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A FRAMEWORK FOR THE RELIABILITY CHARACTERISTICS ESTIMATION ON THE EXPERIMENTAL DATA

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Abstract

This paper presents a framework for the reliability characteristics estimation on the experimental data. The framework consists of the set of failures, the experimental data sources, the set of reliability characteristics, the estimation methods, the estimation goodness tests and the expert system supporting estimation and statistical inference processes.

The experimental data was obtained with two main theoretical means: control theory and diagnostics. It has been observed that changes of the functioning condition potential could serve to determine the symptoms of transient (momentary) failures and the changes in the potential of the technical condition to determine the symptoms of parametric faults. Such an information is sufficient to calculate reliability characteristics before dangerous catastrophic failures occur and to calculate reliability characteristics for single object without having to deal with a numerous set of objects.

The set of reliability characteristics models consists of the analysed failures combination and distribution functions used in the reliability engineering. The set of estimation methods includes analytical and numerical ones.

The proposed expert system supporting estimation and statistical inference processes consists of data base (the experimental data), rule base and inferring machine.

Keywords: *reliability, experimental data, framework, expert system*

1. Introduction

The individual object reliability assessment problem based on the number of parametric and momentary failures (before the occurrence of catastrophic failure) is still open. Its solution is largely dependent on the identification of the number of parametric and momentary failures, which is especially difficult when a relatively small number of measurements are available [4, 5, 7, 8].

It was noticed that there exists a close relationship between the activities related to adjustment and diagnostics of technical object and its reliability within its system of technical exploitation [9, 10].

In practice, the following sequence of events can be noticed:

- adjustment of module is usually caused by wear and tear of components hence the need of adjustments is connected with diagnostic operations,
- excessive wear leads to failure thus diagnostic operations are connected with the reliability of the object,
- reliability of the object and the developed map of failures leads to establishing an optimal set of diagnostic signals, thus reliability is connected with diagnostics.

In the paper, a framework for the reliability characteristics estimation on the experimental failure data obtained from maintenance, adjustment and diagnostic sources is presented.

2. The set of failures

In the process of assessment of the technical object reliability different kinds of failure should be taken into account: a catastrophic (a total damage or destruction), a parametric one (ageing, non-total) and transient (momentary) one [6, 13, 16].

Catastrophic failures (complete) are sudden events leading to a full disability of a technical object. These failures are clear and obvious therefore easy to identify.

A parametric failure (non-complete, due to ageing, or degradation) is an event resulting in a gradual incapability of an object. Identification of parametric failures is difficult. Standard and special measuring systems for inspection (evaluation of the system functioning) and for diagnosing checks (estimation of the system technical condition) are required.

A transient (momentary) failure is an event occurring randomly and after some time going back without leaving any clear signs of its occurrence before. Transient failures are difficult to identify; checks and diagnostic steps with exhaustive technical analysis are required.

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

$$\frac{du}{dt} = a_{R_c} u + b_{R_c} D, \tag{1}$$

$$\frac{dD}{dt} = a_{R_b} D + b_{R_b} u, \tag{2}$$

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} , b_{Rc} and b_{Rb} are calculated with the formulas (1)-(2) 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. The reliability data sources

The number of failures and their distribution in time serve as a background to determine reliability-related characteristics of technical object.

The set of reliability data sources can be established using following statements:

- every full disability of a technical object indicates a catastrophic failure,
- change in the parameters of the technical condition is a source of measurable and available diagnostic signals,
- diagnostic signals enable indirect monitoring of unavailable and essential parameters of technical condition.
- diagnostic signals make possible to predict that any essential parameter is about to reach it threshold limit.

It is convenient to split observed failure data into three streams:

- catastrophic failures,
- parametric failures,
- momentary failures.

Each of mentioned above streams has separate representation of ordered pairs:

$$S_a = \{\langle t_a, m_a \rangle\}, \tag{3}$$

$$S_b = \{\langle t_b, m_b \rangle\}, \tag{4}$$

$$S_c = \{\langle t_c, m_c \rangle\}, \tag{5}$$

where:

$t_{(.)}$ – time of a failure type (.) occurrence,

$m_{(.)}$ – number of failures of type (.).

4. The reliability characteristics

The general model of the reliability characteristics is:

$$R_{abc}(t) = f\left(R_a(t), R_b(t), R_c(t)\right), \tag{6}$$

where:

$R_{abc}(t)$ – the object reliability function,

$R_a(t)$ – probability of no catastrophic failure,

$R_b(t)$ – probability of no parametric failure,

$R_c(t)$ – probability of no momentary failure.

There are possible other kinds of the reliability characteristics model taking into account different types of failure:

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

$$R_{\_b\_}(t) = f\left(\_, R_b(t), \_\right), \tag{8}$$

$$R_{\_\_c}(t) = f\left(\_, \_, R_c(t)\right), \tag{9}$$

$$R_{ab\_}(t) = f\left(R_a(t), R_b(t), \_\right), \tag{10}$$

$$R_{\_bc}(t) = f\left(\_, R_b(t), R_c(t)\right), \tag{11}$$

$$R_{\{ab\}\_}(t) = f\left(R_{ab}(t), \_\right), \tag{12}$$

$$R_{\_\{bc\}}(t) = f\left(\_, R_{bc}(t)\right). \tag{13}$$

The symbol '_' denotes type of failure not covered by the model.

The models (7) – (9) include only one type of failure. The model (10) includes catastrophic and parametric failures, the model (11) – parametric and momentary failures. It should be stressed that in the equations (6) – (11) the failures are analysed separately.

The equations (12) – (13) describe the models where some set of the failure types is treated as compound type of failure or the failures 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 failure covered by the model. For example, the model (6) needs following estimators:

$$R^*_{abc}(t) = f\left(R^*_a(t_i),\ R^*_b(t_i),\ R^*_c(t_i)\right). \tag{14}$$

The estimators for the models (7)-(9):

$$R^*_{a\_\_}(t) = f\left(\left\{R^*_a(t_i)\right\}, \_, \_\right), \tag{15}$$

$$R^{*}_{\_\mathrm{b}\_}(t) = f\left(\_,\left\{R^{*}_{b}(t_i)\right\},\_\right), \tag{16}$$

$$R^{*}_{\_\_\mathrm{c}}(t) = f\left(\_,\_,\left\{R^{*}_{c}(t_i)\right\}\right). \tag{17}$$

The estimators for the model (12):

$$R^{*}_{\{ab\}\_}(t) = f\left(\left\{R^{*}_{ab}(t_i)\right\},\_\right), \tag{18}$$

and the model (13):

$$R^{*}_{\_\{bc\}}(t) = f\left(\_,\left\{R^{*}_{bc}(t_i)\right\}\right). \tag{19}$$

The choice of specific model depends on the problem analysed.

5. The reliability estimation methods

The general approach is to gain the field reliability data, evaluate empirical estimation $\widehat{F}(t)$ of cumulative distribution function $F(t)$ and fit the parameters of one or more statistical distribution [1-3, 11, 13]. Eqn. (20) describes the general form of distribution set taking into account:

$$SDM = \left\{SDM_1, SDM_2, \ldots, SDM_M\right\}, \tag{20}$$

where:

- SDM – the set of statistical distribution models taken into account,
- SDM_1 – exponential distribution,
- SDM_2 – Weibull distribution,
- SDM_3 – lognormal distribution,
- SDM_M – …,

If mapping of distribution function (21):

$$distrib\left(T, W\right), \tag{21}$$

into linear form:

$$y = mx + c, \tag{22}$$

exists [1, 17], least-squares method can be used to minimize (23):

$$S^2 = \sum_{i=1}^{N}\left[\hat{y}\left(x_i\right) - y\left(x_i\right)\right]^2, \tag{23}$$

where:

$distrib$ – a distribution name;
T – random variable (time to failure, time between failures),
W – vector of distribution parameters.

For example Weibull distribution mapping is [14, 17]:

$$x = \ln\left(t\right),\ y = \ln\left(\ln\left[\frac{1}{1-\widehat{F}\left(t\right)}\right]\right). \tag{24}$$

For estimation of distribution function (21) parameters vector W maximum likelihood method is used:

$$L(W)=\prod_{i=1}^{n} f\left(t_i|W\right), \tag{25}$$

or in logarithmic form:

$$\ln(W)=\sum_{i=1}^{n}\ln\left(f\left(t_i|W\right)\right). \tag{26}$$

The necessary conditions for maximum likelihood estimators of distribution parameters are:

$$\frac{\partial \ln L(W)}{\partial W_i}=0,\ i=1,2,...,Card(W). \tag{27}$$

In many cases, the system of equations (27) is solved numerically.

6. The test of the estimation goodness

The test of the estimation goodness consists of following steps:

- for observed values of random variable T a chosen statistic is calculated,
- if statistic's value is less than critical value read from an appropriate table then null hypothesis H_0 is accepted:

$$H_0: \text{the distribution function of random variable is the specified distribution}. \tag{28}$$

- If statistic's value is greater than critical value the alternative hypothesis H_1 is accepted:

$$H_1: \text{the distribution function of random variable is } \textit{not} \text{ the specified distribution}. \tag{29}$$

On the (20) and (28), the sub-set of unfalsified distribution models can be obtained

$$SDM_{unfalsified}=\left\{SDM_{unfalsified(1)},SDM_{unfalsified(2)},...,SDM_{unfalsified(\mathrm{K})}\right\}, \tag{30}$$

where: $K \le M$.

7. The concept of the expert system supporting estimation and statistical inference processes

The reliability analysis extensively exploits the set of rules in almost all stages. Therefore, it is justified to use expert system as a platform suitable to solve sub-problems concerning statistical reasoning and decision making to accept or reject reliability estimates based on experimental data.

PC-Shell system [12] is convenient tool because of its architecture enabling procedural programming and artificial intelligence reasoning.

The concept of expert system functioning is as follows.

Stage 1

- evaluate empirical estimation $\widehat{F}(t)$ of cumulative distribution function $F(t)$,
- choose the first distribution function from the set (20),
- map the analysed distribution into linear form (22),
- compute linear regression according to (23),
- if estimation error is less then assumed value – include analysed distribution into unfalsified set according to (30),
- if there exist unanalysed distribution choose the next distribution function from the set (20) and repeat three previous operations,
- if cardinality of unfalsified distribution function equals zero substitute.

$$SDM_{unfalsified}=SDM. \tag{31}$$

Stage 2

- choose the first distribution function from the set (31),
- establish likelihood function (26),
- solve the system of equations (27),
- execute the test of goodness of fit,
- if hypothesis H_0 is not accepted – exclude analysed distribution from unfalsified set (31),
- if there exist unanalysed distribution choose the next distribution function from the set (31) and repeat four previous operations
- if cardinality of unfalsified distribution function equals zero substitute.

$$SDM_{unfalsified} = \varnothing . \tag{32}$$

The result (32) means that there is no solution of the stated problem in "classical" approach.

The PC-Shell software [12] enables construction of self-developing system with feedback from unsolved problems. In some cases, the system needs information concerning non-standard methods.

8. Summary

Presented framework for the reliability characteristics estimation uses the experimental data from maintenance, diagnostics and adjustment fields. It has been observed that changes of the functioning condition potential could serve to determine the symptoms of transient (momentary) failures and the changes in the potential of the technical condition to determine the symptoms of parametric faults.

Proper classification of observed data into three streams enables reliability estimation taking into account three main failure types: catastrophic, parametric and momentary.

All necessary modules of reliability data and methods of distribution estimation and evaluation should be represented in the form appropriate to used informatic tool – for example PC Shell.

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