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THE TECHNICAL OBJECT RELIABILITY EVALUATION BASED ON THE PARAMETRIC AND MOMENTARY FAILURES

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Abstract

The presented paper concerns with the technical object reliability evaluation based on the parametric and momentary failures during the process of object operating. The real world data observation shows that in the case of high quality technical objects the catastrophic failure events are too rare to the credible evaluation of the object's reliability. For that reason, the parametric and momentary failures are in the centre of attention in this paper. The set of analysed failures was obtained with the classifiers of the field data provided by the monitoring system (the failure alarms) and the diagnostic system (the functional and technical condition parameters deviation). The changes of the functioning condition potential are used to determine the symptoms of momentary failures and the changes in the potential of the technical condition to determine the symptoms of parametric failures (non-total). The assumed reliability characteristics model has the form R(t) = f(_, Rb(t), Rc(t)), (where: Rb(t) and Rc(t) – the estimators of reliability for parametric and momentary failures, symbol '_' denotes catastrophic failures not covered). For the identification of R (t) as an analytical function, the estimators are computed with the field data. The Weibull distribution function due to its flexibility is often used. Such is the case in this paper. Two parameters a and b known as the scale and the shape parameters are estimated with the computerized procedure realizing least-square method. The presented examples show good fit quality even for small set of data.

Keywords: *reliability, Weibull function, parametric failure, momentary failure*

1. Introduction

In the operation systems of complex technical objects, their continuous degradation is inevitable. The object failure rate grows, what leads to the object destruction and substantial material losses. Such an undesirable situation causes a continuous natural and growing disorganisation of a system [1, 8, 20].

The control of operation and maintenance processes needs the information concerning technical condition and reliability state of an object.

It is known [3] that as we enter into a system information on the object regulation status, which is determined according to the principles of automatics, and further information on the technical condition of an object determined to the rules of diagnostics as well as an information on the object reliability status, determined according to the reliability theory, we can increase the system redundancy and thus raise its usefulness, decrease its failure rate and also increase the safety.

A model of cybernetic organized system of operating technical object has been presented in [3], where the reliability characteristics were computed taking three types of failure into account – catastrophic, parametric, and momentary.

The real world data observation shows that in the case of high quality technical objects the catastrophic failure events are too rare to the credible evaluation of the object's reliability. For that reason, the parametric and momentary failures are in the centre of interest in this paper.

2. Basics of the system reliability assessment

An occurrence of a failure causes the object state of reliability to change, where that change is described quantitatively by reliability function. Three kinds of failure are taken into account:

a catastrophic (a total damage or destruction), a parametric one (ageing, non-total) and transient (momentary) one.

Catastrophic failures are sudden events leading to a full disability of a technical object. An object, in less critical cases must be put out of use or be repaired, i.e. broken part must be replaced with new one. In the process of use of high quality technical objects only a few catastrophic failures occur.

A parametric defect – due to ageing or degradation – is an event resulting in a gradual incapability of an object. In the process of use a substantial set of parametric damages occur. Identification of parametric failures needs standard and special measuring systems for inspection (evaluation of the system functioning) and for diagnosing checks (estimation of the system technical condition) [2, 18].

A transient (momentary) failure is an event occurring randomly and after some time going back without leaving any clear signs of its occurrence before. It is a failure, which at a given time, does not cause an object to lose its worthiness. Transient failures are difficult to identify; checks and diagnostic steps are required.

The general model of the reliability characteristic is:

$$R(t) = f\left(R_a(t), R_b(t), R_c(t)\right), \tag{1}$$

where:

$R(t)$ – reliability function,

$R_a(t)$ – probability of correct functioning of a system affected by a catastrophic failure,

$R_b(t)$ – probability of correct functioning of a system affected by a parametric damage,

$R_c(t)$ – probability of correct functioning of a system affected by a transient damage.

There are possible other kinds of the reliability characteristics models taking into account different types of failures.

For example

$$R_{abc}(t) = f\left(R_a(t), R_b(t), R_c(t)\right), \tag{2}$$

$$R_{a\_\_}(t) = f\left(R_a(t), \_, \_\right), \tag{3}$$

$$R_{ab\_}(t) = f\left(R_a(t), R_b(t), \_\right), \tag{4}$$

$$R_{\_bc}(t) = f\left(\_, R_b(t), R_c(t)\right), \tag{5}$$

$$R_{\{ab\}\_}(t) = f\left(R_{ab}(t), \_\right), \tag{6}$$

$$R_{\_\{bc\}}(t) = f\left(\_, R_{bc}(t)\right). \tag{7}$$

The models (2) and (1) are equivalent. The symbol _ denotes type of failure not covered by the model.

The model (3) includes only the catastrophic failures, model (4) – catastrophic and parametric, model (5) – parametric and momentary failures. In the equations (2) – (5) the failures are analysed separately.

The equations (6) – (7) describe the models where some set of the failure types is treated as compound type of failure or equivalent from certain point of view.

In order to determine the analytic form of the reliability function it is necessary to determine estimators for the types of failures covered by the model. For example, the model (2) needs following estimators:

$$R^*_{abc}(t) = f\left(R^*_a(t_i),\, R^*_b(t_i),\, R^*_c(t_i)\right). \tag{8}$$

The model (3):

$$R^*_{a\_}(t) = f\left(\left\{R^*_a(t_i)\right\}, \_, \_\right),$$
$$R^*_a(t_i) = \frac{n - m_a(t_i)}{n}, \tag{9}$$

where:
n – the equivalent number of the objects observed to the first failure,
$m_a(t_i)$ – the number of catastrophic failures.

The model (6)

$$R_{\{ab\}\_}(t) = f\left(\left\{R^*_{ab}(t_i)\right\}, \_\right),$$
$$R^*_{ab}(t_i) = \frac{n - m_{ab}(t_i)}{n}, \tag{10}$$
$$m_{ab}(t_i) = m_a(t_i) + m_b(t_i).$$

The model (7) describes the way for the reliability estimation taking into account the parametric and momentary failures:

$$R_{\_\{bc\}}(t) = f\left(\_, \left\{R^*_{bc}(t_i)\right\}\right),$$
$$R^*_{bc}(t_i) = \frac{n - m_{bc}(t_i)}{n}, \tag{11}$$
$$m_{bc}(t_i) = m_b(t_i) + m_c(t_i).$$

The number of equivalent objects observed to the first failure can be determined on the ergodicity assumption of parametric and momentary failures:

$$n = \frac{T_{obs}}{\Delta T_{sr}}, \tag{12}$$

where:
T_{obs} – observation period,
ΔT_{sr} – mean time between failures.

Symptoms of parametric and momentary failures are obtained from the two intercorrelated equations of state [5, 11]:

$$\frac{du}{dt} = a_{R_c} u + b_{R_c} D, \tag{13}$$

$$\frac{dD}{dt} = a_{R_b} D + b_{R_b} u, \tag{14}$$

where:
u – vector of control signals resulting from the operation of a technical object,
D – the vector of diagnostic signals related to the technical condition of an object,
a_{R_c} – the parameter of the state of operation,
b_{R_c} – the parameter of the impact of a technical state on the possibility of control,
a_{R_b} – the parameter of the technical condition (diagnosis),

b_{R_b} – the parameter of the impact of the quality of control on the changes of the technical condition.

Changes of parameters a_{R_c} , a_{R_b} and b_{R_c} i b_{R_b} are calculated with the formulas (13) – (14) based on signals u and D observed in operation period. All changes exceeding standard deviation value are treated as symptoms of parametric $m_b(t_i)$ and momentary $m_c(t_i)$ failures.

3. Estimation of the reliability characteristics

For the identification of the $R(t)$ reliability characteristic (as an analytical function) on the basis of $R^*_{bc}(t_i)$ estimator the best approximating function is determined with LSE method:

$$S = \sum_{i=1}^{N}[R^*(t_i) - R(t_i)]^2 \to \min. \tag{15}$$

The $R(t)$ function is assumed arbitrary (e.g. a Weibull distribution)

$$R(t) = e^{-\left(\frac{t}{a}\right)^b}, \tag{16}$$

where:
a – scale parameter,
b – shape parameter.

In addition, its parameters (e.g. a, b) are determined by equalling functional (15) partial derivatives to zero in relation to searched parameters:

$$\frac{\partial S}{\partial a} = 0 \quad ; \quad \frac{\partial S}{\partial b} = 0. \tag{17}$$

For the estimation of Weibull function parameters in [14] special procedure in FORTRAN is presented. Additionally some further quantities can be computed:

- the object's life time:

$$E(T) = \int_0^\infty R(t)\,dt\,, \tag{16}$$

- the standard deviation of the object's life time:

$$\sigma_{E(T)} = \sqrt{E\left(T^2\right) - E^2(T)}, \tag{17}$$

where:

$$E\left(T^2\right) = 2\int_0^\infty tR(t)\,dt. \tag{18}$$

Further on:

$$E(T)_{\min} = E(T) - \sigma_{E(T)}, \tag{19}$$

$$E(T)_{\max} = E(T) + \sigma_{E(T)}\,. \tag{20}$$

Minimal and maximal lifetimes are good measures for reliability characteristics analysis during an object operation and maintenance.

4. Estimation the parameters of Weibull function [3, 14]

The suggested method is based on the Weibull function described by (17). Having found the logarithm of [13, 14] we obtain:

$$\ln R(t) = \ln e^{-\left(\frac{t}{a}\right)^b}. \tag{21}$$

Next:

$$r(t) = -\left(\frac{t}{a}\right)^b, \tag{22}$$

where:

$$r(t) = \ln R(t).$$

In the discussed case, the functional of the optimisation of the smallest sum square method will take the following form:

$$S_L = \sum_{i=1}^{n}\left(r_i^* + \left(\frac{t_i}{a}\right)^b\right)^2 = \sum_{i=1}^{n}\left(r_i^{*2} + 2r_i^*\left(\frac{t_i}{a}\right)^b + \left(\frac{t_i}{a}\right)^{2b}\right), \tag{23}$$

where:

$r_i^* = \ln R^*(t_i)$.

Parameters a i b are computed from:

$$\frac{\partial S_L}{\partial b} = \sum_{i=1}^{n}\left[r_i^*\left(\frac{t_i}{a}\right)^b + \left(\frac{t_i}{a}\right)^{2b}\right]\ln\frac{t_i}{a} = 0, \tag{24}$$

$$\frac{\partial S_L}{\partial a} = \sum_{i=1}^{n}\left[2r_i^* t_i^b\left(-\frac{b}{a^{b+1}}\right) + t_i^{2b}\left(-\frac{2b}{a^{2b+1}}\right)\right] = 0, \tag{25}$$

finally:

$$\sum_{i=1}^{n}\left(r_i^* t_i^b a^b + t_i^{2b}\right)\ln\frac{t_i}{a} = 0, \tag{26}$$

$$\sum_{i=1}^{n}\left(r_i^* t_i^b a^b + t_i^{2b}\right) = 0. \tag{27}$$

Assuming value of b one can compute a using (29):

$$a = e^z \quad where \quad z = \frac{1}{b}\ln\frac{\sum_{i=1}^{n} t_i^{2b}}{\sum_{i=1}^{n} r_i^* t_i^b}. \tag{28}$$

The essence of the suggested algorithm of determination of analytical reliability characteristics parameters in the form of the Weibull function is to search the null point of the *F* function resulting from the (28)

$$F = \sum_{i=1}^{n}\left(r_i^* t_i^b a^b + t_i^{2b}\right)\ln\frac{t_i}{a}, \tag{29}$$

at an equality limiting condition (29) brought to a form of (30).

To calculate *a* and *b* parameters we assume first that $b = 1$. Further, we proceed as follows:

- Step 1: For a given value of the *b* parameter determine the *a* parameter value from (30),
- Step 2: Determine the value of the *F* function from (31),
- Step 3: If the absolute value of the F function exceeds a permissible error ε take a new value of the *b* parameter and return to Step 1. New values of the parameter *b* are assumed so as to with next iterations the absolute value of the function *F* went down,
- Step 4: Write down the determined parameters of the Weibull distribution.

The selection of $b=1$ results from experience gained from reliability tests with technical objects – the time of operation, when the damaging intensity rate a is constant, $a = const$, is the longest, so it is most sure and most easy to identify.

According to an up-to date experience of operating systems one assumes that with b=1 an object is at a stage of normal use, with b<1 it is being run-in and with b>1 its wear is increased, b=2 its wear is intensified (the intensity rises in a linear way) and finally with b>2 an object is subject to a failure wear (the intensity grows in a non-linear way).

Additional information depends on changes of parameter a – proper value of a and small change Δa show good reliability state of an object.

The mean lifetime for parameters a and b:

$$E(T) = \int_0^\infty e^{-\left(\frac{t}{a}\right)^b} dt. \tag{30}$$

A standard deviation:

$$\sigma_{E(T)} = \sqrt{2\int_0^\infty te^{-\left(\frac{t}{a}\right)^b} dt - \left[\int_0^\infty e^{-\left(\frac{t}{a}\right)^b} dt\right]^2}. \tag{31}$$

5. An example

The field data of three-type objects' failures is presented in the Table 1.

Tab. 1 Examples of real world reliability data [3, 4, 11, 12]

object	failure	PO	A number and time of failure occurrence						KO	ΔT_{sr}
Allison 250 [4]	mom	0/0		1/400		1/1000			1325	225
	param		1/200		1/800		1/1100			
	R_{bc}^*	1	5/6 = 0.833	4/6 = 0.667	3/6 = =0.5	2/6 = 0333	1/6 = 0167			
Pumps set [11]	mom	0/8000	1/8350		1/8760	1/8830			9100	150
	param			1/8720			1/8950			
	R_{bc}^*	1	7/8 = 0.875	6/8 = 0.75	5/8 = 0.625	4/8 = 0.5	3/8 = 0.375			
System pilot-helicopter [12]	mom	0/800		1/1250	1/1315	1/1645			1778	1080
	param		1/1150				1/1650	1/1670		
	R_{bc}^*	1	9/10 = 0.9	8/10 = 0.8	7/10 = 0.7	6/10 = 0.6	5/10 = 0.5	4/10 = 0.4		

PO – start of observation; KO – end of observation.

Table 1 shows the time moments of a parametric and/or transient failure occurrence and computed estimaters of R_{bc}^* for three types of systems.

Using procedure [14] the parameters of Weibull function are computed as follows

- engine Allison 250 – $a=8.57133$, $b=0.76454$,
- pumps set – $a=14.63$, $b=0.85545$,
- pilot-helicopter system $a=1.7846$, $b=1.0545$.

The values of mean lifetime and its standard deviation are:

- engine Allison 250,

$$E(T) = 9.3\Delta T_{sr} = 2093; \quad \sigma_{E(T)} = \quad 10.6\Delta T_{sr} = 2385;$$
$$E(T)_{\min} = 0; \quad E(T)_{\max} = 4478;$$

– pumps set:

$$E(T) = 13.84\Delta T_{sr} = 2086; \quad \sigma_{E(T)} = \quad 12.68\Delta T_{sr} = 1902;$$
$$E(T)_{\min} = 184; \quad E(T)_{\max} = 3988;$$

– pilot-helicopter system:

$$E(T) = 1.68\Delta T_{sr} = 181; \quad \sigma_{E(T)} = \quad 1.65\Delta T_{sr} = 178;$$
$$E(T)_{\min} = 3.0; \quad E(T)_{\max} = 359.$$

It should be stressed that number n of objects computed on the observed data is rather small so further observation are necessary to obtain credible results.

During an object operation Weibull function parameters a,b, reliability characteristic values $R(t_i)$, and $E(T)_{\min}$ should be analysed.

An expert is able to gather information concerning:

– minimal time between failures in observation period converted into number of objects observed,
– minimal time between failures for sequence of observations.

Such information entered into the cybernetic maintenance system enables an optimization of the maintenance and operation procedures.

6. Summary

It has been shown in the paper that system reliability analysis based on the parametric and/or transient failures estimators delivers valuable information for maintenance and operation processes optimization.

The observation of changes in the operational status and in the technical condition can serve as a basis to determine signs of parametric and transient failures and, to calculate the parameters of the Weibull reliability characteristics for each particular object.

The presented method of calculating the reliability characteristic does not need any catastrophic failures occurrence and moreover having to analyse a large set of objects.

References

[1] Ashby, R. W., *Wstęp do cybernetyki*, PWN, Warszawa 1963.
[2] Bobrowski, D., *Modele i metody matematyczne w teorii niezawodności*, WNT Warszawa 1985.
[3] Borowczyk, H., Lindstedt, P., Manerowski, J., *Premises for a practical computer-aided parametric method of evaluation of the technical object reliability*, Journal of KONES Powertrain and Transport, Vol. 16, No. 2, 2009.
[4] Borowczyk, H., Lindstedt, P., *Przesłanki sterowania procesem eksploatacji układu łożyskowania silnika turbinowego na podstawie kompleksowej informacji diagnostycznej*, Diagnostyka, 1(45), 2008.
[5] Cempel, C., *Teoria i inżynieria systemów*, WITE, Radom 2006.
[6] Fidelis, E., Firkowicz, S., Grzesiak, K., Kołodziejski, J., Wiśniewski, K., *Matematyczne podstawy oceny niezawodności*, PWN, Warszawa 1966.
[7] Jaźwiński, J., Żurek, J., *Wybrane problemy sterowania zapasami*, WITE, Radom 2007.
[8] Lerner, A. J., *Zarys cybernetyki*, WNT, Warszawa 1971.

[9] Lewitowicz, J., Kustroń, K., *Podstawy eksploatacji statków powietrznych*, T. 2, Wyd. ITWL, Warszawa 2003.
[10] Lindstedt, P., *The method of complex Worthiness Assessment of an Engineering Object in the process of its Use and Service*, Solid State Phenomena, Trans. Tech. Publications, Vol. 141, pp. 45-52, Switzerland 2009.
[11] Lindstedt, P., Sudakowski, T., *Method of Prediction of Reliability characteristics of Pumping Station on the base of Diagnostic Information*, Journal of KONBiN, Vol. 11, No. 2(5), pp. 202-222, Warsaw 2008.
[12] Lindstedt, P., Sudakowski, T., *Possibilities of Assessment of Reliability of an Antropotechnical System. Journal of Vibroengineering*, Vol. 9, Is. 4, Vilnius 2007.
[13] Manerowski, J., *Identyfikacja modeli dynamiki ruchu sterowanych obiektów latających*, Wyd. Naukowe ASKON, Warszawa 1999.
[14] Manerowski, J., *Estymacja parametrów rozkładu Weibulla – procedura w języku Fortran*.
[15] Oprzędkiewicz, J., Stolarski, B., *Komputerowe monitorowanie niezawodności samochodów*, PWN, Warszawa 2000.
[16] *Poradnik Inżynieria niezawodności, (ed.)* J. Migdalskiego, ATR Bydgoszcz, ZETOM Warszawa 1992.
[17] PN-87/N-04030.
[18] Sotskow, B. S., *Niezawodność elementów i urządzeń automatyki*, WNT, Warszawa 1973.
[19] Tomaszek, H., Żurek, J., Jasztal, H., *Prognozowanie uszkodzeń zagrażających bezpieczeństwu lotów statków powietrznych*, Wyd. Naukowe ITE-PIB, Warszawa 2008.
[20] Wiener, N., *Cybernetyka czyli sterowanie i komunikacja w zwierzęciu i maszynie*, PWN, Warszawa 1971.