Scientifical research on the parameter reliability of risk technical systems in mechanical engineering

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Abstract— Operational capabilityability on the risk technical systems (RTS), creep in the mechanical engineering is determined from the assembly of the parameter assignment and allow the borders to change (i.e., the tolerance field). Breaking of the operational capabilityability is caused by the release (deviation) even on one of the the parameter, set out is determined from the tolerance field in the normative technical documentation. This breaking is associated with the occurrence of a condition, requiring investigation a **function of the catastrophe (FC)** on RTS.

Index Terms— Risk, Technical system, Function of the catastrophe

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1 INTRODUCTION

The set of set parameters of the RTS is determined by the nominal value of a **generalizing parameter (GP)** defined in the technical documentation. Consequently, the event of a gradual failure linked to the exit of the GP of tested system ***Y*** outside of the borders $Y_N \pm \Delta Y_{PER}$.

In this case, the probability of reliability operation (P_{RO}), i.e. the probability of non-occurrence of the RTS is equal to the probability of execution of inequality:

$$P_{RO}(t) = P\left[\left(Y_N - \Delta Y_{PER}\right) < Y < \left(Y_N + \Delta Y_{PER}\right)\right] \tag{1}$$

where:

- **Y_N** - nominal value of the GP of the investigated RTS.

If ***Y*** is a random magnitude with mathematical expectation m_Y and an average quadratic deviation σ_Y, for the normality of the distribution of the estimates of ***Y***, we record by (1) the following equation for P_{RO} [1],[3]:

$$P_{RO}(t) = \frac{1}{\sigma_Y\sqrt{2\pi}} . \int_{Y_N - \Delta Y_{PER}}^{Y_N + \Delta Y_{PER}} \exp\left[-\frac{(Y - m_Y)^2}{2\sigma_Y}\right] dY \tag{2}$$

If it Y_N is equal to the average value in the tolerance field for ***Technical Data (TD)*** for RTS, then for its P_{RO} is obtained:

$$P_{RO}(t) = 2\Phi(z) \tag{3}$$

where:

- ***Φ*** - function of the normal distribution,
- $z = \frac{\Delta Y_{PER}}{\sigma_Y}$ – argument of a function.

Very often, however, the law of distribution of P_{RO} of RTS is unknown and the distribution of the parameters $x_i, (i=1,\dots N)$ of the individual blocks of the same is known. In this case, in order to determine the P_{RO} of RTS according to (2), it is necessary to determine the dependence:

$$Y = f\left(x_1, x_2, \dots\dots, x_N\right) \tag{4}$$

Determination of (4) is extremely difficult and complicated. It is associated with the solution of a system of differential equations, which in engineering practice, causes an unnecessary cost of working time.

2. EXPOSITION

In this article provides a rational method for information processing for RTS. It consists in the fact, that the average values of the individual component parameters $\overline{x}_i$ are known from the theory of reliability. In the case of small amendments to the constituent parameters $\Delta x_i = \hat{x}_i - \overline{x}_i < \overline{x}_i$ variation of the output ***GP*** will be [3]:

$$\Delta Y = \hat{Y} - \overline{Y} = \sum_{i=1}^{N} \left(\frac{\partial Y}{\partial x_i}\right) . \Delta \overline{x}_i \tag{5}$$

where:

- $\Delta \overline{x}_i$ – modification of the average value of the ***i***-parameter in time for technical operation.

Formula (5) follows from the linearization of the function of the ***GP Y*** at the point $\overline{x}_i$. If we decompose (4) in the order of the points of Taylor $\overline{x}_1, \overline{x}_2, \dots, \overline{x}_N$, is obtained:

$$\overline{Y} = f\left(\overline{x}_1, \dots, \overline{x}_N\right) + \sum_{i=1}^{N} \left(\frac{\partial f}{\partial \overline{x}_i}\right) . \left(\hat{x}_i - \overline{x}_i\right) + \frac{1}{2} \cdot \sum_{j=1}^{N} \sum_{i=1}^{N} \frac{\partial^2 f}{\partial x_j . \partial x_i} \cdot \left(\hat{x}_j - \overline{x}_j\right) \cdot \left(\hat{x}_i - \overline{x}_i\right) + \dots \tag{6}$$

If we keep the members that are linear about the difference $\left(\hat{x}_i - \overline{x}_i\right)$ and indicate the corresponding differences with the

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symbol ***Δ***, arrive at an equation (5), observing the Taylor line, delivered by the condition $\Delta x << \bar{x}$, i.e. the parameter deviates slightly from its average. The Taylor line of (6) allows to eliminate all members after the second.

From the theory of linearization follows that the average quadratic deviation ***σ***σ_Y will have value:

$$\sigma_Y = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial Y}{\partial x_i}\right)^2 \cdot \sigma_{x_i}^2 + \sum_{i=1}^{N}\sum_{j=1}^{N}\left(\frac{\partial Y}{\partial x_i}\right)\cdot\left(\frac{\partial Y}{\partial x_j}\right)\cdot \sigma_{x_i}\cdot\sigma_{x_j}\cdot r_{ij}} \qquad (7)$$

where:

- r_{ij} **-** correlation coefficient between individual RTS parameters

Provided there is no dependence between individual RTS parameters, i.e. $r_{ij} = 0$ follows the dependence:

$$\sigma_Y = \sqrt{\sum_{i=1}^{N}\left(\frac{\partial Y}{\partial x_i}\right)^2 \cdot \sigma_{x_i}^2} \qquad (8)$$

Equation (8) is recommended for practical calculations, private derivatives **$\partial Y/\partial X_i$** are determined by practical testing of the risk technical systems.

The value of an average quadratic deviation $\boldsymbol{\sigma_{Xi}}$ of the individual parameters are determined by:

$$\sigma_{X_i} = \sqrt{\frac{1}{N-1}\cdot\sum_{i=1}^{N}\left(\hat{x}_i - \bar{x}_i\right)} \qquad (9)$$

Therefore, in order to determine the $\boldsymbol{P_{RO}}$ of RTS on a generic parameter ***Y*** (parametric reliability), it is necessary to know:

- the laws of probability dilution of the constituent parameters and the probability parameters of these laws;

- the behaviour of the average values of the individual ***GP***.

The main practical difficulty consists is to determining the aposthetory behavior of the parameters over time and to determine the moment of occurrence of a parametric denial.

For this purpose the apriori behavior of RTS is defined by a polynomial expression for the generalizing parameter $Y = \Pi(t)$ according to [3],[4],[9]:

$$\begin{aligned}&\Pi\left(t_2 - t_1 + T_{\mathrm{AETI}}\right) = \\ &n_0 + n_1.\left(t_2 - t_1 + T_{\mathrm{AETI}}\right) + \ldots\ldots + n_K.\left(t_2 - t_1 + T_{\mathrm{AETI}}\right)^K \geq \mathrm{X}_{\mathrm{BV}}\end{aligned} \qquad (10)$$

where:

- t_2, t_1 - studied apriori time interval;

- T_{AETI} - aposteriori estimated time interval;

- $n_0, n_1, \ldots., n_K$ - coefficients of polynomial, defined by [2], [3], [6];

- X_{BV} - the border value of the test parameter according to the relevant RTS.

Study of the parameters according to (10), has been made in the situation for the normality of their distribution, in which case the probability density of the parametric failure by a generalized parameter is determined by [6],[10]:

$$f_Y(t) = \frac{1}{\sigma_Y\sqrt{2\pi}}\cdot\prod_{i=1}^{N}\exp\left[-\frac{\left(\hat{x}_i - m_{X_i}\right)^2}{2\sigma_{X_i}^2}\right], \qquad (11)$$

where:

- m_{X_i} - model area of the constituent parameters x_i .

Given the formula (6) for the intensity of flow of progressive failure from § 1.3 of [4]:

$$\omega_Y(t) = \frac{f_Y(t)}{P_Y(t)} \qquad (12)$$

is determined according $\boldsymbol{\omega_Y(t)}$ to (11) and (3) the following ratio:

$$\omega_Y(t) = \frac{1}{2.\sigma_Y.\sqrt{2\pi}\,.\Phi\left(\frac{\Delta \mathrm{Y}_{\mathrm{PER}}}{\sigma_{\mathrm{Y}}}\right)}\cdot\prod_{i=1}^{N}\exp\left[-\frac{\hat{x}_i - m_{X_i}}{2.\sigma_{X_i}^2}\right] \qquad (13)$$

From formula (13) it can be concluded that the determination of the parametric reliability of ***RTS***, i.e. the processing of information for their condition on generalizing parameter ***Y*** is a complex process requiring large volumes and complex calculations.

3. EXAMPLE

The bearings used in the assembly and operation of railway Wheelsets (RTS), are extremely heavy duty-load variations in the process of operation. In view of this constant monitoring of their parametric reliability is extremely important.

In this publication is offered an example for vibration spectrum diagnosis of the rolling bearing, expressing the symptom of typical defects, the change in the amplitude of a certain frequency [13],[16]. The example is based on the interpretation of the classical vibrational analysis by modern approaches to diagnostics based on artificial intelligence (fuzzy logic and neural networks, etc.) [8],[12], increasing the efficiency of the diagnostic process.

The control includes several characteristic aspects [11]:

- spectral analysis of vibrations;

- measuring vibration intensity (vibration velocity or vibration acceleration) and comparing them with the standard values in the ISO;

- processing a vibration signal to control a specific diagnostic parameter, in this case the amplitude and its attenuation serving to assess the nature and extent of the failure.

For example used modify network-based fuzzy inference (ANFIS) is a combination of two soft-computing methods of ANN and fuzzy logic [11] – fig. 1. Fuzzy logic has the ability to change the qualitative aspects of human knowledge and insights into the process of precise quantitative analysis [8],[9].

Generally, an artificial neural network (ANN) is a system developed for information processing, where it has a similar way with the characteristics of biological neural systems [8],[9].

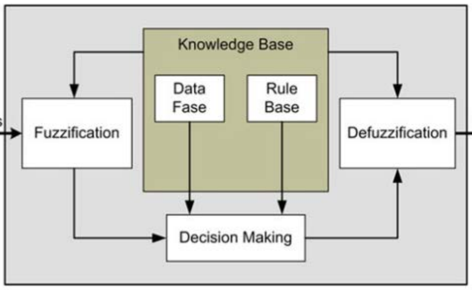

Fig.1 Fuzzy inference system [8],[9]

ANFIS architecture is an adaptive network that uses supervised learning on learning algorithm, which has a function similar to the model of Takagi–Sugeno fuzzy inference system. Figure 2 a, b shows the scheme fuzzy reasoning mechanism for Takagi–Sugeno model and ANFIS architecture. For simplicity, assume that there are two inputs **x** and y, and one output **f**. Two rules were used in the method of "If-Then" for Takagi–Sugeno model [8],[9].

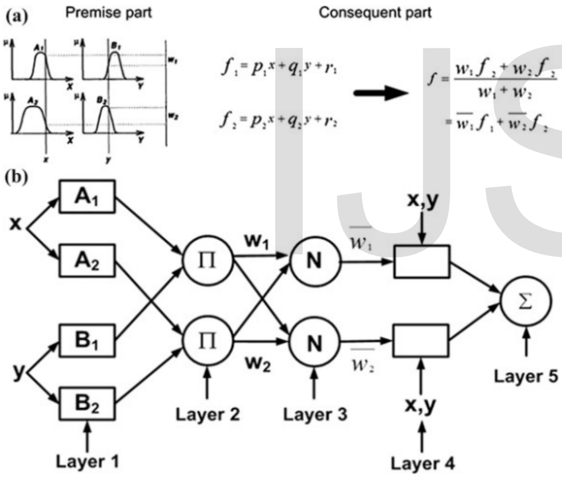

Fig.2 Sugeno fuzzy interference system "If-Then" [8]: fuzzy logic mechanism, b) ANFIS architecture

Referring to Fig. 2, ANFIS architecture has five layers. The first and fourth layers contain an adaptive node, while the other layers contain a fixed node. A brief description of each layer is as follows [8], similarly by measurement [9].

The methodology is represented by vibration meter A4900 Vibrio M [19] – fig.3 with DDS (Digital Diagnostics System) software represents a powerful tool for storage and evaluation of vibration and technical diagnostics data. It allows the user to connect and work with data collected by portable data collectors and on-line monitoring systems. In the full configuration, it includes all the functions necessary for data transfer, analysis and data storage [19].

Laboratory tests were carried out on healthy and defective bearings using a stend with capable of rotating sample bearing from n=100min-1 up to 1000min^{-1}(RPM).

Fig.3 Vibration meter A4900 Vibrio M [19]

Laboratory tests were carried out on healthy and defective bearings using a stend with capable of rotating sample bearing from n=100min^{-1} up to 1000min^{-1}(RPM). In order to minimise the effect of the predominantly low frequency mechanical background rolling and engine noise and maximise the detection of the high frequency signals arising from axle bearing fault suitable resonant AE sensors have been employed [7]. A piezoelectric type R50α resonant AE sensor. The AE signals were amplified using a pre-amplifier and amplifier also from PAC by 43 dB.

Data acquisition was carried out for 5s (2×106 points) during laboratory testing[7].

The bearing samples used in the laboratory rig tests were PFI Inc., model NJP 130x240 TN/VA820 with dimensions of 130×240×80 mm. The results from 500 RPM measurements were considered for both healthy and defective (outer race defect) bearings.

The results of the analysis of the variation of the bearing burst spectrum are shown in Fig. 4 and 5. They are based on data from Table 1.

Table 1 Fundamental frequencies of bearings in the rig test – 79,2 Hz frequency and its harmonics were expected to observe in n=500min^{-1}.

Defect	frequency of rotation , n [min^{-1}]						
types	100	200	300	500	600	800	1000
FTF	1	1,9	2,4	3,1	3,9	4,7	8,2
BPFO	18,5	40,2	49,3	79,2	102,5	137,5	167,2
BPFI	32	50,1	73,6	92,3	121,2	145,6	212,75
BSF	18,2	24,1	37,5	62,1	78	91	127,3

where [7]:
- BPFI = Ball pass frequency inner race (Hz)
- BPFO = Ball pass frequency outer race (Hz)
- FTF = Fundamental train frequency (Hz)
- BSF = Ball spin frequency circular frequency of each rolling element as it spins (Hz).

Fig. 4 shows the AE signal envelope and power spectral analysis on a new bearing, and fig. 5 results for a sample bearing with an artificially defect.

On the fig.4. no indication appears in the envelope analysis approach confirming that there is no defect present.

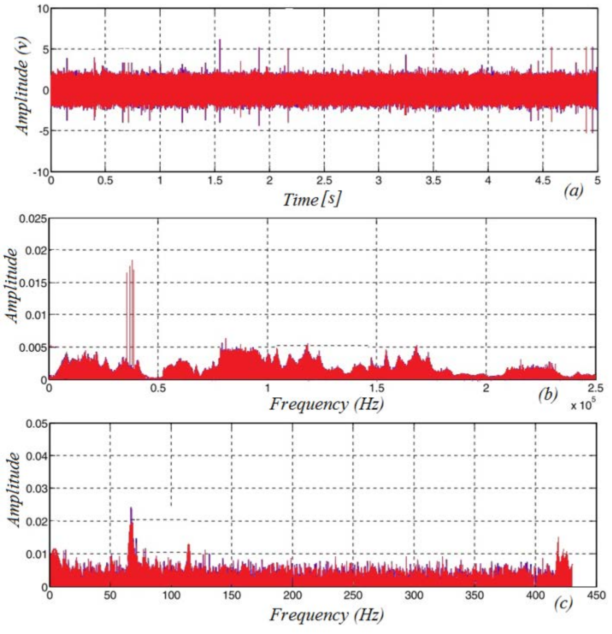

Fig.4 Healthy bearing rig test [7]:
a) Raw data, b) Power spectral analysis, c) Envelope analysis

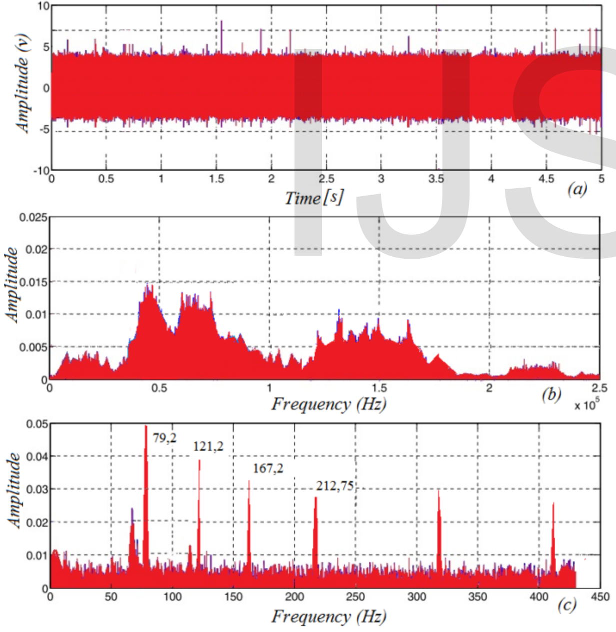

Fig. 5 Defective outer race bearing rig test [7] :
a) Raw data, b) FFT analysis, c) Envelope analysis

On the fig. 5. carried out a peak at the characteristic frequency of 79,2 Hz is evident.

The peak seen at the aforementioned characteristic frequency confirms the presence of the roller fault as it is in agreement with the fundamental frequency of the bearing at the rotating speed used during testing [7].

4. CONCLUSIONS

1. The processing of the information about the state of the risk technical systems is done by calculating the parametric reliability of separate functional blocks, extremely responsible for their functioning.

2. The parametric failure of one functional element of risk technical system does not mean a denial of the same as a whole.

3. The proposed method of processing information allows the determination of the critical functional element, i.e., the one element, whose tolerances most strongly influence the change in the output parameter of the risk system.

REFERENCES

[1] Гиндев, Е. Основи на приложната надеждност. София, Акад. изд. „Марин Дринов”, 2000.
[2] Димитров Д., Д. Данчев. Надеждност на строителни машини и системи. Изд. „Техника", София ,1994, ISBN 954-03-0343-5, с. 1-348.
[3] Петров, Н. Оптимизация и управление на авиационни системи. Дисертация за присъждане на научна степен „ДТН”, ВА „Раковски”, 2001.
[4] Петров Н. Експлоатационна надеждност. Монография и учебник за ВУЗ, Бургаски университет „Проф. д-р Асен Златаров”, 198 с.
[5] Петров, Н. Вероятност, независимост, информационно общество. Монография. ТУ-София, ЕЦНОК – Бургас, 2010, 140 с.
[6] Петров, Н. Изследване на операциите при осигуряване на надеждността на РТС. Монография. Акад. изд. „Марин Дринов”, 2016, 232 с.
[7] Amini A., M. Entezami, M. Papaelias, Onboard detection of railway axle bearing defects using envelope analysis of high frequency acoustic emission signals, Case Studies in Nondestructive Testing and Evaluation 6, 8–16, 2016
[8] Changzheng Ch., M. Changtao, A method for intelligent fault diagnosis of rotating machinery, DSP, vol.14, pp. 203- 217, 2004.
[9] Dimitrov V., Types, geometry and measurement of tool parameters of single flute end mill cutters, International Journal of Scientific & Engineering Research (IJSER), Volume 6, Issue 5, May 2015, pp.1263-1269, ISSN 2229-5518
[10] Dimitrov V., Influence of feed on the quality, for simulate the work of cutting modul from composite tools system for cutting and surface plastic deformation, International Journal of Innovative Science, Engineering & Technology (IJISET), Vol. 1 Issue 8, October 2014, ISSN 2348 – 7968, 2014
[11] Hristova N., V.Pogidaeva, Bearing fault diagnosis, Anniversary Scientific Conference with International Participation, 40 Years Department of Industrial Automation, Sofia, 2011
[12] Jyh-Shing, R. J., ANFIS: Adaptive- Network-Based Fuzzy Inference System, IEEE Transactions on Systems, Man, and Cybernetics, Vol. 23, No.3, 1993.
[13] Klyuev V.,G . Zusman, Nondestructive Testing and Diagnostics, Handbook Edited by Russian Society for Nondestructive Testing and Technical Diagnostics, Moscow, Russia, Metrix Instrument Co., Houston, USA 2004.
[14] Petrov N. Reliability and Risk as a World Cybernetic Problem. Study, RL „Rakovski”, Yambol, 2016, 50 p.
[15] Petrov N., V.Dimitrov, V.Dimitrova, "Reliability of technology systems in industrial manufacturing", AkiNik Publications, New Delhi, India,2018
[16] Rao, J. S., Vibratory Condition Monitoring of Machines, Alpha Science International Ltd., 2000.
[17] Suparta W, K.M. Alhasa, Modeling of Tropospheric Delays Using ANFIS, Springer Briefs in Meteorology, DOI 10.1007/978-3-319-28437-8_2
[18] Suparta W, Alhasa KM (2013) A comparison of ANFIS and MLP models for the prediction of precipitable water vapor. 2013 IEEE international conference on space science and communication (IconSpace), pp 243–248
[19] https://adash.com/software-vibration-diagnostics/digital-diagnostics-

system.