ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

UDC 629.33.017:656.13

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ASSESSMENT OF THE MOTOR VEHICLE RELIABILITY KEY INDICATORS

Introduction. The problem of guaranteeing the designed life resource for units, assemblies, parts, including metal structures such as frames, transmission cases, which mass can range from 30 to 60 % of the vehicle weight [1] has a great economic importance.

The mean lifespan, i.e. resource R_{mean} is a mid-longevity characteristic of products (taking into account the limit, including extreme values) used for:

— evaluation of the required spare parts (pieces, components, assemblies) production volume;
— assigning the required number of products' repair for a given total resource;
— planning the vehicle fleet decrease and increase;
— calculations of the motor vehicles operation economy;
— assessment of the technical and economic efficiency of works to improve the products' longevity.

The gamma-percentile life R_γ represents a characteristic of products' minimum longevity used for the selected non-destruction probability level to:

— Justify the selection of products' guaranteed life and warranty period, given early failures;
— Determine the need for replacement parts, depending on the products' operating time;
— Effect the economic calculations.

Literature review. Increased requirements to the reliability of motor vehicle components and assemblies do impose the need to obtain numeric values of all products' average life in a whole as well as the ciphers of longevity for the products never reaching the mid-resource point, especially those causing early failures.

The minimum required data to be considered is the selected products portion resource (γ, %), i.e. operational time (OT) expressed in kilometers, at which the probability that the product will not reach the limit state, with some degree of certainty is γ, %. Namely this this information is represented with the gamma-percentile life as a non-destruction probability characteristics.

Some data on early destruction is also embodied in R_{mean} in conjunction with the standard deviation. The R_γ, unlike to R_{mean} is found during not finished tests when the test pieces assemblies or units are not brought to destruction.

An effective direction here embraces rapid-tests of vehicles, components, assemblies, parts, including the bench tests. This widespread type of testing, as one of the progressive methods of lifespan accelerated assessment, requires defining key statistical longevity indicators: the mean resource R_{mean} (mean time to limit state) and gamma-percentile resource R_γ, (product minimum longevity characteristic) [2].

The Aim of the Research refers to use gamma-percentile life R_γ (Fig. 1) as the basis for selecting the products' guaranteed TBF. In mechanical engineering the products' longevity assessment in mainly based on the use of mean resource R_{mean}, while the practical use of R_γ is necessary to determine the relationship between R_γ and R_{mean}. When incomplete tests, these ratios information as to the natural products is needed for R_γ and R_{mean} preliminary evaluation.

Main Body. As a criterion for bearing systems (ladder type frame) failure we selected the emergence and development of fatigue cracks [2].

DOI 10.15276/opu.1.45.2015.08

Coefficient characterizing the relative operating time when crack occurred:

$$C = N_2 / N_{\lim} ,$$

where N_2 — OT from the crack emergence point to its extreme length $l_{\lim}$ reaching;

$N_{\lim}$ — OT at full length of the crack.

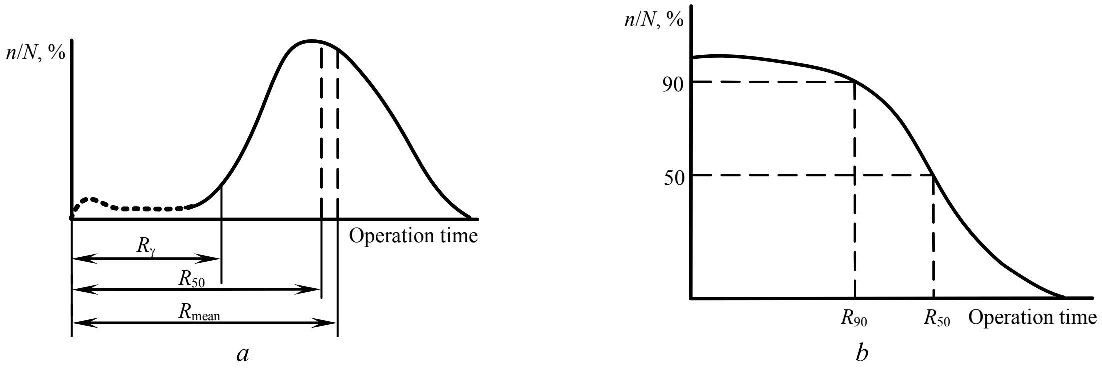

Fig. 1. Curves of resource distribution (s) and products' wastage (b):R_{50} — 50 % (median) resource; n — number of failed products;N — number of tested or operated products

The main statistical indicators of machine parts' longevity include both the gamma-percentile resource R_γ and the mean resource R_{mean}. For the mean resource the transition coefficient K_t is determined by the ratio of mean resource (found at rapid tests) to the mean operational resource. The $K_{t\,\gamma}$ value is found similarly, while instead of R_{mean} used is the R_γ, respectively

$$K_t = \frac{R_{mean\ rap}}{R_{mean\ op}} ,$$

where $R_{mean\ rap}$, $R_{mean\ op}$ — mean resource for rapid-test and practical operation respectively;

$$K_{t\gamma} = \frac{R_{\gamma rap}}{R_{\gamma op}} ,$$

where $R_{\gamma\,rap}$, $R_{\gamma\,op}$ — are respectively the gamma-percentile rapid-test and operational resource.

At fracture mechanics as a parameter characterizing the fracture growth, used is the stress intensity factor at the crack apex:

$$K = \sigma\sqrt{\pi l} ,$$

where σ — normal nominal tensions;

l — half the fracture length.

For the case of crack growth linear dependence the structure life span is:

$$R = \frac{l_{\lim} - \overline{a}}{l_j} ,$$

where $\overline{a}$ — average coefficients' value for equations of $l_j = a + bN$ type;

$l_{\lim}$ — increment of crack length determined using the linear summation principle for damage and crack growth rate depending on the level of stress.

According to the accelerated tests' results the exploitation resource estimate will be

$$R_{op} = \frac{N_1}{(1-C)K_t} ,$$

where K_t — factor of transition from the rapid-tests longevity parameters to those when operational use;

N_1 — OT until the fracturing, determined experimentally based on the hypothesis of linear damage summation.

The R_γ value is one of the most convenient quantitative characteristics of the early destruction of the tested unit, and facilitates the indicators' norming and standardization, as well as the comparison of different models and product different batches' test results. At the same time, changing the γ value, it is possible to use R_γ for various calculations, tests for assessing the vehicle's parts, assemblies and units longevity.

The choice of γ depends on the characteristics of the tested assembly unit and a number of technical and economic reasons the most important thereof are the consequences of failure.

As the vehicle basic units' longevity standard adopted is the 80 % lifespan. The use of gamma-percentile life as the basis for selecting some assembly' warranty TBF in mechanical engineering confirms this indicator importance and its application feasibility. As the experience of engineering products longevity assessment is based primarily on the use of R_{mean}, then introducing into the practice the R_γ index it is necessary to determine the relationship between R_γ and R_{mean} for the given model.

In addition, when uncompleted tests the information on these ratios for similar products is useful for preliminary R_{mean} assessment by R_γ.

When the γ is (80...99,9 %), the ratio between the gamma-percentile and the mean or median resource varies widely depending on the type of resource distribution. its parameters and the coefficient of the selected γ variation.

It is necessary to distinguish between assemblies and components replaceable after the first failure, and those that are recovered in the operation. The limit state after recovery depends on the amount, number and quality of repairs; in this regard, the number of factors affecting the resources of units, assemblies and the relationship between the R_γ and R_{mean} increases (See Table).

Some automobile and tractor parts longevity coefficients at γ=95 and 99,5%.

Components	R_{95}/R_{50}	$R_{95,5}/R_{50}$
Wheels	0,66	0,45
Forewheels journal axles	0,33	0,13
Spring plates	0,60	0,38
Ventilators	0,57	0,35
Transmission box gears	0,49	0,26
Crank-shafts of two engine models	0,40; 0,46	0,22; 0,18
Engines' exhaust valves	0,20	0,05
Hypoid gears σ = 6540 and 7380 kg/cm^2	0,33; 0,37	0,13; 0,16
Conic gears σ = 5270 and 6540 kg/cm^2	0,32; 0,27	0,11; 0,08
Ball-bearings σ = 21850, 23960, 28280, 31330, 33390 kg/cm^2 respectively	0,34; 0,24; 0,34; 0,26; 0,30	0,14; 0,07; 0,13; 0,08; 0,11
Cars' semi-axles σ = 1900 and 2670 kg/cm^2	0,35; 0,46	0,14; 0,24
Agricultural tractor semi-axles σ = 2110 and 3790 kg/cm^2	0,57; 0,52	0,34; 0,29
Roller chains loaded with 300 and 360 kg	0,35; 0,32	0,14; 0,12

As an example, products replaceable after the first failure include antifriction bearings. Analyzing the data of automotive wheel bearings (six different bearings' groups) established is that R_{90}/R_{mean} varies within range of 0,15...0,31.

The various parts' test bench carrying out proposed is to use the "longevity factor", characterizing the ratio of parts' gamma-percentile life at a chosen γ value to their median lifespan. This ratio small value corresponds to significant resources dispersion, and a large value on the contrary, indicates a relatively small dispersal.

The relationship between the recoverable components' and assemblies' gamma-percentile and mean resource is assessed and considered at trucks example.

With trucks' units and accessories 90%-lifespan to the first overhaul, the gamma-percentile resource makes a fraction of the average: 0,50...0,70 for engines; 0,50...0,60 for transmissions and foreaxles; 0,06...0,65 for rear-axles; 0,45 for brake systems; 0,56...0,60 for suspension units. All these units' resource distribution follows the normal law; in this regard, the R_{50} index value is close to the units' mean resource, and the R_{90} value makes a fraction of the mean resource value: 0,78...0,85 for transmissions, steering and front suspension; 0,65...0,75 for engines and rear axles (Fig. 2: the ratio is represented as a percentage).

The ratio of gamma-percentile and mean-resource for the truck models' various units and accessories does differ slightly, and before the first overhaul is: 0,89...0,95 for R_{50}/R_{mean}; 0,45...0,52 for R_{90}/R_{mean}; 0,26...0,40 for R_{95}/R_{mean}. Between overhauls the ratio is following: 0,71...0,78 for R_{50}/R_{mean}; 0,13...0,30 for R_{90}/R_{mean}; 0,06...0,14 for R_{95}/R_{mean}.

Increased incidence of early failure of the units exposed to a non-specific overhaul, at a significant increase in their resource dispersion (variation coefficient 2...3 times increased) leads to a drastic change in relations R_γ/R_{mean}.

These data give an idea about the R_γ/R_{mean} relationship in some special cases, and highlight the need for systematic collection and compilation of relevant experimental data.

In all cases the resources dispersion increasing involves R_γ/R_{mean}. reduction, since a large dispersion correlates to early failures' increased number, thus leading to a decrease in the of gamma- percentile resource. The combination of low gamma-percentile life with high mean resource indicates a large number of early failure cases.

When the variation coefficient value is not more than 0,5 the searched ratio is

$$\frac{R_\gamma}{R_{mean}} = 1...0,42\upsilon$$

at that the error never exceeds 4 %.

The simplified method for gamma-percentile life determination relates to the experimental identification of resource that value γ, %, of all products have reached; for example, found is that 40 units' resource is determined as γ=90 %. In this case, the resources are positioned in ascending order and the 90% lifespan is admitted as equal to OT at which the fourth unit is destroyed (four items make 10 % of the experimental batch).

This method allows estimating approximately the 50 %-lifespan of the tested units when destroying the first 10 % of the total quantity. In this case, more accurate estimates are found when assessing the gamma-percentile resource by flattened distribution curve or the curve of the tested units decrease (Fig. 1).

We plot on the graph a horizontal line from a point on the ordinate axis corresponding to the selected γ value up to intersection with the curve to determine the gamma percentile resource value.

When equally reliable estimates the gamma-percent life requires a larger number of tested units than the mean lifespan does, that causes the appropriateness of close consideration as to estimation techniques and accuracy R_γ.

Implementation into engineering practice of units' and accessories' longevity assessment in terms of R_γ and R_{mean} allows formulating the respective field's mechanical engineering problem as follows.

It is necessary to increase the components' and assemblies' lifespan, enlarging their longevity, and gamma-percentile life, thus increasing the OT before early failures and decreasing the failures number, to reduce the resource dispersion and bring together the resources of bearing parts, assemblies, units and vehicles.

To improve resource calculation methods required is, departing from the causal failures' preconditions analysis, to develop a logic model of parts', components' and assemblies' failures. Forming such a structural cause-effect element/detail failure model is rather used for cases of sudden and gradual destruction following the exponential and normal laws, respectively.

The failure-free operation probability $P(t)$ under the condition the above failures are independent (primary) [3]

$$P(t) = e^{-\lambda t}\left\{1-(\sqrt{2\pi}\tau)^{-1}\int_0^t \exp\left[\frac{-(t-m)^2}{2\tau^2}\right]dt\right\},$$

where λ — exponential law parameter;

m, τ — normal law parameters.

Results. The results of analytical study as to the operated parts' failures observed do evidence that those components' failure models simulation should be based onto the three destructive processes' dependency types:

— $x_i(t)$ processes, taking place in the various sections of items (or at one section) and giving rise to independent failures;

— $y_i(t)$ processes, never leading to failure when the limit state but causing other processes $x_i(t)$, that lead to failures;

— $x_i(t)$ processes, causing the failures and developed depending on whether other destructive processes $y_i(t)$, — not involving a failure, — did reach a certain state which is some failure's precondition.

Example. In the presence of the hardened thickness layer C_{hard} its wearing variances are described by the function $S(t)=S_1(t)$, where S_1 is the wear rate random variable, following the normal distribution law when $\overline{S}_1$ and σ_{S2} parameters. The hardened layer worn out, the wearing process does also follow the $S(t)=S_1(t)$ dependency, at an average wear rate $\overline{S}_2 = k\overline{S}_{S1}$, and $\sigma_{S2}=\sigma_{S1}$. The wear limit value at which some piece's failure occurs is C_{LIM}.

To calculate the densities' distribution parameters $f_1(t)$ and $f_2(t)$, i.e. OT before the hardened layer C_{hard} wearing out and the wear limit C_{LIM} reaching we assume that the $f_1(t)$ and $f_2(t)$ distributions are normal and the resource random variables T_1 and T_2 are independent. In this case, the resource distribution density $f(t)$ follows the normal distribution law [3].

Fig. 3 represents the results of $f_1(t)$ and $f_2(t)$ calculation at such initial data: $\overline{S}_1$=1,1 mcm/thou.km; $\overline{S}_2$=1,54 μm/thou.km; σ_{S2}=0,4 kg/cm^2; C_{hard}=200 μm; C_{LIM}=300 μm.

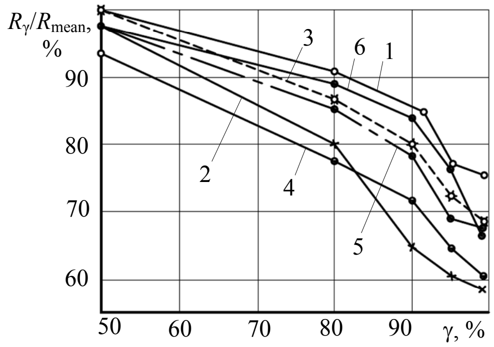

Fig. 2. Correlation between gamma-percentile and mean lifespan of "Volga" car assemblies: 1 — car (224 pcs.); 2 — engine (390pcs.); 3 — transmission (405 pcs.); 4 — rear axle (336pcs.); 5 — steering (475 pcs.); 6 — front suspension (389 pcs.)

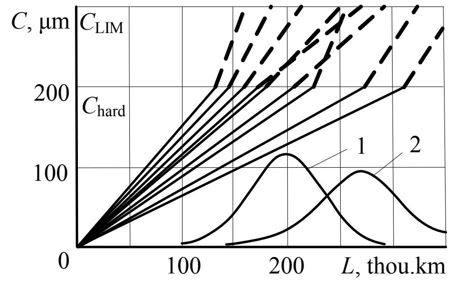

Fig. 3. Structural component lifespan calculation when hardened layer wearing: 1 — OT distribution before hardened layer C_{hard} wearing-out; 2 — OT MTBF distribution

The main stages of the details' resource calculation methodology:

— identifying the parts' sections (elements) subject to the longevity calculation. For parts having analogues, we must depart mainly from the test results, performance observation, and micro-metering during overhaul. For the newly designed pieces the selection basic principle relays on the expert survey results;

— identifying the predominant types of destructive processes (wear, fatigue, etc.) for each section; computational models' selection and assessing the processes' mutual relation;

— identifying the initial data to calculate the density distributions (mostly based on forecasting methods) of the piece's individual sections;

— forming the logical model of a piece's resource and evaluating the item's resource characteristics.

Conclusions. The research studies have shown the need to:

— Increase in the units' and assemblies' mean resource by improving their longevity;

— Increase in gamma-percentile life by increasing the operating time before early failures and reducing their number;

— Reduce the resources dispersion and to converge the supporting parts, assemblies, equipment, vehicles useful life resources.

Of practical interest is to develop methods predicting the components' resource without logical model building, but taking into account the accumulated data on the previously manufactured analogic vehicles' operation (test series).

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АНОТАЦІЯ / АННОТАЦИЯ / ABSTRACT

В.Г. Максимов, О.Д. Ніцевич, О.А. Ткачьов. **Оцінка основних показників надійності автомобілів.** Розглянуто проблему оцінки довговічності і забезпечення заданого ресурсу деталей, вузлів, агрегатів автомобіля. До основних статистичних показників довговічності деталей машин відносяться гамма-процентний і середній ресурси. Визначено роль гамма-процентного ресурсу як основи для вибору гарантійного напрацювання виробів на відмову. Ефективним напрямом в оцінці середнього і гамма-процентного ресурсу розглянуто проведення прискорених випробувань. При стендових випробуваннях різних деталей запропоновано використання "коефіцієнта довговічності", що характеризує відношення гамма-процентного ресурсу виробу до його медіанного ресурсу. Оцінку співвідношень між гамма-процентним і середнім ресурсами вузлів і агрегатів наведено на прикладі вантажних автомобілів. Запропоновано алгоритм переходу за результатами прискорених випробувань до середнього ресурсу в експлуатації. Основні етапи методики розрахунку ресурсу містять приклади визначення середнього ресурсу для деталей трансмісії.

Ключові слова: надійність, гамма-процентний ресурс, довговічність виробу.

В.Г. Максимов, А.Д. Ницевич, А.А. Ткачёв. **Оценка основных показателей надежности автомобилей.** Рассмотрена проблема оценки долговечности и обеспечения заданного ресурса деталей, узлов, агрегатов автомобиля. К числу основных статистических показателей долговечности деталей машин относятся гамма-процентный и средний ресурсы. Определена роль гамма-процентного ресурса как основы для выбора гарантийной наработки изделий на отказ. Эффективным направлением в оценке среднего и гамма-процентного ресурса рассмотрено проведение ускоренных испытаний. При стендовых испытаниях различных деталей предложено использование "коэффициента долговечности", характеризующего отношение гамма-процентного ресурса изделия к его медианному ресурсу. Оценка соотношений между гамма-процентным и средним ресурсом узлов и агрегатов приведена на примере грузовых автомобилей. Предложен алгоритм перехода по результатам ускоренных испытаний к среднему ресурсу в эксплуатации. Основные этапы методики расчета ресурса содержат примеры определения среднего ресурса для деталей трансмиссии.

Ключевые слова: надежность, гамма-процентный ресурс, долговечность изделия.

V.G. Maksimov, A.D. Nitsevych, A.A. Tkachev. **Assessment of the motor vehicle reliability key indicators.** Considered is a problem of longevity estimation and guaranteeing the preplanned lifespan of the automobile's parts, assemblies and structural units. The main statistical indicators of machine parts durability include such parameters as their gamma-percentile life and the mean lifespan index. Estimated is the role of gamma-percentile life as the basis for the wares' guaranteed MTBF selecting. Rapid-tests represent an effective direction in the estimation of the mean and gamma-percentile wares' life. While various parts' bench tests suggested is the use of "longevity factor" that characterizes the ratio of a piece's gamma-percentile life to its median resource. Such assessment of the relationship between components' and assemblies' gamma-percentile life and their mean lifespan is shown on the example of trucks. The algorithm offered uses the rapid tests' results for transition to the mean lifespan in practical exploitation. Main stages of the resource calculation methodology are described with examples of determining the mean lifespan for transmission parts.

Keywords: reliability, gamma-percentile resource, product longevity.

Received August 14, 2014