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THE ASSESSMENT OF OBJECT USABILITY ON THE BASIS OF INSTANTANEOUS VALUES OF TECHNICAL CONDITION AND REGULATION STATE PARAMETERS

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Abstract

In the process of using a complex technical object, it is deregulated, worn and its reliability is decreased. Therefore, it is required that its status, technical state and reliability should be observed during its normal use and handling. The results of such observations allow a synthetic (complex) assessment of suitability of the object, determining its ability to properly carry out its tasks in accordance with its intended purpose. A continuous observation of changes of technical condition on the basis of relationship between the diagnostic signals (output) and the input signals (environment) allow evaluation of the regulation state of the object [4, 5].

An innovative method of assessment of the operated system usability presented in the article concerns an adequate analysis of the changes to a_{Rb} *technical condition and* $a_{Rc,}$ *regulation state current parameters formed from coupled equations of state (1 and 2) [1, 2, 3, 7]. While analysing the waveforms of instantaneous values of* a_{Rb} *technical condition and* a_{Rc} *regulation state parameters, it has been observed that parameter and instantaneous damage can be identified on the basis of quantitative relationships between the instantaneous threshold value of* d_{pr} *and the corresponding instantaneous value of* $d_{pr\,dop}$*, which are calculated from the following formulas (7, 8, 9). It is assumed that damage exists if for the instant* θ_i*:* $d_{pr_i} > d_{prdop_i}$*. Having the quantity of damage, reliability characteristics can be determined for every time of technical object exploitation (prior to the occurrence of catastrophic damage) [6].*

Keywords*: parametric damage, instant damage, technical condition parameter, state regulation parameter, reliability characteristics*

1. Introduction

In the process of using a complex technical object, it is deregulated, worn and its reliability is decreased. Therefore, it is required that its status, technical state and reliability should be observed during its normal use and handling. The results of such observations allow a synthetic (complex) assessment of suitability of the object, determining its ability to properly carry out its tasks in accordance with its intended purpose.

A continuous observation of changes of technical condition on the basis of relationship between the diagnostic signals (output) and the input signals (environment) allow evaluation of the regulation state of the object [4, 5].

A continuous observation of changes of technical condition parameters on the basis of relationship between the diagnostic signals associated with the wear of components and accompanying ambient signals is possible due to diagnostics of the object [4].

A continuous accumulation of knowledge about the damage to the object that represents level limits of deregulation and wear of the object, and then (according to PN-77/N-04005) conversion of such identified number of defects into reliability characteristics, allow to test the reliability of the object.

The assessments of regulatory, diagnostics and reliability states are basic, closely related elements, which, in the cybernetic system of operation, constitute the basis for a comprehensive assessment of the suitability of the object [1, 6, 7].

The method described in the article concerning the evaluation of the object usability is based on an adequate analysis of changes of current values of aRb technical condition and aRc state regulation parameters set from interactive, coupled equations of state [5, 7].

It was discovered that the analysis of the value of aRb technical condition and aRc state regulation parameters could identify the defects (parametric and temporary respectively) on the basis of quantitative relationship between the instantaneous d_{pr} threshold values ($a_{Rb,}a_{Rc}$ parameter) and corresponding instantaneous d_{prdop} permissible values.

2. Theoretical basis of the assessment of technical object suitability

The assessment of the usability of the object is based on the assumption that each technical object in the environment is described by two correlated equations of state [5, 7]:

$$\frac{\Delta D_K}{\Delta\Theta} = a_{R_b} D_K + b_{R_b} U \,, \tag{1}$$

$$\frac{\Delta Y}{\Delta\Theta} = a_{R_c} U + b_{R_c} D_K \,, \tag{2}$$

where:

D_K – comprehensive diagnostic signal,

U – comprehensive utility signal (operation),

a_{Rb} – technical condition parameter,

a_{Rc} – the parameter of the state of regulation (use),

b_{Rb} – the parameter of quality of use impact on technical condition,

b_{Rc} – the parameter of quality of technical condition impact on the state of operation,

$\Delta\Theta$ – increase in operation life.

These equations are based on the obvious observation that the value of use (operation) of an object depends on technical condition (physical wear and tear), and technical condition depends on the intensity of use and regulation quality, i.e. DK technical condition is an environment for the U state of usability and vice versa.

aRb technical condition and aRc state regulation parameters are calculated from the equations of state (1 and 2):

$$a_{R_b} = \frac{\Delta D_K}{\Delta\Theta\left(D_K + \hat{a}_{R_b} U\right)} \,, \tag{3}$$

$$a_{Rc} = \frac{\Delta U}{\Delta\Theta\left(U + \hat{a}_{R_c} D_K\right)} \,, \tag{4}$$

where:

$$\hat{a}_{R_b} = -\frac{\sum_{i=1}^{n} \Delta D_{K_i} \Delta U_i}{\sum_{i=1}^{n} \Delta U_i^2} \,, \tag{5}$$

$$\hat{a}_{R_c} = -\frac{\sum_{i=1}^{n} \Delta D_{K_i} \Delta U_i}{\sum_{i=1}^{n} \Delta D_{K_i}{}^2} \,, \tag{6}$$

From the correlations of (3 and 4), it can be inferred that at any time $\Theta_i + \Delta\Theta$ ($\Delta\Theta$ – sufficiently large) can be calculated from the instantaneous values of a_{Rb} and a_{Rc}, which constitute the basis for quantitative evaluation of technical condition and regulation state. In addition, the strings of, $a_{Rb}(\theta)$ and $a_{Rb}(\theta)$ values can constitute the basis for the identification of parametric and instantaneous damage, and, therefore, reliability characteristics (before the onset of catastrophic damage).

In order to accurately determine the technical parameters, the threshold characteristics of a diagnostic signal from correlation (7), the limit value of a summary diagnostic signal (8) and the limit value of a_{Rb}, and a_{Rc} parameters (9) should be determined.

$$d_{pr}(\Theta) = i \cdot \mu + a \cdot \sigma \cdot \sqrt{i}\,, \tag{7}$$

$$d_{pr}(\Theta) = i \cdot \mu + a \cdot \sigma \cdot \sqrt{i}\,, \tag{8}$$

$$d_{prdop} = \frac{\Theta_i}{\Theta_{\max}} d_{dop}\,, \tag{9}$$

where:

$d_{pr}(\theta)$ – the threshold of a_{Rb} and a_{Rc} parameters,
d_{dop} – limit values of a_{Rb} and a_{Rc} parameters,
d_{prdop} – limit values of a_{Rb} and a_{Rc} parameters for θ_i instantaneous value,
μ – mean value,
σ – standard deviation,
i – number of the next measurement, $a<3$, $m = \frac{\Theta_{\max}}{\Delta\Theta_{sr}}$,
θ_{max} – service life.

The basis of formulas (7) and (8) constitutes Linderberg - Levy statement concerning the limit of a summary diagnostic signal [4].

3. Threshold characteristic of diagnostic signal, the limit value of a summary diagnostic signal

For each operating time of Θ technical object $d_{pr}(\Theta)$, threshold diagnostic signal is established. Its course within Θ time function is called a threshold characteristic (7). A threshold characteristic is used for representing the maximum value of summary diagnostic signal in the function of duration of Θ technical object operation.

d_{dop} (8) limit value is the largest value that the signal can achieve after a Θ_{max} time, corresponding to service life.

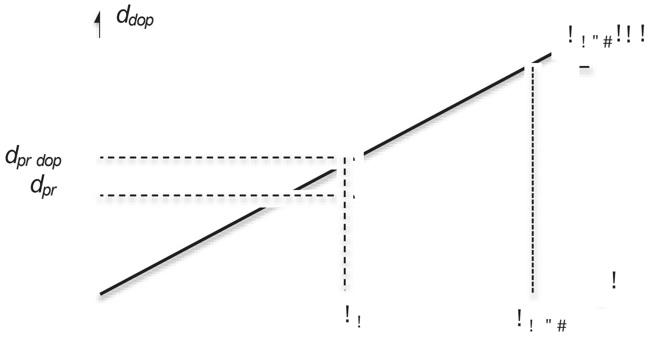

Fig. 1. Determination of the value of d_{dop} on the basis of d_{dop} threshold characteristics

4. Instantaneous threshold values of diagnostic signal, limit values and threshold limit values of diagnostic signals

Tables 1a, 1b and 2a, 2b show the instantaneous threshold values of diagnostic signals, limit values and diagnostic signal limit values. On their basis, the moments when parametric and temporary damage occurred were established. Parametric damage occurs when, for the course of a_{Rb} parameter *'i' at any time,* $d_{pr}(\theta) > d_{prdop.}$. Temporary damage occurs when, for the course of a_{Rc} parameter *'i' at any time,* $d_{pr}(\theta) > d_{prdop.}$. The number of m_b and m_c parameter and instantaneous damage constitutes the basis for establishing R_b^* and R_c^* estimates of reliability and $R(t) = R(R_b^*, R_c^*)$ reliability characteristics.

Tab. 1a. The parameter values of a_{Rb} technical condition and a_{Rc} state regulation for the No. 3 [7] team, the mean and standard deviation as well as threshold values and threshold limits (formulas 7, 8, 9), and also identified numbers of parametric and temporary damage

No.	θ	a_{Rb}	a_{Rc}	$\mu_{a_{Rb}}$	$\mu_{a_{Rc}}$	$\sigma_{a_{Rb}}$	$\sigma_{a_{Rc}}$
1	8329	9.68	-5.00				
2	8354	-497.72	3335.29				
3	8401	207.70	702.68	-93.44	1344.33	363.85	1760.16
4	8442	6062.20	-483.49	1445.47	887.37	3092.13	1703.14
5	8487	9347.85	-4411.58	3025.94	-172.42	4434.01	2791.29
6	8531	936.85	1000.00	2677.76	22.99	4056.57	2542.07
7	8578	1116.52	1296.45	2454.73	204.91	3749.85	2369.97
8	8602	1322.84	-1059.28	398.30	-116.03	3494.67	2239.23
9	8648	-498.19	2100.00	2000.86	275.01	3400.64	2203.58
10	8675	-7245.89	-5938.46	1076.19	-346.34	4339.32	2859.53
11	8699	-6380.60	2187.06	398.30	-116.03	4690.59	2818.28
12	8744	739.93	-503.03	426.77	-148.28	4473.39	2689.45
13	8769	1080.59	-909.55	477.06	-206.84	4286.78	2583.59
14	8819	1421.26	121.17	544.50	-183.41	4126.33	2483.78
15	8838	317.78	3739.36	529.39	78.11	3976.66	2598.92
16	8861	1724.83	-4025.47	604.10	-178.36	3853.42	2712.30
17	8909	-8079.52	-12150.30	93.30	-882.60	4284.44	3915.07
18	8937	-4214.94	1807.99	-146.05	-733.12	4278.76	3850.76
19	8982	-350.37	5986.19	-156.80	-379.47	4158.47	4047.32
20	9006	5891.05	11246.45	145.59	201.82	4267.50	4719.83
21	9029	8737.81	-3385.51	554.75	31.00	4562.51	4666.45
22	9079	5106.85	1862.98	761.66	114.27	4557.10	4570.70
23	9097	12365.21	-4594.70	1266.16	-90.47	5067.27	4572.29
24	9121	9059.11	9206.48	1590.87	296.91	5204.92	4857.81
25	9235	417.53	1927.12	1543.93	362.11	5100.73	4766.69
26	9256	5317.39	669.32	1689.07	373.93	5052.17	4670.77
27	9278	10217.25	-2086.11	2004.93	282.82	5218.85	4604.47
28	9322	-920.42	4610.51	1900.45	437.38	5151.05	4591.82
29	9333	3315.09	340.53	1949.23	434.04	5065.05	4509.11
30	15182	-4.50	-2.04	1884.11	419.50	4989.72	4431.40
31	15206	-21559.13	-12432.92	1127.87	4.91	6464.98	4930.65
32	15312	155.01	642.05	1097.47	24.82	6362.17	4851.78
33	15352	-2103.25	2357.73	1000.48	95.51	6286.72	4792.60
34	15388	1836.98	-83.44	1025.08	90.25	6192.39	4719.53
35	15407	-23705.14	1022.12	318.50	116.87	7395.38	4652.27

Tab. 1b. The parameter values of a_{Rb} *technical condition and* a_{Rc} *state regulation for the No. 3 [7] team, the mean and standard deviation as well as threshold values and threshold limits (formulas 7, 8, 9), and also identified numbers of parametric and temporary damage*

No.	$d_{pra_{R_b}}$	$d_{dopa_{R_b}}$	$d_{prdopa_{R_b}}$	$d_{pra_{R_c}}$	$d_{dopa_{R_c}}$	$d_{prdopa_{R_c}}$	$m_{a_{Rb}}$	$m_{a_{Rc}}$
1								
2								
3	1610	2253	316	13179	23792	3331	1	1
4	24335	4806543	676281	13768	2918813	410677	0	0
5	44874	9313915	1317453	17862	-43747	-6188	0	1
6	45876	8152134	1159098	18818	468258	66578	0	0
7	46947	7282200	1041112	20245	930147	132980	0	0
8	32840	1807075	259074	18072	15619	2239	0	1
9	48614	6475298	933306	22307	1173323	169115	0	0
10	51928	4145500	599370	23665	-615127	-88937	0	1
11	51052	2173069	315059	26765	98639	14301	0	1
12	51610	2151272	313512	26170	-21828	-3181	0	1
13	52570	2382777	348243	25257	-253912	-37109	0	1
14	53941	2457796	361255	25313	-168119	-24711	0	1
15	54145	2526026	372084	31368	727183	107114	0	0
16	55907	2869016	423706	29694	-153999	-22743	0	1
17	54582	1071481	159097	33423	-2334376	-346616	0	1
18	51831	248178	36966	35816	-1883627	-280566	1	1
19	51400	194813	29163	45716	-579473	-86747	1	1
20	60166	1267703	190282	67360	1544985	231902	0	0
21	74374	2829046	425724	64804	953920	143549	0	0
22	80881	3436695	520029	66829	1201207	181763	0	0
23	102027	5481215	831044	63703	497517	75432	0	0
24	114677	6824919	1037502	78521	1982326	301347	0	0
25	115109	5598055	861634	80553	1907035	293524	0	0
26	121199	6243075	963098	81171	1983954	306058	0	0
27	135487	7495583	1159067	79413	1723037	266439	0	0
28	134983	7042725	1094205	85139	2202768	342237	0	0
29	138356	7529928	1171280	85434	2268873	352923	0	0
30	138513	786940	199122	85400	343033	86799	0	0
31	142950	678027	171835	82510	258631	65546	0	1
32	143089	687276	175393	83132	266899	68113	0	1
33	141359	680173	174034	85746	295095	75505	0	1
34	143175	711781	182548	85627	298148	76465	0	1
35	142403	547957	140706	86660	313504	80502	1	1

Tab. 2a. The parameter values of a_{Rb} technical condition and a_{Rc} state regulation for the No. 4 [7] team, the mean and standard deviation as well as threshold values and threshold limits (formulas 7, 8, 9), and also identified numbers of parametric and temporary damage

No.	θ	a_{Rb}	a_{Rc}	$\mu_{a_{Rb}}$	$\mu_{a_{Rc}}$	$\sigma_{a_{Rb}}$	$\sigma_{a_{Rc}}$
1	8315	-0.25	7.23				
2	8340	3348.23	-24272.14				
3	8365	-610.19	1958.90	912.60	-7435.34	2131.26	14613.72
4	8437	730.49	-2584.31	867.07	-6222.58	1742.54	12176.08
5	8447	6115.71	5261.78	1916.80	-3925.71	2790.52	11729.06
6	8484	595.73	-1865333.27	1696.62	-314160.30	2553.52	759988.87
7	8509	817.05	2356.21	1570.97	-268943.66	2354.62	704010.69
8	8567	-1471.58	110.33	1022.97	4972.12	2430.91	658692.16
9	8591	-1191.02	1933662.85	926.02	5685.28	2408.51	949925.15
10	8615	2063.22	2643.62	1039.74	5381.12	2299.06	895598.53
11	8660	855.23	882.14	1022.97	4972.12	2181.79	849640.45
12	8699	3837.62	-3259.92	1257.52	4286.12	2233.31	810103.87
13	8735	2387.92	1066.48	1344.47	4038.45	2161.09	775615.92
14	8756	13020.62	0.00	2178.49	3749.99	3748.21	745188.45
15	8780	3127.65	0.00	2241.76	3499.99	3620.17	718082.21
16	8826	4156.69	-81.57	2361.45	3276.14	3530.03	693733.91
17	8850	31790.12	152.22	4092.54	3092.38	7913.67	671705.39
18	8900	1470.90	-75.05	3946.90	2916.42	7702.22	651650.38
19	8924	843.38	0.00	3783.55	2762.92	7519.00	633290.69
20	8949	1785.12	70713.50	3683.63	6160.45	7332.09	616587.13
21	8995	1293.94	1320.91	3569.84	5929.99	7165.43	600975.72
22	9017	-161058.82	-101107.81	-3913.28	1064.64	35788.75	586936.06
23	9067	15331.09	1231.52	-3076.57	1071.90	35195.41	573441.47
24	9091	3278.62	795.97	-2811.77	1060.40	34446.23	560836.83
25	9115	-1066.03	54562.62	-2741.94	3200.49	33722.77	549132.68
26	9243	0.00	0.00	-2636.48	3077.39	33045.81	538038.31
27	9256	-147124.16	4673.81	-7987.88	3136.52	42699.36	527590.06
28	9338	-3521.76	331.66	-7828.37	3036.34	41909.67	517727.97
29	9362	8083.25	-1955.42	-7279.70	2864.21	41260.41	508399.62
30	9386	401.57	1089.70	-7023.65	2805.06	40567.03	499557.31
31	15247	13.38	0.69	-6796.65	2714.60	39905.20	491161.05
32	15253	5199.87	161330.29	-6421.76	7671.34	39313.53	483987.07
33	15353	566090.28	-7558.62	10927.09	7209.83	106909.68	476372.13
34	15416	1498.93	1089.45	10649.79	7029.82	105289.80	469100.02
35	15427	146.29	-575.89	10349.69	6812.51	103745.05	462151.80

Tab. 2b. The parameter values of a_{Rb} technical condition and a_{Rc} state regulation for the No. 4 [7] team, the mean and standard deviation as well as threshold values and threshold limits (formulas 7, 8, 9), and also identified numbers of parametric and temporary damage

No.	$d_{pra_{Rb}}$	$d_{dopa_{Rb}}$	$d_{prdopa_{Rb}}$	$d_{pra_{Rc}}$	$d_{dopa_{Rc}}$	$d_{prdopa_{Rc}}$	$m_{a_{Rb}}$	$m_{a_{Rc}}$
1								
2								
3	13812	23715	3306	53629	64099	8937	1	1
4	13924	2405363	338234	48166	-13579108	-1909449	0	1
5	28303	7453180	1049283	59052	-12113524	-1705382	0	1
6	28944	6370896	900845	3699793	-961247643	-135920417	0	1
7	29686	6378720	904609	3705306	-887708352	-125891839	0	1
8	28811	3614599	516104	5628965	126215043	18021405	0	0
9	30011	3587295	513641	8600494	186032247	26636717	0	0
10	32208	4210267	604524	8550205	181927134	26121704	0	0
11	32961	3880990	560156	8508509	166059204	23967878	0	0
12	38299	4610157	668396	8470280	155208796	22502689	0	0
13	40854	4884331	711077	8442069	148292634	21588936	0	0
14	72572	8435348	1230998	8417220	146825833	21426783	0	0
15	75689	8968856	1312443	8395861	144112389	21088446	0	0
16	80144	8942514	1315444	8377225	135025153	19862200	0	0
17	167460	16362425	2413458	8361107	132986273	19615475	0	0
18	169077	14967935	2220244	8346651	124860357	18520953	0	0
19	170211	14835100	2206474	8333846	123286197	18336767	0	0
20	172043	14809437	2208828	8395593	134435191	20051009	0	0
21	173475	13856135	2077266	8386580	127924621	19178033	0	0
22	417500	-7770132	-1167721	8282345	110126945	16550244	1	0
23	435613	-4487481	-678133	8275040	105284369	15910223	1	0
24	438772	-3872829	-586798	8268034	104386541	15816301	1	0
25	437293	-3911536	-594227	8317002	111347098	16915480	1	0
26	436955	-2463143	-379447	8310416	97472781	15015682	1	0
27	449944	-17960124	-2770648	8309001	98682058	15223352	1	0
28	446101	-15991512	-2488812	8303694	92603886	14412251	1	0
29	455471	-15030959	-2345331	8296509	92053793	14363460	1	0
30	455875	-14864785	-2325348	8292716	91774167	14356539	1	0
31	455852	69515	17665	8288160	25853648	6569843	1	1
32	461676	90628	23039	8459016	27865696	7083924	1	1
33	2203042	9293133	2377958	8447573	28011903	7167779	0	1
34	2203912	9436835	2424637	8444913	28319623	7276255	0	1
35	2203531	9621183	2473767	8440819	28735330	7388332	0	1

On the basis of analysis presented in Tab. 1a, 1b and 2a, 2b it can be concluded that, during the study, m_{Rb} parametric and m_{Rc} instantaneous damage occurred.

5. Summary

The problem of determination of reliability for each individual object based on the number of parametric and instantaneous failures (before the onset of catastrophic damage) is still open. Its solution is largely dependent on the identification of the number of parametric and instantaneous damage, which is especially difficult when a relatively small number of measurements are available. The diagnostic threshold and the exceedance of diagnostic threshold (failure) are determined on the basis of statistical processing of obtained measurements. $\mu+\sigma$, $\mu+2\sigma$, $\mu+3\sigma$ thresholds (where μ - average value of measurements, σ - standard deviation) are imprecise, because they are solely based on statistics. Another threshold determined on the basis of Lidenberg - Levy statement (7 and 8) is more accurate, because it includes additional information such as: for the early operation of the object, the use amounts to zero and, for θ_{max} service life, the use defined by direct methods amounts to d_{dop}. The result of the new approach is that, for example, for $\theta = 8401$ hours, the adoption of $(\mu+\sigma)$ threshold does not show a parametric damage, whereas the acceptance of d_{prdop} threshold also indicates damage.

References

[1] Borowczyk, H., Lindstedt, P., Manerowski, J., *Permises for a practical computer – aided parametric method of evaluation of the technical object reliability*, Journal of KONES, Vol. 16, No. 2, Warsaw 2009.

[2] Cempel, C., *Teoria i inżynieria systemów*, ITE – PIB, Radom 2006.

[3] Lindstedt, P., *The method of complex worthiness assessment of an engineering object in the proces of its use and service*, Solid State Phenomena, Vol. 144, Trans Tech Publications, Switzerland 2009.

[4] Lindstedt, P., Borowczyk, H., Magier, J., *Badania możliwości kompleksowego diagnozowania układu łożyskowania na podstawie informacji uzyskanej z metod funkcjonalnej, tribologicznej, wibroakustycznej*, Projekt badawczy KBN Nr 5T12D01122, sprawozdanie ITWL Nr 1371/50, Wyd. ITWL, Warszawa 2003.

[5] Lindstedt, P., Sudakowski, T., *Method of prediction of reliability characteristics of a pumping station on the base of diagnostic information*, Journal of KONBiN 2(5)2008, ITWL, Warszawa 2008.

[6] Sotskow, B. S., *Niezawodność elementów i urządzeń automatyki*, WNT, Warszawa 1973.

[7] Sudakowski, T., *Permises of operational method of calculation of reliability of machines on the base of parametric and momentary symptoms of damage*, Acta Mechanica et Automatica, Vol. 3, No. 4, Bialystok 2009.