PREMISES OF OPERATIONAL METHOD OF CALCULATION OF RELIABILITY OF MACHINES ON THE BASE OF PARAMETRIC AND MOMENTARY SYMPTOMS OF DAMAGE

Tomasz SUDAKOWSKI*

*Department of Automation and Robotics, Faculty of Mechanical Engineering, Białystok Technical University, ul. Wiejska 45C, 15-351 Białystok

sudak@plusnet.pl

Abstract: In the article presented was the practical method of calculation of standard reliability characteristics of technical objects of unchanging and changeable structure during their work, based only on parametric and momentary symptoms of damage, the method of determination of symptoms of parametric damage on the base of diagnostic and momentary information and on the base of information about the state of adjustment of the object.

1. INTRODUCTION

In the process of use of an operational technical object arise randomly defects (catastrophic, parametric and momentary), which cause that the object changes its state from operational to inoperable.

Catastrophic defects are sudden and total defects. They cause immediate and total loss of object's ability to correct work. Among this kind of defects are: break, deformation, notch, burning or melting of individual elements.

Parametric defects lead to partial and removable damage of some elements. In the initial phase they cause increasing deterioration of quality of their functioning. These defects can have conventional character (e.g. exceeding of acceptable value of adjustment quality ratio).

Momentary defects are characterised by the fact that they can disappear automatically without interference of an operator after disappearing of cause, which generated them. The causes of this kind of damage are e.g. occasional variations of temperature, humidity, accelerations and vibrations.

These defects are the base for to calculation of reliability characteristics. The serious problem is the appearance of catastrophic damage. Therefore continuous efforts are aimed at development of new effective methods of calculation of reliability on the base of only relatively harmless parametric and momentary defects.

2. CENTRAL REMARKS CONCERNING METHODS OF CALCULATION OF RELIABILITY

During calculation of reliability of any complex object it is necessary to determine the probability of appearance of its damage. The calculation should consider three types of damage: catastrophic, parametric and momentary. Additionally, it is assumed usually that appearing defects are independent events, then (Lindstedt and Sudakowski, 2007b; Sotskow, 1973):

$$R(t)=R_a(t)R_b(t)R_c(t) \tag{1}$$

$R(t)$ – probability of correct operation in view to all appearing defects, $R_a(t)$ – probability of correct operation in view to catastrophic damage, $R_b(t)$ – probability of correct operation in view to parametric damage, $R_c(t)$ – probability of correct operation in view to momentary damage.

Probability of correct operation in view to momentary damage depends on a variety of factors, which are difficult to consider during calculation. Therefore the probability $R_c(t)$ is determined experimentally or assumed as equal to 1.

Parametric defects (R_b) are the defects, which do not stop operation of the object but its parameters are beyond admissible limits. These defects can be caused by excessively big dispersion of technical parameters of object elements (Lindstedt and Sudakowski, 2007b; Sotskow, 1973). May be designated the density function changes diagnostic parameter (Tomaszek et al., 2008)

However, we deal with catastrophic damage (R_a), when the object does not work at all, i.e. does not fulfil its function. This damage can be caused by defects of object structure (Lindstedt and Sudakowski, 2007b; Sotskow, 1973).

2.1. Reliability of objects of unchangeable structure in the process of operation

In the case of objects of unchangeable structure the probability of correct operation is defined with the formula:

$$R(t) = R_a(t)R_b(t) \tag{2}$$

where: $R_a(t)$ – probability of correct (failure-free) operation in view to total damage (catastrophic), causing total damage to the element, $R_b(t)$ – probability of correct (failure-free) operation in view to partial damage (parametic), changing the parameter of an element beyond admissible limits.

Probability of correct operation defined as the reliability characteristic of the object depends on probability of correct operation of elements, fulfilling basic functions in the course of operation of given object. Other elements fulfilling secondary role are so-called auxiliary elements, e.g. elements of control system, protective elements etc., which influence the reliability of the object to small extent only. Damage to auxiliary elements can cause certain insignificant changes of parameters and operational conditions of basic elements.

The course of method of determination of probability of correct operation of the object of unchangeable structure is as follows (Sotskow, 1973):

1. Determination of basic part of the object, which fulfils its preset functions.
2. Determination of technical parameters of basic elements of the object.
3. Determination of changes of parameters of entire object and its basic elements resulting from damage to auxiliary elements:
   a) in the case of total damage (catastrophic) e.g. short circuits or breaks;
   b) in the case of partial damage (parametric) consisting in change of parameters of auxiliary elements beyond admissible limits.
4. Definition of intervals of physical and physicochemical variations of external factors during operation:
   a) temperature;
   b) humidity;
   c) accelerations and impacts;
   d) vibrations;
   e) air pressure;
   f) composition and quantity of active additives in surrounding atmosphere;
   g) radioactive radiation.
5. Determination of value of reliability of each basic element in relation to total (catastrophic) damage.

$$R_a = e^{-(\lambda + \lambda' f)T} \tag{3}$$

The values of damage intensity λ and λ' should be selected with consideration of technical parameters and operational conditions of individual elements. For this purpose λ and λ' in normal conditions and at nominal technical parameters (values of current, voltage, power, frequency, phase) should be replaced with values corresponding to real technical parameters in real operational conditions.

The operational reliability of an element R_{ai} should consider the probability of damage of type break F_0 and of type short circuit F_z.

$$R_{ai} = 1 - F = 1 - \left(F_0 + F_z\right) \tag{4}$$

6. Determination of reliability of individual elements in relation to partial damage (parametric) F_{bi}, which can be caused by changes of:
   a) properties of an element itself;
   b) parameters of power supply of an element (voltage, current, power, frequency, phase);
   c) operational conditions of an element (temperature, humidity, vibrations, accelerations).
7. Calculation of reliability of operation for individual elements:

$$R_i = R_{ai} R_{bi} \tag{5}$$

8. Calculation of reliability of operation for the object:

$$R(t) = R_{\Sigma} = \prod_{i=1}^{n} R_i \tag{6}$$

where: **n** – number of Basic elements.

$$R(t) = R_{\Sigma} = \prod_{i=1}^{n} R_{ai} \prod_{i=1}^{n} R_{bi} = R_{a\Sigma} R_{b\Sigma} \tag{7}$$

In given case it is assumed that the probability of absence of momentary damage R_c=1.

2.2. Reliability of objects of changing structure in the process of operation

Calculation of reliability of objects of changing structure i.e. such objects, in which during their operation in various moments of time work various elements, has certain metodological curiosities:

a) the entire cycle of operation is divided into steps corresponding to individual operational states,
b) for each step of operation prepared is the scheme containing all elements working during given step,
c) determined are parameters of power supply for elements during individual steps of operation.

Next determined is the reliability of operation of the object $R_{\tau x}$ or intensity of damage $\lambda_{\tau x}$ corresponding to individual steps of operation.

In general case, where considered are total and partial damage, the reliabilities during individual steps of operation can be described with formulas:

$$R_{\tau 1} = R_{\tau b_1} e^{-\lambda_{\tau 1} t_{01}}, R_{\tau 2} = R_{\tau b_2} e^{-\lambda_{\tau 2} t_{02}}, \dots, R_{\tau k} = R_{\tau b_k} e^{-\lambda_{\tau k} t_{0k}} \tag{8}$$

where: R_{tb1}, R_{tb2},…, R_{tbk} – values of reliability in relation to partial damage corresponding to individual steps of operation.

Total reliability corresponding to one operational cycle is equal to:

$$R = R_{\tau b_1} R_{\tau b_2} \dots R_{\tau b_k} e^{-(\lambda_{\tau 1} t_{01} + \lambda_{\tau 2} t_{02} + \dots + \lambda_{\tau k} t_{0k})} = \prod_{x=1}^{k} R_{\tau b_x} e^{-\lambda_{\tau x} t_{0x}} \tag{9}$$

Reliability of operation during N occurring repeatedly cycles:

$$R_N = R_b^N R_a^N = \prod_{x=1}^{k} R_{tb_x}^N \left[e^{-\lambda_{tx} t_{0x}} \right]^N \tag{10}$$

It is necessary to consider that the intensity of damage λ is not a constant value, but has certain dispersion around average value λ, defined usually with normal or log-normal distribution. This dispersion for various elements can be characterised with variation coefficient, which in the case of normal distribution is equal to $\chi = \frac{\sigma_\lambda}{\lambda}$, and in the case of log-normal distribution amounts to $\chi_{\ln \lambda} = \frac{\sigma_{\ln \lambda}}{\ln \lambda}$.

3. CALCULATION OF RELIABILITY CHARACTERISTICS IN THE PROCESS OF OPERATION ON THE BASIS OF PARAMETRIC AND MOMENTARY DAMAGE

The basis for calculation of *R(t)* are three basic types of damage: catastrophic *(R_a)*, parametric *(R_b)* and momentary (R_c) (Bobrowski, 1985; Lindstedt, 2006; Lindstedt and Sudakowski, 2008; Sotskow, 1973; Tomaszek et al., 2008; Zamojski, 1981).

The fundamental task of maintenance is elimination of causes of catastrophic defects *(Ra(t)=1)*. Thus, the reliability characteristics can be determined only on the basis of parametric and momentary defects, which are hard to degfine:

$$R(t)= R_b(t)R_c(t) \tag{11}$$

It has been observed that the basic knowledge about parametric and momentary defects can be achieved through observation of changes of technical condition parameter „a_{Rb}“ and adjustment state parameter „a_{Rc}” determined during diagnostic and adjustment of the object (Lindstedt et al., 2003; Paton et al., 1989).

4. SYMPTOMS OF KNOWLEDGE ABORT PARAMETRIC AND MOMENTARY DEFECTS

Basic knowledge about parametric defects *(R_b)* can be achieved through observation of changes of technical condition parameter „a_{Rb}“ determined during diagnostic of the object. To calculate the parameter „a_{Rb}“ we use the equation of state:

$$\frac{dD_K}{d\Theta} = a_{R_b} D_K + b_{R_b} U \tag{12}$$

where: D_K – variable of technical condition, U – variable of adjustment state (utility signal), a_{Rc} – parameter of adjustment state, b_{Rb} – parameter of technical condition (influence of environment).

The equation of state connecting dynamics of given process $dD_K/d\Theta$ with his process D_K and its environment U is applied in automation, diagnostics and reliability depending on needs occurring in these autonomous subjects (Ashby, 1963; Girtler, 2003; Lindstedt and Sudakowski, 2007a).

According to principles of static and dynamic identification (Söderström i Stoica, 1997) from the equation (12) we obtain:

$$D_K = \left(-\frac{b_{R_b}}{a_{R_b}}\right) U = \hat{a}_{R_b} U \tag{13}$$

$$\hat{a}_{R_b} = \frac{\Sigma D_{Ki} U_i}{\Sigma U_i^2} \tag{14}$$

and

$$\frac{\Delta D_K}{\Delta\Theta} = a_{R_b} D_K + a_{R_b} \hat{a}_{R_b} U = a_{R_b}\left(D_K + \hat{a}_{R_b} U\right) \tag{15}$$

$$a_{R_b} = \frac{\Delta D_K}{\Delta\Theta\left(D_K + \hat{a}_{R_b} U\right)} \tag{16}$$

Determined parameters in turn negative $\hat{a}_{Rb}$ (static identification $\dot{D}_K = 0$), and then „a_{Rb}“ (dynamic identification) and „b_{Rb}“ allow assessment of technical condition of the object „a_{Rb}“ and its relationship with environment „b_{Rb}“. It has been observed that the parameter of change of technical condition can be connected with parametric damage, thus, it is the symptom of parametric defects.

To calculate the parameter of adjustment state „a_{Rc}“ we use the equation of state:

$$\frac{dU}{d\Theta} = a_{R_c} U + b_{R_c} D_K \tag{17}$$

where: U – variable of adjustment state (utility signal), D_K variable of technical condition, a_{Rc} – parameter of adjustment state, b_{Rb} – parameter of technical condition (influence of environment) (Ashby, 1963; Girtler, 2003; Lindstedt and Sudakowski, 2007a).

According to principles of static and dynamic identification from the equation (17) we obtain:

$$U = \left(-\frac{b_{R_c}}{a_{R_c}}\right) D_K = \hat{a}_{R_c} D_K \tag{18}$$

$$\hat{a}_{R_c} = \frac{\Sigma D_{Ki} U_i}{\Sigma D_{Ki}^2} \tag{19}$$

and

$$\frac{\Delta U}{\Delta\Theta} = a_{R_c} U + a_{R_c} \hat{a}_{R_c} D_K = a_{R_c}\left(U + \hat{a}_{R_c} D_K\right) \tag{20}$$

$$a_{R_c} = \frac{\Delta U}{\Delta\Theta\left(U + \hat{a}_{R_c} D_K\right)} \tag{21}$$

Determined parameters in turn negative $\hat{a}_{Rc}$, and then „a_{Rc}“ (dynamic identification) and „b_{Rc}“ allow assessment of adjustment state of the object „a_{Rc}“ and its relationship with environment „b_{Rc}“. It has been observed that the parameter of change of adjustment state can be connected with momentary damage, thus, it is the symptom of momentary defects.

5. ASSESSMENT OF RELIABILITY OF A PUMP UNIT ON THE BASIS OF DIAGNOSTIC AND ADJUSTMENT INFORMATION

5.1. Structure and operation of a pump unit

In the course of operation of the object realised are periodical examinations consisting in measurement of following values: *A* (vibration amplitude), *V* (vibration velocity), *f* (variation frequency), *I* (current), *p* (pressure). Results of examination are shown in Tab. 1.

Tab. 1 proves that measured values are of various physical nature.

It is hard to make use of these values in equations (12) and (17) (in equations used are two values, and in the table there are five measured values).

Hence appears the need of reduction of all signals to consistent form, e.g. number of exceedings of statistic thresholds for individual values (Fig. 2).

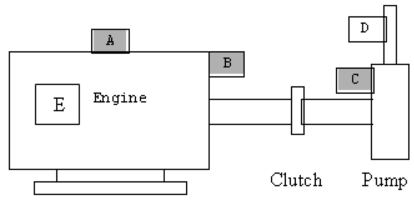

Fig. 1. Structure of a pump unit (A, B, C – points of installation of vibration accelerometers, D – manometer (pressure measurement), E – amperemeter (current measurement))

Tab. 1. Results of measurements characterising the state of pump unit

Working time	*A*	*V*	*f*	*I*	*p*
[h]	[m/s2]	[mm/s]	[1/s = Hz]	[A]	[MPa]
8329	48.000	24.000	0.64303	124	0.30
8354	40.500	20.500	0.60997	89	0.30
8401	45.000	25.000	0.56401	59	0.28
8442	24.000	17.000	0.43420	63	0.30
8487	45.000	26.000	0.54208	137	0.29
8496	42.000	18.500	0.69954	112	0.24
8531	42.000	21.500	0.60307	105	0.24
8578	39.000	19.000	0.63829	122	0.29
8602	39.000	19.250	0.64146	111	0.29
8648	30.000	14.000	0.69233	59	0.30
8675	30.000	18.000	0.53004	87	0.29
8699	24.000	17.000	0.43420	67	0.29
8744	25.500	22.000	0.35321	73	0.29
8769	30.000	18.500	0.52179	79	0.30
8819	24.000	19.000	0.38917	78	0.30
8838	31.500	17.000	0.39308	55	0.29
8861	24.000	15.500	0.49312	73	0.30
8909	33.000	25.500	0.41792	140	0.30
8937	33.000	25.500	0.41792	155	0.30
8982	39.000	19.000	0.63829	129	0.29
9006	34.500	17.500	0.63931	78	0.30
9029	42.000	21.500	0.60307	100	0.30
9079	30.000	19.000	0.51092	90	0.30
9097	42.000	20.500	0.64264	105	0.29
9121	34.500	17.500	0.63931	78	0.30
9235	24.000	15.500	0.49312	70	0.30
9256	24.000	15.500	0.49312	65	0.30
9278	33.000	17.750	0.59790	79	0.30
9322	39.000	19.000	0.63829	123	0.30
9333	31.500	17.000	0.60224	55	0.30

To reduce all signals to consistent form i.e. number of exceedings of statistic thresholds we use the formulas (22), (23):

$$S_1 = \sigma\sigma_t, N = \frac{S}{S_1} \qquad (22)$$

$$N_{D_K} = \sqrt{N_A^2 + N_V^2 + N_f^2}, N_U = \sqrt{N_I^2 + N_p^2} \qquad (23)$$

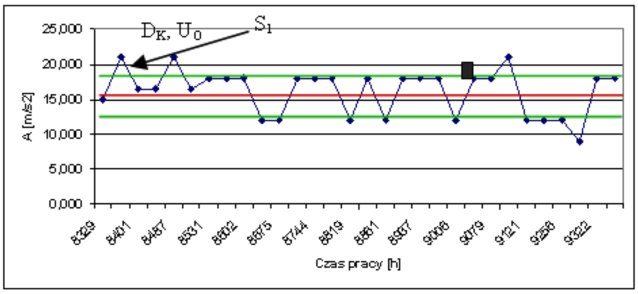

Fig. 2. Method of reduction of signals to the form of number of exceedings of statistic thresholds

Tab. 2. Numbers of exceedings of statistic thresholds

Work time	Vibration amplitude	Vibration velocity	Vibration frequency	Motor current	Pumping pressure	Complex diagnostic	Environment
Θ	n_{D_A}	n_{D_V}	n_{D_f}	n_{U_I}	n_{U_p}	N_{DK}	N_U
8329	**0.03065**	**0.00063**	0.00000	0.00000	0.00000	**0.03065**	0.00000
8354	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8401	**0.00701**	**0.01519**	0.00000	**0.17986**	0.00000	**0.01672**	**0.17986**
8442	**0.00584**	0.00000	**0.03160**	0.00000	0.00000	**0.03213**	0.00000
8487	**0.01051**	**0.02531**	0.00000	**0.26979**	0.00000	**0.02741**	**0.26979**
8496	0.00000	0.00000	**0.02565**	0.00000	**0.10461**	**0.02565**	**0.10461**
8531	0.00000	0.00000	0.00000	0.00000	**0.10461**	0.00000	**0.10461**
8578	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8602	**0.00467**	0.00000	**0.02816**	0.00000	0.00000	**0.02854**	0.00000
8648	0.00000	**0.01519**	**0.04324**	**0.04496**	0.00000	**0.04583**	**0.04496**
8675	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
8699	**0.01751**	0.00000	0.00000	0.00000	0.00000	**0.01751**	0.00000
8744	**0.19848**	**0.24588**	**0.08548**	0.00000	0.00000	**0.32735**	0.00000
8769	0.00000	0.00000	**0.07040**	0.00000	0.00000	**0.07040**	0.00000
8819	**0.00701**	0.00289	**0.14733**	0.00000	0.00000	**0.14753**	0.00000
8838	**0.01637**	0.00000	**0.09251**	**0.21697**	0.00000	**0.09395**	**0.21697**
8861	**0.02447**	**0.00726**	0.00000	0.00000	0.00000	**0.02552**	0.00000
8909	0.00000	**0.06415**	**0.04412**	**0.20602**	0.00000	**0.07786**	**0.20602**
8937	0.00000	**0.05830**	0.00000	**0.12656**	0.00000	**0.05830**	**0.12656**
8982	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9006	**0.00567**	**0.00134**	0.00000	0.00000	0.00000	**0.00583**	0.00000
9029	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9079	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9097	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9121	**0.02149**	**0.01118**	0.00000	0.00000	0.00000	**0.02423**	0.00000
9235	**0.06075**	**0.02959**	0.00000	0.00000	0.00000	**0.06758**	0.00000
9256	**0.03875**	**0.01840**	**0.05274**	0.00000	0.00000	**0.06798**	0.00000
9278	0.00000	0.00000	**0.05208**	0.00000	0.00000	**0.05208**	0.00000
9322	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
9333	**0.00154**	0.00000	**0.01140**	**0.00771**	0.00000	**0.01150**	**0.00771**

5.2. Assessment of reliability of a pump unit on the basis of parametric defects

Tab. 3. Values of the parameter „a_{Rb}“ as symptoms of parametric defects

Working time	Complex diagnostic	Environment	$\hat{a}_{R_b}$	a_{R_b}
Θ [h]	D_K	U		
8329	0.03065	0.00000	-0.80973	0.00012
8354	0.03065	0.00000	-0.80973	0.00000
8401	0.04738	0.17986	-0.80973	-0.00002
8442	0.07951	0.17986	-0.80973	-0.00006
8487	0.10691	0.44965	-0.80973	-0.00001
8496	0.13256	0.55426	-0.80973	-0.00001
8531	0.13256	0.65887	-0.80973	0.00000
8578	0.13256	0.65887	-0.80973	0.00000
8602	0.16110	0.65887	-0.80973	-0.00001
8648	0.20694	0.70383	-0.80973	-0.00001
8675	0.20694	0.70383	-0.80973	0.00000
8699	0.22445	0.70383	-0.80973	-0.00001
8744	0.55180	0.70383	-0.80973	-0.00207
8769	0.62220	0.70383	-0.80973	0.00015
8819	0.76973	0.70383	-0.80973	0.00008
8838	0.86368	0.92080	-0.80973	0.00009
8861	0.88920	0.92080	-0.80973	0.00002
8909	0.96705	1.12682	-0.80973	0.00016
8937	1.02536	1.25338	-0.80973	0.00062
8982	1.02536	1.25338	-0.80973	0.00000
9006	1.03118	1.25338	-0.80973	0.00004
9029	1.03118	1.25338	-0.80973	0.00000
9079	1.03118	1.25338	-0.80973	0.00000
9097	1.03118	1.25338	-0.80973	0.00000
9121	1.05541	1.25338	-0.80973	0.00007
9235	1.12299	1.25338	-0.80973	0.00007
9256	1.19097	1.25338	-0.80973	0.00004
9278	1.24305	1.25338	-0.80973	0.00002
9322	1.24305	1.25338	-0.80973	0.00000
9333	1.25455	1.26109	-0.80973	0.00001

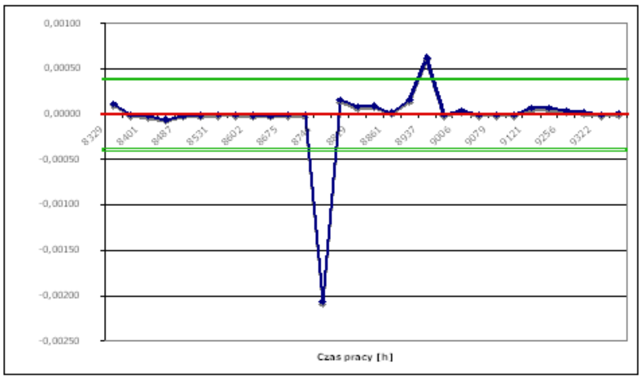

Fig. 3. Variation of the parameter „a_{Rb}“ (red line – average, green line – standard deviation)

Using the relation (16) and results of measurements shown in the table we have determined the parameter of technical condition a_{Rb}, which can be determined as the symptom of parametric defects. Values of the parameter a_{Rb} are shown in Tab. 3.

Regarding the exceeding of statistic threshold as the symptom of parametric damage we can determine the estimators of reliability function R_b^*.

Tab. 4. Values of estimators of reliability and fallibility functions for $\mu + \sigma$ (n – number of measurements (30 for 1000 hrs, then 300 for 10000 hrs)

Working time	a_{R_b}	$n_{Rb}(t)$	n	$P_b^*(t)$	$R_b^*(t)$
Θ [h]		number of symptoms			
8329	0.00012	0	300	0.00000	1.00000
8354	0.00000	0	300	0.00000	1.00000
8401	-0.00002	0	300	0.00000	1.00000
8442	-0.00006	0	300	0.00000	1.00000
8487	-0.00001	0	300	0.00000	1.00000
8496	-0.00001	0	300	0.00000	1.00000
8531	0.00000	0	300	0.00000	1.00000
8578	0.00000	0	300	0.00000	1.00000
8602	-0.00001	0	300	0.00000	1.00000
8648	-0.00001	0	300	0.00000	1.00000
8675	0.00000	0	300	0.00000	1.00000
8699	-0.00001	0	300	0.00000	1.00000
8744	-0.00207	1	300	0.00333	0.99667
8769	0.00015	1	300	0.00333	0.99667
8819	0.00008	1	300	0.00333	0.99667
8838	0.00009	1	300	0.00333	0.99667
8861	0.00002	1	300	0.00333	0.99667
8909	0.00016	1	300	0.00333	0.99667
8937	0.00062	2	300	0.00667	0.99333
8982	0.00000	2	300	0.00667	0.99333
9006	0.00004	2	300	0.00667	0.99333
9029	0.00000	2	300	0.00667	0.99333
9079	0.00000	2	300	0.00667	0.99333
9097	0.00000	2	300	0.00667	0.99333
9121	0.00007	2	300	0.00667	0.99333
9235	0.00007	2	300	0.00667	0.99333
9256	0.00004	2	300	0.00667	0.99333
9278	0.00002	2	300	0.00667	0.99333
9322	0.00000	2	300	0.00667	0.99333
9333	0.00001	2	300	0.00667	0.99333

5.3. Assessment of reliability of a pump unit on the basis of momentary defects

Using the relation (21) and results of measurements shown in the table we have determined the parameter of adjustment state a_{Rc}, which can be determined as the symptom of momentary defects. Values of parameter a_{Rc} are shown in Tab. 5.

Regarding the exceeding of statistic threshold as the symptom of parametric damage we can determine the estimators of reliability function R_c^*.

Tab. 5. Values of the parameter „a_{Rc}“ as symptom sof momentary defects

Working time	Complex diagnostic	Environment	a_{R_c}	a_{R_c}
Θ [h]	D_K	U		
8329	0.03065	0.00000	-0.80973	-0.00015
8354	0.03065	0.00000	-0.80973	0.00000
8401	0.04738	0.17986	-0.80973	0.00001
8442	0.07951	0.17986	-0.80973	0.00003
8487	0.10691	0.44965	-0.80973	0.00001
8496	0.13256	0.55426	-0.80973	0.00001
8531	0.13256	0.65887	-0.80973	0.00000
8578	0.13256	0.65887	-0.80973	0.00000
8602	0.16110	0.65887	-0.80973	0.00001
8648	0.20694	0.70383	-0.80973	0.00001
8675	0.20694	0.70383	-0.80973	0.00000
8699	0.22445	0.70383	-0.80973	0.00000
8744	0.55180	0.70383	-0.80973	0.00015
8769	0.62220	0.70383	-0.80973	0.00004
8819	0.76973	0.70383	-0.80973	0.00021
8838	0.86368	0.92080	-0.80973	0.00005
8861	0.88920	0.92080	-0.80973	0.00001
8909	0.96705	1.12682	-0.80973	0.00003
8937	1.02536	1.25338	-0.80973	0.00002
8982	1.02536	1.25338	-0.80973	0.00000
9006	1.03118	1.25338	-0.80973	0.00000
9029	1.03118	1.25338	-0.80973	0.00000
9079	1.03118	1.25338	-0.80973	0.00000
9097	1.03118	1.25338	-0.80973	0.00000
9121	1.05541	1.25338	-0.80973	0.00001
9235	1.12299	1.25338	-0.80973	0.00002
9256	1.19097	1.25338	-0.80973	0.00003
9278	1.24305	1.25338	-0.80973	0.00002
9322	1.24305	1.25338	-0.80973	0.00000
9333	1.25455	1.26109	-0.80973	0.00001

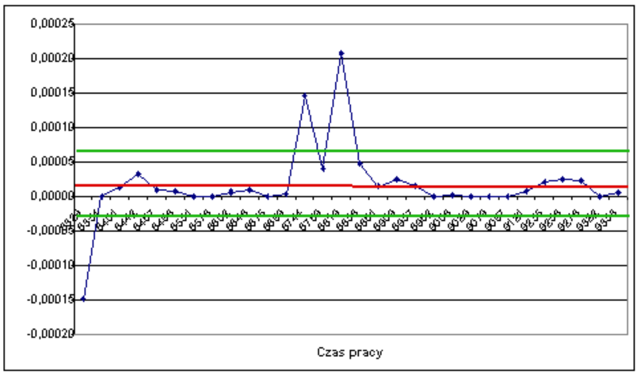

Fig. 4. Variation of the parameter „a_{Rc}“ (red line – average, green line –standard deviation)

Tab. 6. Values of estimators of reliability and fallibility functions for $\mu + \sigma$

Working time	a_{R_b}	$n_{Rb}(t)$	n	$P_c{}^*(t)$	$R_c{}^*(t)$
Θ [h]		number of symptoms			
8329	-0.00015	1	300	0.00333	0.99667
8354	0.00000	1	300	0.00333	0.99667
8401	0.00001	1	300	0.00333	0.99667
8442	0.00003	1	300	0.00333	0.99667
8487	0.00001	1	300	0.00333	0.99667
8496	0.00001	1	300	0.00333	0.99667
8531	0.00000	1	300	0.00333	0.99667
8578	0.00000	1	300	0.00333	0.99667
8602	0.00001	1	300	0.00333	0.99667
8648	0.00001	1	300	0.00333	0.99667
8675	0.00000	1	300	0.00333	0.99667
8699	0.00000	1	300	0.00333	0.99667
8744	0.00015	2	300	0.00667	0.99333
8769	0.00004	2	300	0.00667	0.99333
8819	0.00021	3	300	0.01000	0.99000
8838	0.00005	3	300	0.01000	0.99000
8861	0.00001	3	300	0.01000	0.99000
8909	0.00003	3	300	0.01000	0.99000
8937	0.00002	3	300	0.01000	0.99000
8982	0.00000	3	300	0.01000	0.99000
9006	0.00000	3	300	0.01000	0.99000
9029	0.00000	3	300	0.01000	0.99000
9079	0.00000	3	300	0.01000	0.99000
9097	0.00000	3	300	0.01000	0.99000
9121	0.00001	3	300	0.01000	0.99000
9235	0.00002	3	300	0.01000	0.99000
9256	0.00003	3	300	0.01000	0.99000
9278	0.00002	3	300	0.01000	0.99000
9322	0.00000	3	300	0.01000	0.99000
9333	0.00001	3	300	0.01000	0.99000

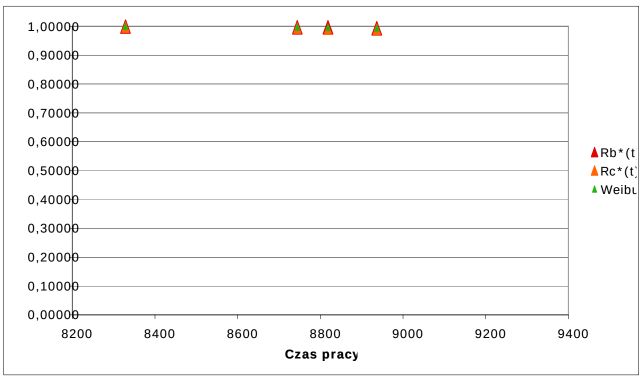

Fig. 5. Variation of estimators reliability $R(t)$ function and Weibull distribution $R(t) = e^{-at^b}$, where a=1 and b=1 with consideration of parametric defects and standard deviation for $\mu+\sigma$

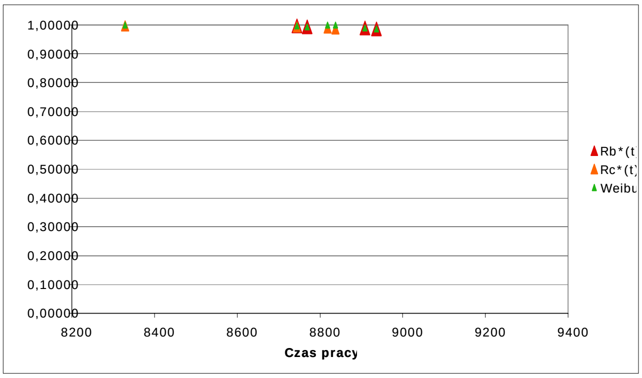

Fig. 6. Variation of estimators reliability $R(t)$ function and Weibull distribution $R(t)=e^{-at^b}$, where a=1 and b=1 with consideration of parametric defects and standard deviation for μ+0.5σ

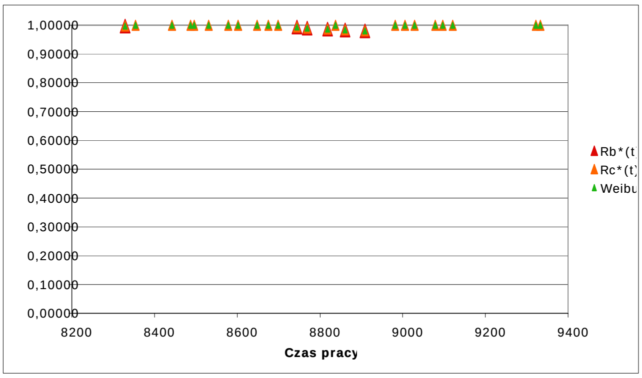

Fig. 7. Variation of estimators reliability R(t) function and Weibull distribution $R(t)=e^{-at^b}$, where a=1 and b=1 with consideration of parametric defects and standard deviation for μ+0.25

6. SUMMARY

The reliability characteristics are very important information determining the state of applicability of the object. The method of their determination is still an open problem, especially when the maintenance crew has no full information abort catastrophic, parametric and momentary defects. In the article presented is the innovative method of utilisation of operational information (presented in the form of numbers of exceedings of statistic thresholds“ of utility, environment and accompanied signals) for determination of reliability characteristics. Presented method is very practical because allows verification of reliability characteristics without information about occurring catastrophic defects, which cannot occur in their pure form in the process of operation. Determined reliability characteristics should be analysed according to principles of diagnostics i.e. in connection with past characteristics of given object and with reliability characteristics of other objects of the same type.

REFERENCES

1. **Ashby R. V.** (1963), *Wstęp do cybernetyki*,. Warszawa.
2. **Bobrowski D.** (1985), *Modele i metody matematyczne teorii niezawodności w przykładach i zadaniach*, Warszawa.
3. **Girtler J.** (2003), Aspekty tworzenia modeli do prognozowania niezawodności systemów technicznych, Metody prognozowania w inżynierii niezawodności, *XXXI zimowa szkoła niezawodności*. Sekcja Podstaw Eksploatacji Komitetu Budowy Maszyn PAN, Szczyrk.
4. **Lindstedt P.** (2006), Kompleksowa diagnostyka w procesie oceny jekości użytkowania silnika śmigłowcowego w inżynieryjno – lotniczym otoczeniu, *Diagnostyka*, 3(39).
5. **Lindstedt P., Borowczyk H., Magier J.** (2003), Badanie możliwości kompleksowego diagnozowania układu łożyskowania na podstawie informacji uzyskanej z metod funkcjonalnej, tribologicznej i wibroakustycznej, *Projekt badawczy KBN Nr 5T12D01122*, sprawozdanie ITW nr 1371/50, Wyd. ITWL, Warszawa.
6. **Lindstedt P., Sudakowski T.** (2007a), Possibilities of assessment of reliability of an anthropotechnical system, *JVE Journal Of Vibroengineering*, Vol. 9, Issue 4.
7. **Lindstedt P., Sudakowski T.** (2007b), Prediction the bearing reliability on basis diagnostic information, *International Journal Of KONBiN*, 1(3).
8. **Lindstedt P., Sudakowski T.** (2008), Metod of prediction of realibility charakteristics of a pumping stadion on the base of diagnostic information, *Journal Of KONBiN*, 2(5), Vol. 2, Warsaw.
9. **Paton R., Frank P., Clark R.** (1989), *Fault diagnostic in dynamic systems. Theory and applications*, Cambridge University Press, London.
10. **Söderström T., Stoica P.** (1997), *Identyfikacja systemów*, PWN, Warszawa.
11. **Sotskow B. S.** (1973), *Niezawodność elementów i urządzeń automatyki*, WNT, Warszawa.
12. **Staniszewski R.** (1980), *Sterowanie zespołów napędowych.* WKŁ, Warszawa..
13. **Tomaszek H., Żurek J., Jasztal M.** (2008), *Prognozowanie uszkodzeń grożących bezpieczeństwu lotów statków powietrznych*, Wydawnictwo Naukowe Instytutu Technologii Eksploatacji – PIB, Warszawa.
14. **Zamojski W.** (1981), *Niezawodność i eksploatacja systemów*, Politechnika Wrocławska, Wrocław.
15. vlsi.imio.pw.edu.pl/pmk_W8_1.html