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EVALUATION OF THE RANDOM ERROR OF THE METHODS OF ACCELERATED DETERMINATION OF THE ENDURANCE LIMIT

A. Konoplev
Doctor of technical sciences, Professor, head of the department «Machine Science»
O. Kibakov
Candidate of technical sciences, Professor, head of the department «Hoisting and transport machines and engineering of port technological equipment»
O. Kononova
Candidate of technical sciences,
associate professor of the department «Machine Science»
L. Dukre
Senior lecturer, department of the department «Machine Science»

Odessa National Maritime University

V. Vovk
Senior lecturer, department of dynamics, machines strength and material resistance

National University «Odessa Polytechnic»

***Abstract**. The article considers a task related to the general approach to determining the random error in determining the endurance limit by accelerated methods.*

Based on the conducted analysis, it was shown that in the calculation of the accuracy of accelerated methods for determining the endurance limit, it is necessary to separately determine the systematic and random components of the total error.

It was also proposed to determine the random error of accelerated methods for determining the endurance limit using a general statistical approach. At the same time, it is proposed to find the accuracy of the assessment of the endurance limit itself, depending on the specific test scheme of one or another accelerated method.

***Keywords**: accelerated tests, systematic, random and total errors of endurance limit estimation.*

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ОЦІНКА ВИПАДКОВОЇ ПОХИБКИ МЕТОДІВ ПРИСКОРЕНОГО ВИЗНАЧЕННЯ ГРАНИЦІ ВИТРИВАЛОСТІ

А.В. Коноплькoв
д.т.н., професор, завідувач кафедри «Машинознавство»
О.Г. Кібаков
к.т.н., професор, завідувач кафедри «Підйомно-транспортні машини
та інжиніринг портового технологічного обладнання»
О.М. Кононова
к.т.н., доцент кафедри «Машинознавство»
Л.Г. Дюкре
старший викладач кафедри «Машинознавство»

Одеський національний морський університет

В.В. Вовк
старший викладач кафедри динаміки, міцності машин та опору матеріалів

Національний університет «Одеська політехніка»

***Анотація**. У статті розглянуто завдання, пов'язане із загальним підходом до визначення випадкової похибки визначення границі витривалості прискореними методами.*

На основі проведеного аналізу було показано, що при розрахунковій оцінці точності прискорених методів визначення границі витривалості необхідно окремо визначати систематичну та випадкову складову загальної похибки.

Також було запропоновано випадкову похибку прискорених методів визначення границі витривалості визначати за допомогою загального статистичного підходу. У цьому точність оцінки безпосередньо границі витривалості запропоновано знаходити залежно від конкретної схеми випробувань тієї чи іншої прискореного методу.

***Ключові слова**: прискорені випробування, систематична, випадкова та загальна похибка оцінки границі витривалості.*

Introduction. In the experimental assessment of the accuracy of methods for accelerated determination of the endurance limit, their errors are evaluated by comparing the results of accelerated and long-term tests. In the case of its calculated determination, the systematic and random components of the total error are considered separately [1]. It should be borne in mind that the random error in assessing the endurance limit by accelerated methods will depend on the number of tested objects (samples, models, parts, structural elements), their geometric and strength characteristics, conditions and modes of the experiment, and so on. At the same time, their systematic error will be associated with the initial assumptions (using hypotheses, assumptions, and so on). For example, the Lokati method [2] uses the linear hypothesis of fatigue damage summation and conditionals fatigue curves of various failure probabilities. As is known, the sum of accumulated fatigue damage can significantly differ from unity depending on a number of factors, for example, on the test modes [3]. As for the conditionals of fatigue curves, they are built on the basis of data obtained from testing other (analogous) objects. These data in each case depend mainly on the number of objects tested, and therefore may differ significantly.

The above example shows that the approach to assessing the accuracy of accelerated methods, based on a separate assessment of the systematic and random errors, is relevant and requires further development.

This article considers a task related to the general approach to determining the random error of accelerated methods for determining the endurance limit. This error is due to a number of factors, the main among which are:

- inaccuracy of determining the rated voltages;
- inaccuracy of determining the number of loading cycles to failure or operating time at a separate stage (under stepped loading);
- loading frequency fluctuations;
- temperature;
- fluctuations in the composition of the environment;
- the presence of oscillatory processes or inertial influences;
- instability of the geometric characteristics of test objects;
- non-compliance with the technology of manufacturing objects of test ;
- instability of the chemical composition and structure of the material of the tested objects;
- the presence on the surface of the test objects of various kinds of pollution, oxides, and so on.

The random error of accelerated methods, as noted above, depends on the number of tested objects and their scattering characteristics, and therefore can be determined using a statistical approach.

The purpose of the article is to develop and substantiate a general approach to assessing the random error of methods for the accelerated determination of the endurance limit.

Presentation of the main material. When determining the sample volume of objects to ensure the required accuracy, one should proceed from the purpose of the experiment. So, if its purpose is to estimate the mathematical expectation, then the sample size n can be determined by the formula [4]

$$n = \frac{V_a^2}{\Delta_a^2} z_{1-q/2}^2 \tag{1}$$

or

$$n = \frac{z_{1-q/2}^2}{\delta_a^2}, \tag{2}$$

where V_a – the coefficient of variation of the determined characteristic of fatigue resistance;

Δ_a – the maximum relative error in estimating the average value of the characteristic being determined;

$z_{1-q/2}$ – quantile of the level $P = 1 - \alpha/2$ of normalized normally distributed random variable;

$P = 1 - \alpha/2$ – statistical reliability, which is the probability of not exceeding the actual error when estimating the average value of the maximum errors characteristic Δ_a or δ_a modulo;

δ_a – the maximum relative error in estimating the mean value of the quadratic deviation of the corresponding fatigue resistance characteristic.

When testing with increasing load, the characteristic to be determined is the breaking stress σ_p. In this case, formulas (1) and (2) will take the form, respectively:

$$n = \frac{V_{\sigma_p}^2}{\Delta_{\sigma_p}^2} z_{1-q/2}^2 \tag{3}$$

or

$$n = \frac{z_{1-q/2}^2}{\delta_{\sigma_p}^2}. \tag{4}$$

Using dependence (3), we will establish a relationship between the number of tested objects n and the random error in the magnitude of the breaking stress σ_p during testing with an increasing load. To do this, consider an example using an approach based on virtual simulation of fatigue tests.

To carry out the calculation, we will accept the normal law of distribution of the endurance limit. Then, by the method of generating random numbers, we determine the scattering of ten of its values relative to the average, equal to 200 MPa. Let us calculate the breaking stress σ_p for the rate of load increase $\alpha = 300\ \text{Pa}/\text{cycle}$. To do this, we use the formula of the unified Weibull equation with constant parameters

$$\sigma_p = \sigma_R + \sqrt{2 \cdot 10^7 \cdot \alpha}\,. \tag{5}$$

We will also assume that the load acting on the objects is normal [5].

These values are chosen based on the fact that the rate of $300\ \text{Pa}/\text{cycle}$ is close to the maximum loading rate, and at the same time, it guarantees the destruction of objects in the high-cycle fatigue area [6]. At the same time, the fatigue limit equal to 200 MPa corresponds to the case when the design breaking stresses depend least of all on the chosen model of the fatigue curve and the relationship of its parameters with the fatigue limit.

Results of calculation of values of breaking stresses σ_p, their of root mean square deviation S_{σ_p}, coefficient of variation V_{σ_p}, as well as the number of objects n at several values of the maximum relative error Δ_{σ_p} are given in Table.

Table

Calculated values of quantities σ_p, S_{σ_p}, V_{σ_p} *and* n

σ_R, MPa	σ_p, MPa	S_{σ_p}, MPa	V_{σ_p}	n at $(q = 0.10 \cdot z_{1-q/2} = z_{0.95} = 1.645)$				
				$\Delta_{\sigma_P} = 0.2V_{\sigma_R} = 0.011$	$\Delta_{\sigma_P} = 0.4V_{\sigma_R} = 0.022$	$\Delta_{\sigma_P} = 0.6V_{\sigma_R} = 0.033$	$\Delta_{\sigma_P} = 0.8V_{\sigma_R} = 0.044$	$\Delta_{\sigma_P} = 1.0V_{\sigma_R} = 0.055$
172,0	249,5	11,0	0,055	8 (7,36)	4 (3,68)	3 (2,45)	2 (1,84)	2 (1,47)
187,1	264,6							
191,3	268,7							
193,6	271,1							
197,0	274,4							
197,0	274,5							
200,2	277,6							
202,5	280,0							
207,2	284,6							
211,0	288,4							

Table shows in parentheses the calculated values of the number of samples. Rounding of these values to integers is carried out in all cases upwards.

The values Δ_{σ_P}, S_{σ_P} and V_{σ_P} were determined according to the recommendations according to the formulas [4]

$$\Delta_{\sigma_p} = (0.2 \ldots 1.0) V_{\sigma_R}, \tag{6}$$

$$S_{\sigma_p} = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} \left(\sigma_{p_i} - \bar{\sigma}_p\right)^2}, \tag{7}$$

$$V_{\sigma_p} = \frac{S_{\sigma_R}}{\bar{\sigma}_p}. \tag{8}$$

According to Table, we build a graph of dependency $\Delta_{\sigma_p}(n)$

Breaking stress σ_p is most often used as an experimental parameter in the accelerated determination of the endurance limit. However, there are accelerated methods, in which that use other and characteristics, for example, the summary fatigue life before destruction under an increasing load or the fatigue life under a stationary load [7]. In these cases, formulas (6)÷(8) remain valid.

Shown in Figure dependency $\Delta_{\sigma_p}(n)$, is general in nature, and does not apply to any specific accelerated method. It allows estimation of the random error of accelerated methods based on tests with increasing loading. At the same time, for each of them, it is necessary to carry out a calculation in which the random error in the assessment of the breaking stress will be linked to the random error in the endurance limit for a specific experimental scheme.

Conclusions

1. When estimated estimate the accuracy of accelerated methods for determining the endurance limit, it is advisable to separately determine the systematic and random components of the total error.
2. The random error of the accelerated methods for determining the endurance limit can be defined using a general statistical approach.

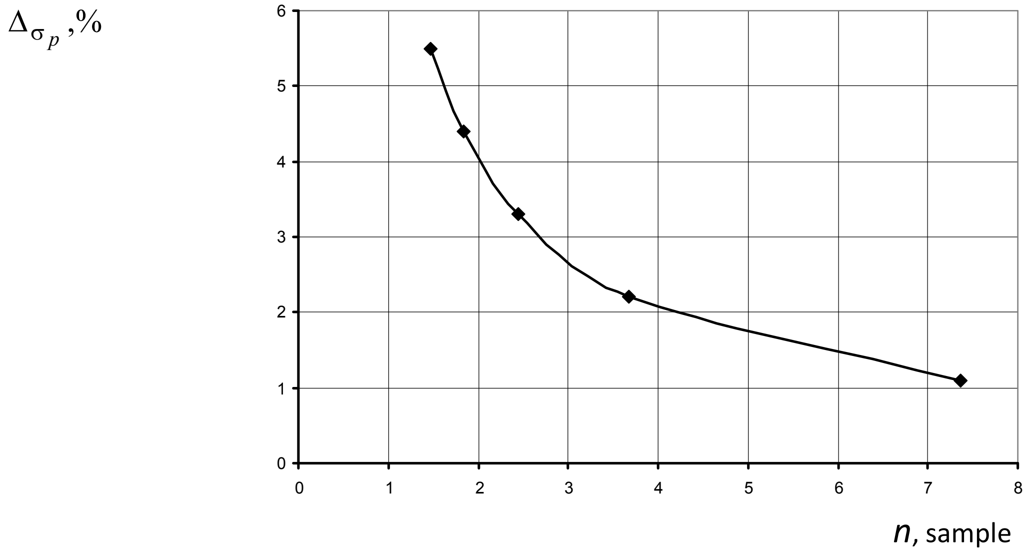

Figure. Dependence of the maximum relative error Δ_{σ_p} *in at estimating the average value of the breaking stress* σ_p *on the number of tested objects n*

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