m_o \tag{6}$$

whereat:
m_o – assumed mean time until malfunction

Based on the expression (5) we obtain:

$$t_o = \varepsilon \cdot (1-\varepsilon) \cdot m_o \tag{7}$$

By replacing t_o from (7) into (5), we obtain:

$$t_i = \frac{\varepsilon}{(1-\varepsilon)^{i-1}} \cdot m_o \tag{8}$$

If in (8) the expression next to m_o is replaced by the coefficient:

$$K_\varepsilon(i) = \frac{\varepsilon}{(1-\varepsilon)^{i-1}} \tag{9}$$

we obtain:

$$t_i = K_\varepsilon(i) \cdot m_o \tag{10}$$

The width of the time interval between subsequent preventive checks is represented by the following expression:

$$\Delta t_i = t_i - t_{i-1} \tag{11}$$

Based on expressions (3) and (11), we obtain:

$$\Delta t_i = \varepsilon \cdot t_i \tag{12}$$

By replacing t_i from (10) into (12), we obtain:

$$\Delta t_i = \varepsilon \cdot K_\varepsilon(i) \cdot m_o \tag{13}$$

i.e.:

$$\Delta t_i = K_\varepsilon^*(i) \cdot m_o \tag{14}$$

whereat:

$$K_\varepsilon^*(i) = \frac{\varepsilon^2}{(1-\varepsilon)^{i-1}} \tag{15}$$

Mathematical calculations result in a formula for the time of carrying out the first preventive check (10), i.e. for the expression for calculating preventive checks that are to follow (14).

For determining the moment t_i, when the first preventive check is to be carried out and in which time periods Δt_i, it is necessary to adopt the value of the maximum relative error and mean time until malfunction m_o.

Tables 1, 2 and 3 and Fig. 3 present numerical values of coefficients K_ε and K_ε^* for some values of the ordinal number of the preventive check (i) for three values of the maximum relative error.

Table 1. Numerical values for coefficients $K_\varepsilon(i)$ and $K_\varepsilon^*(i)$ for the value of the maximum relative error ε = 0.10

i	$K_\varepsilon(i)$	$K_\varepsilon^*(i)$	i	$K_\varepsilon(i)$	$K_\varepsilon^*(i)$
1	0.1000		9	0.2323	0.0232
2	0.1111	0.0111	10	0.2581	0.0258
3	0.1235	0.0123	11	0.2868	0.0287
4	0.1372	0.0137	12	0.3187	0.0319
5	0.1524	0.0152	13	0.3541	0.0354
6	0.1694	0.0169	14	0.3934	0.0393
7	0.1882	0.0188	15	0.4371	0.0437
8	0.2091	0.0209			

Table 2. Numerical values for coefficients $K_\varepsilon(i)$ and $K_\varepsilon^*(i)$ for the value of the maximum relative error ε = 0.20

i	$K_\varepsilon(i)$	$K_\varepsilon^*(i)$	i	$K_\varepsilon(i)$	$K_\varepsilon^*(i)$
1	0.2000		9	1.1921	0.2384
2	0.2500	0.0500	10	1.490l	0.2980
3	0.3125	0.0625	11	1.8626	0.3725
4	0.3906	0.0781	12	2.3283	0.4657
5	0.4883	0.0977	13	2.9104	0.5821
6	0.6104	0.1221	14	3.6380	0.7276
7	0.7629	0.1526	15	4.5475	0.9095
8	0.9537	0.1907			

Table 3. Numerical values for coefficients $K_\varepsilon(i)$ and $K_\varepsilon^*(i)$ for the value of the maximum relative error ε = 0.30

i	$K_\varepsilon(i)$	$K_\varepsilon^*(i)$	i	$K_\varepsilon(i)$	$K_\varepsilon^*(i)$
1	0.3000	0.1286	9	5.2040	1.5612
2	0.4286	0.1837	10	7.4343	2.2303
3	0.6122	0.2624	11	10.6204	3.1861
4	0.8746	0.3748	12	15.1720	4.5516
5	1.2495	0.5355	13	21.6743	6.5023
6	1.7850	0.7650	14	30.9633	9.2890
7	2.5500	l.0928	15	44.2332	13.2700
8	3.6428				

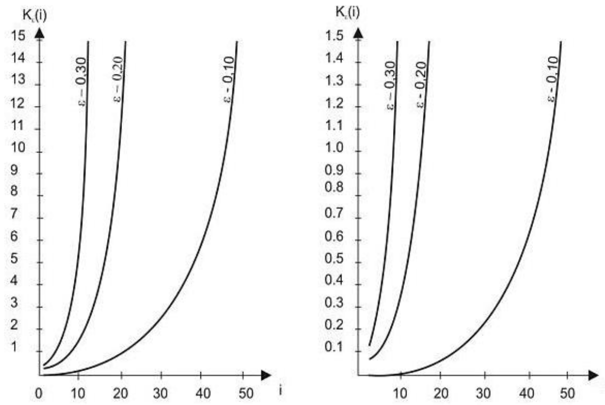

Figure 3. Graphical representation of coefficients K_ε and K_ε^* for some values of the ordinal number of the preventive check (i), whereat ε= 0.10, ε= 0.20 and 0.30.

3. APPLICATION OF THE DESCRIBED PROCEDURE IN A REAL TECHNICAL SYSTEM

In a concrete case for one mechatronic system the anticipated mean time until malfunction is three years (based on data from exploitation and maintenance interventions). Time t_i is defined when measurement of the most vital characteristics is to be carried out for the purpose of defining the moment at which the malfunction occurs, so that the maximum relative error remains constant during any measuring process and ε = 0.30. Thereafter time intervals Δt_i are defined between measurements with the same maximum relative error.

Numerical values for t_i and Δt_i are calculated based on expressions (10) and (14), by replacing in these expressions coefficients $K_\varepsilon(i)$ and $K_\varepsilon^*(i)$ with their numerical values from Table 3. The results are shown in Table 4.

Table 4. Values for t_i and Δt_i (ε = 0.30) in a concrete case

i	t_i		Δt_i	
	hours	days	hours	days
1	7884	328.50	2365	98.55
2	11263	469.29	3379	140.79
3	16090	670.41	4827	201.12
4	22985	957.73	6896	287.32
5	32836	1368.18	9851	410.45
6	46909	1954.54	14073	586.36
7	67013	2792.20	20104	837.66
8	95733	3988.86	28720	1196.66
9	136761	5698.38	41028	1709.51
10	195373	8140.54	58612	2442.16

Based on the data from the table it may be concluded that the first preventive check on the critical unit, i.e. mechatronic system upon being commissioned, should be carried out after 328 days of usage, the second one after 141 days, the thirds after 201 days etc. Due to simplicity in planning preventive checks, and based on the maximally adopted value m_o, moments of preventive checks may be adopted, as shown in Table 5.

Table 5. Moments of carrying out preventive checks

THE MOMENT OF CARRYING OUT THE CHECK				
t_0	t_1	t_2	t_3	t_4
m o n t h s				
0	12	6	6	12

4. CONCLUSION

The presented methodology of determining the periods of preventive checks for technical devices refers to the case when tests and checks are performed after the first malfunction. However, the procedure may also be applied in cases when the device is repaired after the malfunction and tested and checked again until the next malfunction. In this case time schedule of testing and t_i from the moment of repeated commissioning of the device until the second malfunction is the same as the schedule from the moment of the beginning of testing until the first malfunction. The same applies to testing from the second until the third malfunction etc.

5. LITERATURE

[1] Wireman, T.: Developing performance indicators for managing maintenance, Industrial Press, New York, 1998

[2] Kondić, Ž.; Čikić, A.: Održavanje mehatroničkih sustava, VTŠBJ, Bjelovar, 2014

[3] Womack, J. P.; Jones, D. T.; Roos D.: The Machine that changed the World (How Japan's secret weapon in the global auto wars will revolutionize western industry), Harper Perennial, New York, 1991

[4] Kondić, Ž.: Prilog usavršavanju organizacije održavanja za opremu izvan eksploatacije, magistarski rad, FSB, Sveučilište u Zagrebu, 1991

[5] Rejec, E.: Terotehnologija - Suvremena organizacija održavanja sredstava, Informator, Zagreb, 1974

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