DEFINING THE RELIABILITY LEVEL OF THE CAR BRAKING SYSTEM BASED ON THE MEASURED DIAGNOSIS PARAMETERS

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Rezumat. Evaluarea fiabilității funcționale se realizează, în mod clasic, prin studii statistice dezvoltate asupra unor eşantioane de dispozitive a căror stare tehnică este apreciată în sistem binar: stare de bună funcționare, respectiv defect. Lucrarea propune aprecierea nivelului de fiabilitate al dispozitivelor pe baza coeficienților de evaluare k_{ij}^{β} şi de importanță k_j^{α} raportați la parametrii măsurați prin diagnosticare. Se calculează coeficienții de stare tehnică pentru fiecare dispozitiv Kst_i şi pentru întreg eşantionul Kst_{N0} care servesc la calculul funcției fiabilității funcționale. Metoda prezintă avantajul posibilității evaluării graduale a nivelului de fiabilitate, atunci când dispozitivele testate se află în bună stare de funcționare, dar înregistrează niveluri diferite de uzare.

Cuvinte cheie: fiabilitate funcțională, parametri de diagnosticare, coeficient de evaluare, coeficient de importanță, coeficient de stare tehnică, system de frânare.

Abstract. The evaluation of the functional reliability is classically based on statistical studies developed on samples of devices of which technical state is evaluated in a binary system: trouble-free or fault. The paper proposes to assess the level of reliability of the devices taking into account the evaluation coefficient k_{ij}^{β} and importance coefficient k_j^{α}, related to the parameters measured by diagnosis. One calculates the coefficient of the technical state of each device Kts_i and for the entire sample Kts_{N0} that helps determining the reliability function. The method has the advantage of a gradual evaluation of the reliability level when the tested devices are in trouble-free state, but with different levels of wear recorded.

Keywords: functional reliability, diagnosis parameters (DP), coefficients for the DP evaluation, coefficients of DP importance, technical state coefficients, braking system.

1. INTRODUCTION

The evaluation of the functional reliability of complex devices such as the car braking system relies on the registration of faults during a statistical experiment. In this case, at a given moment, the value of the function of reliability is calculated, usually, as ratio between the number of devices which did not present any faults till this moment – $N(t)$ and the number of devices that initially formed the sample – N_0:

$$R(t) = \frac{N(t)}{N_0} \tag{1}$$

The existence of faults that affect the automobile systems is emphasized by diagnosis. This one consists in measuring the so-called “diagnosis parameters” (DP) which are physical-chemical parameters that can be measured without dismantling the tested devices and which values strictly depends on the technical condition of these devices.

In the case of complex devices, because of their structural constructive and functional complexity, the use of several *DP* is needed. The values of *DP* may be situated in relative large domains for which one can be defined:

- P_{id} – ideal values – those that reflect the perfect technical condition of the tested device;
- $P_{adm.}$ – admissible values that define a domain corresponding to a trouble-free operation of the tested device;
- $P_{lim.}$ – limit values corresponding to the frontier beyond which the tested device is declared in a fault state;
- $P_{unacc.}$ – inacceptable values that exceed the limit value and that point out the fault state of the tested device.

Figure 1 represents a possible relative position of the above-mentioned *DP* values.

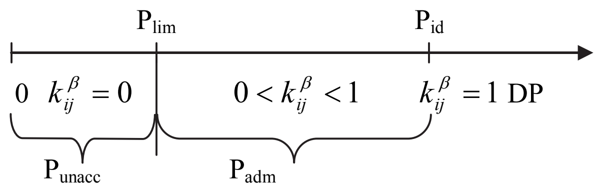

Fig. 1. Characteristic values of DP.

2. USING DIAGNOSIS FOR DEFINING THE RELIABILITY LEVEL OF TECHNICAL SYSTEMS

The positioning of a *DP* inside the P_{adm} domain, though it means a normal operation of the tested device, emphasizes different situations, as it is closer to the P_{lim} or P_{id} values. In the first case, the life resource is lower than in the second one, assigning measures of precaution during operation and planning future technical corrective actions. That is why, when studying reliability of complex devices by using diagnosis, the classical defining of only two technical conditions (trouble-free, respectively fault) is not sufficient.

For a more accurate defining of the reliability level of the devices in a sample one can use the coefficients for the *DP* evaluation, k_{ij}^{β} , which values are smaller as the value of DP is closer to the limit value. The indexes used in the above notation represent:

i – the device identification within the studied sample;

j – the identification of the *DP* used in defining the technical state of the tested devices.

The evaluation coefficients can reach values within the domain [0, 1] (Fig. 1):

- $k_{ij}^{\beta}=1$ when the measured value of a DP_j is inside the domain of the perfect values;
- $k_{ij}^{\beta}=0$ when the measured value of a DP_j is inside the domain of the unaccepted values.

In the domain of the DP acceptable values one can be established n_j sub-domains to which different values of k_{ij}^{β} correspond, providing $0 < k_{ij}^{\beta} < 1$. These values are closer to 1 as the respective sub-domain is closer to P_{id} and closer to 0 as the respective sub-domain is closer to P_{lim} (Fig. 2).

Assigning values to k_{ij}^{β} corresponding to the n_j sub-domains of admissible *DP* values is made with respect to each DP in part.

The DP used in evaluating the complex devices may track down faults with different degrees of importance, with respect to the gravity of the consequences these faults involve. Thus, in the case of motor cars, some *DP* emphasize the presence of the so-called “malign” faults, which may lead to accidents with severe consequences or get out of work the tested devices. Other *DP* point out another type of faults, so-called “benign” of which consequences are less dangerous: rising fuel consumption, affecting the on-board comfort, aggravating the chemical and phonic pollution etc.

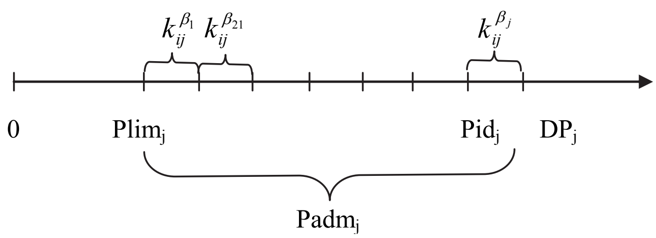

Fig. 2. Sub-domains of evaluation.

To make a difference between the weightone DP contributes in defining the reliability of complex devices, a coefficient of *DP* importance, k_j^{α}, is assigned to each DP. It reaches values in the domain $k_j^{\alpha} \in (0,1]$, values that are as greater as the importance of DP is higher. The value "0" is expelled because it would designate the case of a DP of null importance, the use of which would be, therefore, unjustified.

As in the case of k_{ij}^{β}, assigning values to k_j^{α}, corresponding to the *jDP*, is made with respect to the characteristics of each *DP* in part, but also to the characteristics of the tested device.

Using coefficients k_{ij}^{β} and k_j^{α} one defines the coefficient of the technical state of device "*i*":

$$Kts_i = \prod_{j=1}^{n_{DP}} \left(k_{ij}^{\beta}\right)^{k_j^{\alpha}} \tag{2}$$

Where n_{DP} represents the number of the *DP* used for technical state evaluation of the respective device.

It is noticed that if any of the k_{ij}^{β} is equal to 0 (*DP* reaches a value in the unacceptable domain), the respective device will be declared as defective, no matter the DP_j importance.

A perfect technical state of a device will be declared only if the values of all the used *DP* are in the domain of the perfect values: $k_{ij}^{\beta} = 1, \forall j \in [1, n_{DP}]$. For the entire sample built up of N_0 devices, one defines the coefficient of the sample technical state:

$$Kts_{N_0} = \sum_{i=1}^{N_0} \prod_{j=1}^{n_{DP}} \left(k_{ij}^{\beta}\right)^{k_{ij}^{\alpha}} \tag{3}$$

One notices that two limit situations can occur:

- $Kts_{No} = 0$, when all the devices of the sample has at least one fault each;
- $Kts_{No} = N_0$, when all the devices of the sample are in a perfect technical state.

Using the coefficients of the technical state for the complex devices and samples made up of these devices allows a more shaded and closer to reality evaluation of the technical state then the classical reliability investigation which uses only two categories: trouble-free or fault.

The values of the two coefficients of the technical state change along the period of devices utilization, as the technical state of the respective devices is modifying.

One defines the weighted reliability function which value can be calculated with reference to Kts_{No}:

$$\hat{R}(t) = \frac{1}{N_0} Kts_{N_0} = \frac{1}{N_0} \sum_{i=1}^{N_0} \prod_{j=1}^{n_{DP}} \left(k_{ij}^{\beta}\right)^{k_j^{\alpha}} \tag{4}$$

It is obvious that the values of $\hat{R}(t)$ computed using the relation (4) are smaller or at the most equal to the values of R(t) computed using relation (1). This is natural and justified by the fact that, at the moment t, the trouble-free devices accumulate a certain degradation of their technical state. Using relation (4) emphasizes precisely this aspect that the diagnosis can quantify.

3. *CASE STUDY*: DETERMINING THE LEVEL OF RELIABILITY (FUNCTIONAL RELIABILITY) EVALUATION OF A MOTORCAR BRAKING SYSTEM

The evaluation of the functional reliability of motorcar braking system using diagnosis relies on the measurement, on a special stand, of the braking forces developed at each of its wheels. With the four measured values, $(F_{br})_i$, corresponding to the four wheels one can calculate the subsequent DP:

1. Efficiency:

$$E = \frac{\sum_{i=1}^{4}(F_{fr})_{max\,i}}{G} \cdot 100\,[\%] \quad (5)$$

where: $(F_{br})_{\max i}$ is the maximum braking force at the wheel "i"; G – the motorcar weight;

2. Unbalance of the braking forces for each of the motor car two axles:

$$D = \frac{\left|F_{frstg} - F_{frdr}\right|}{Max(F_{frstg} - F_{frdr})} \cdot 100\,[\%] \quad (6)$$

Using the experimentally obtained data and the relations (5) and (6), one can consider the subsequent DP:

- Braking efficiency for vehicle (E);
- Braking unbalance to front vehicle axle (D_{fa}) ;
- Braking unbalance to rear vehicle axle (D_{ra}) ;
- Braking unbalance to parking brake (D_p);
- Braking efficiency to parking brake (E_p).

The first three *DP* (E, D_{fa} and D_{ra}) have a superior importance as they can track down malign faults while the two others (E_p and D_p) have a lower importance, as the faults tracked down by them are benign. Therefore, for the coefficients of *DP* importance, k_j^{α}, will be assigned the values presented in Table 1.

Table 1

The assigned values for the importance coefficients

DP_j	$DP_1 = E$	$DP_2 = D_{fa}$	$DP_3 = D_{ra}$	$DP_4 = E_p$	$DP_5 = D_p$
k_j^{α}	1	0,9	0,9	0,7	0,5

With the purpose of assigning values to the coefficients for the *DP* evaluation, k_{ij}^{β}, the ideal and limit values for each *DP* were established (Table 2).

A possible assignation of values for the evaluation sub-domains and the corresponding evaluation coefficients, k_{ij}^{β}, for the considered five DP, is presented in Table 3.

Table 2

Ideal values and limit values for DP

Nr. crt.	DP_j	P_{id}	P_{lim}
1	$DP_1 = E$	>90%	50%
2	$DP_2 = D_{fa}$	<5%	30%
3	$DP_3 = D_{ra}$	<5%	30%
4	$DP_4 = E_p$	>90%	25%
5	$DP_4 = D_p$	<5%	30%

Table 3

Assignation of values for the evaluation sub-domains and the corresponding evaluation coefficients

E%	k_{i1}^{β}	D_{fa}, D_{ra}	k_{i2}^{β}, k_{i3}^{β}	E_p	k_{i4}^{β}	D_p	k_{i5}^{β}
<50	0	>30	0	<25	0	>30	0
50,1-55	0,25	25,1-30	0,2	25,1-35	0,2	25,1-30	0,2
55,1-60	0,5	20,1-25	0,3	35,1-50	0,4	20,1-25	0,3
60,1-70	0,75	15,1-20	0,5	50,1-65	0,65	15,1-20	0,5
70,1-80	0,85	10,1-15	0,75	65,1-80	0,8	10,1-15	0,75
80,1-90	0,95	5,1-10	0,9	80,1-90	0,95	5,1-10	0,9
90,1-100	1	0-5	1	90,1-100	1	0-5	1

The evaluation sub-domains are unequal because of the necessity of detecting the differences concerning the level of the technical state in zones more sensitive, such as the vicinities of DP_{id} and DP_{lim}.

The experimental data were obtained during the periodical technical inspections of a Dacia Logan fleet. Taking into account the above mentioned aspects and on the basis of the measured values of the braking forces, the coefficients k_{ij}^{β} and Kts_i were assigned for a sample made-up of 60 motorcars (Table 4). It is found that for one of these vehicles $Kts_i = 0$ because of the positioning of one or several *DP* in the unacceptable values domain.

The coefficient of the sample technical state, calculated with relation (3), has the value Kts_{60}=15,379, to which corresponds a value of the weighted reliability function, calculated with relation (4) $\hat{R}(t) = 256$. Using the classic method of reliability function evaluation – relation (1), for which $N(t)$ = 59, it results R(t) = 0,983, that is over 3,8 times higher. The difference between the two results is due to the fact that in the case of the classic method the technical state of the trouble-free devices is considered 100%, even if their design values and working characteristics have a certain degree of modification, while the proposed method emphasizes this aspects. The values of Kts_i on which basis the R(t) was calculated, reaches values between 0,051 and 0,555 for the trouble-free devices, while in the case of the classic method the maximum value of 1 is accepted for all these devices.

Table 4

The values of coefficient of the technical state of device for each motorcar

Nr. vehicle	$Kts._i$	N(t)	Nr. vehicle	$Kts._i$	N(t)
1	0,505	1	31	0,080	1
2	0,169	1	32	0,251	1
3	0,428	1	33	0,247	1
4	0,213	1	34	0,262	1
5	0,291	1	35	0,290	1
6	0,191	1	36	0,389	1
7	0,202	1	37	0,209	1
8	0,260	1	38	0,406	1
9	0,265	1	39	0,265	1
10	0,121	1	40	0,137	1
11	0,097	1	41	0,041	1
12	0,051	1	42	0,437	1
13	0,479	1	43	0,336	1
14	0,495	1	44	0,319	1
15	0,337	1	45	0,277	1
16	0,060	1	46	0,331	1
17	0,480	1	47	0,247	1
18	0,220	1	48	0,058	1
19	0,555	1	49	0,099	1
20	0,370	1	50	0,198	1
21	0,101	1	51	0,146	1
22	0,058	1	52	0,125	1
23	0,000	0	53	0,080	1
24	0,319	1	54	0,081	1
25	0,370	1	55	0,150	1
26	0,290	1	56	0,203	1
27	0,526	1	57	0,160	1
28	0,480	1	58	0,389	1
29	0,271	1	59	0,119	1
30	0,526	1	60	0,314	1

4. CONCLUSIONS

In the case of complex systems, the evaluation of functional reliability by the classic method has the disadvantage of not taking into account the extent in which the systems working characteristics are diminished. System diagnosis offers, through the measured values of *DP*, information that eliminates this disadvantage.

The use of the coefficients for the *DP* evaluation, k_{ij}^{β} , together with the coefficients of *DP* importance, k_j^{α}, enables the technical state estimation of each device by the coefficients, Kts_i.

The real technical state of the entire sample is measured by the coefficient Kts_{No} used, at its term, to calculate the value of the weighted reliability function, $\hat{R}(t)$. The last one succeeds in emphasizing not only the proportion of trouble-free devices in the sample, but also their technical state, which the function R(t) classically calculated does not.

The paper succeeds in creating a more complex and complete connection between the diagnosis and the reliability studies, thus offering an image closer to the reality of the reliability of the studied devices.

References

[1] Andreescu, Cr., Fileru, I., Toma, M., *Evaluating the functional reliability of a complex device by diagnosis – 20042133* – CONAT 2004, Brașov.
[2] Boicu, I., Alexandrescu, C.,M., Andreescu, Cr. *Model for Functional Reliability Analysis of the Braking System of Dacia 1300 Car*, Revista inginerilor de automobile, nr. 4-5/1992, pp 20-22, and 1/1993 pp 33-34.
[3] Andreescu, Cr. et all. *Aplicații numerice la studiul fiabilității automobilelor*, Editura Magie, Bucureşti, 1996.
[4] Mihoc, Gh., Muja, A., Diatcu, E., *Bazele matematice ale teoriei fiabilității*, Editura Dacia, Cluj-Npoca, 1976.
[5] Târcolea, C., Filipoiu, A., Bontaş, S. *Tehnici actuale în teoria fiabilității*, Editura Ştiințifică şi Enciclopedică, Bucureşti, 1989.
[6] Burlacu, G., *Ingineria fiabilității şi mentenabilității instalațiilor industriale*, Editura Paideia, Bucureşti 2010.
[7] Dzițac, Simona, Felea, I., *Fiabilitatea echipamentelor şi sistemelor energetice. Aplicații*, Editura Universității din Oradea, Oradea 2006.
[8] Boicu, I., Bădescu, I. *Fiabilitatea funcţională în electronică. Teorie. Aplicații în transporturi*, Editura Politehnica Press, Bucureşti 2009.
[9] Petrescu, E., Vodă, V., Gh. *Managementul fiabilității*, Editura ASAB, Bucureşti 2008.
[10] Țîțu, M., *Fiabilitate şi mentenanță*, Editura AGIR, Bucureşti 2008.
[11] http://www.rarom.ro/RO/article--Reglementari, RNTR 1.