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IMPROVING SAFETY OF EQUIPMENT BY RELIABILITY PROVISION

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The issues of ensuring the reliability of equipment in order to improve the safety of its work are considered. The article proposes a method for modeling a general population of a finite volume using small samples of input data. The optimization of truck maintenance intervals is provided.

Keywords: safety, reliability, equipment failure, cost minimization, strength, loading, resource.

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ПОВЫШЕНИЕ БЕЗОПАСНОСТИ РАБОТЫ ТЕХНИКИ ПУТЕМ ОБЕСПЕЧЕНИЯ ЕЕ НАДЕЖНОСТИ

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Рассматриваются вопросы обеспечения надежности техники в целях повышения безопасности ее работы. В работе предлагается метод моделирования генеральной совокупности конечного объема с применением малых выборок исходных данных. Проведена оптимизация периодичности технического обслуживания грузового автомобиля.

Ключевые слова: безопасность, надежность, отказ техники, минимизация затрат, прочность, нагруженность, ресурс.

Introduction. To ensure equipment safety in such industries as construction, transport, engineering, there is the need to justify the indicators and reliability criteria that reflect the properties of the created technical systems. Safety requirements are functionally related to reliability requirements. The actual tasks of the industry in modern conditions are improving the safety of work, equipment reliability, labor costs and operating costs minimization.

Cost minimization. Technical failures and an insufficient level of reliability in general can lead to industrial injuries, increase in the cost of work, significant losses of time. In reliability calculation, it is necessary to apply the methods of reduction of labor, duration of tests and financial cost in obtaining the original data [1, 2]. The decrease in sample numbers in strength, loading and resource, as well as the use of indirect correlation methods for determining the strength of samples and parts lead to minimization of costs of production, operation and forecasting of the life of a part or vehicle as a whole (Fig. 1).

Reliability optimization. Reducing the samples volume in strength, loading and resource at the minimum error was carried out using the developed method to ensure the basic indicator of resource reliability. The method under consideration is based on the use of small samples of initial data and the distribution of absolute amplitudes for modeling the general population of a finite volume [3-5].

Distribution function of absolute amplitudes $W_{r_s} = x_r - x_s$. (r,s=1,...,n) has the form:

$$F(W)=\int_0^W f(W)dW,$$

where $f(W_{rs})$ is the density of amplitude distribution (in a general form):

$$f(W_{rs})=C_{rs}\int_{-\infty}^{+\infty} P^{r-1}(x)p(x)[P(x+W_{rs})-P(x)]^{s-r-1}p(x+W_{rs})\times[1-P(x+W_{rs})]^{n-s}\,dx,$$

$C_{rs}=\dfrac{n!}{(r-1)!(s-r-1)!(n-s)!}$; $P(x)$ — characteristic distribution function;
$p(x)$ is the characteristic probability density of the.

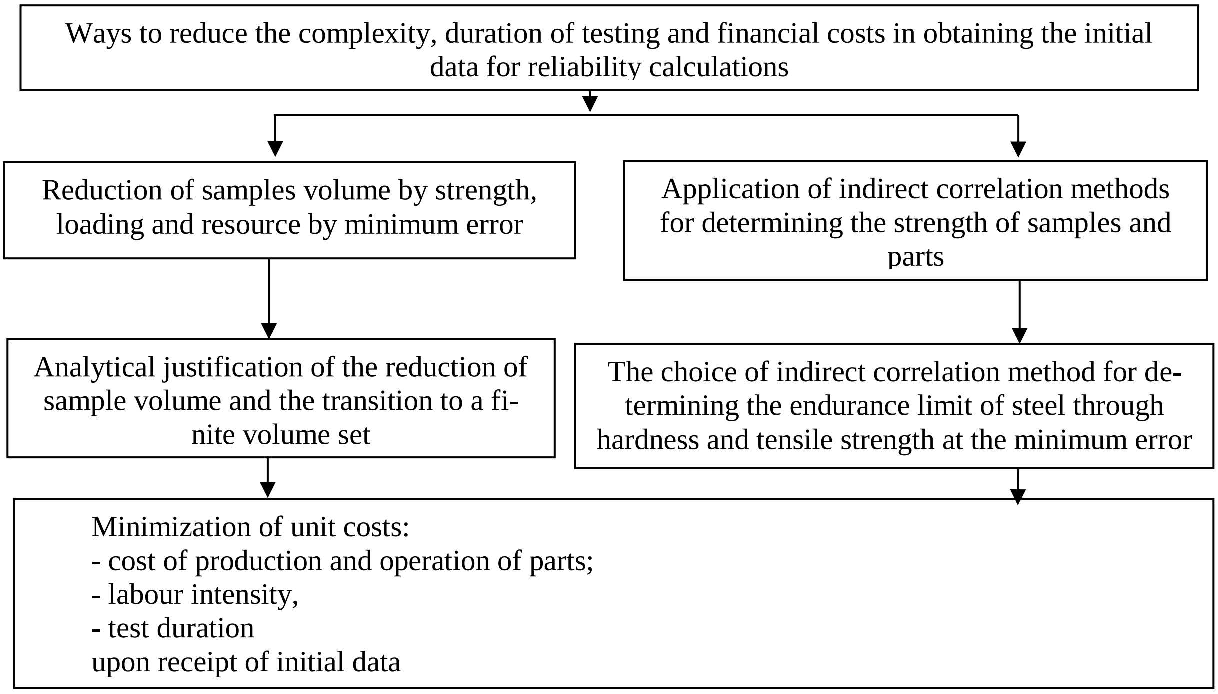

Fig. 1. Improving the efficiency of optimal reliability of equipment and its components

Fig. 2 shows the empirical and approximating distribution functions of the general population of the final resource volume of KAMAZ-4308 truck engine *Tp*. Optimization of the value of probability of no-failure operation (PNFO) of the car engine is carried out according to the criterion of optimization of the specific cost *Ci* (Fig. 3).

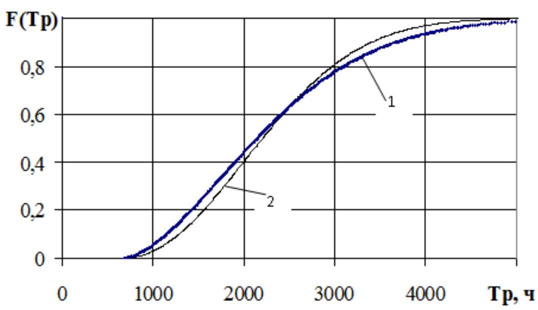

Fig. 2. Functions of distribution of GSKO resource of KAMAZ–4308 truck engine: 1 — empirical; 2 — approximating

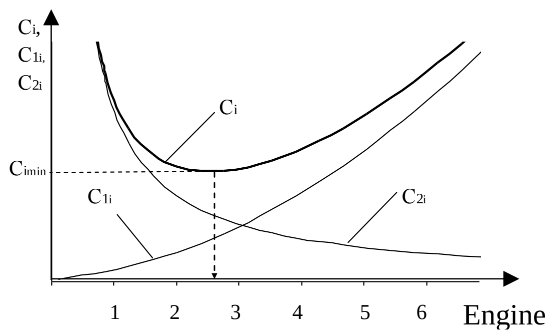

Fig. 3. Optimization of operation modes of the vehicle engine (and, accordingly, the probability of its no-failure operation)

It is necessary to calculate several *Ci* values for different modes of the car engine operation (use of different types of fuel; use of additives that increase the gasoline proknock properties; scheduled maintenance, etc.) and to determine the probability of no-failure operation $P(t)$. With the known functions $P(t)$ and failure rate $\lambda(t)$, it is possible to optimize the duration of the technical object operation in the periods between the scheduled maintenance. It is necessary to take into account the possibility of implicit failures.

Let us denote by u the additional financial losses where there is the agreement of other total expenses from implicit failures:

$$S(\tau)=Up(t<\tau)+Cp(t\geq\tau)+u\int_0^\tau tf(\tau-t)dt=U\left[1-P(\tau)\right]+CP(\tau)+u\int_0^\tau\left[1-P(t)\right]dt=$$

$$=U+(C-U)P(t)+u\left[\tau-\int_0^\tau P(t)dt\right].$$

Average unit cost over the time τ:

$$s(\tau)=\frac{1}{\tau}\left\{U+(C-U)P(t)+u\left[\tau-\int_0^\tau P(t)dt\right]\right\}.$$

Differentiating the expression by τ and equating the derivative to zero, we obtain the equation:

$$P(\tau)-\tau\frac{dP(t)}{dt}-\frac{u}{U-C}\left[\tau-\int_0^\tau P(t)dt\right]=\frac{U}{U-C}.$$

The desired solution of the equation is the optimal frequency of maintenance.

Let us imagine the risk function for a technical object with periodic maintenance in the form of:

$$S=CP_2(t)+UP_3(t).$$

Based on the minimization of the quantitative value of risk [6], we solve the problem of optimizing the value of the period between the planned maintenances. The value will have the size of the total unit costs associated with losses on the recovery and repair of equipment, as well as with the violation of the period of work due to machine complex downtime.

Obtaining practical results. The results of the optimization of the maintenance periodicity T_{opt} are summarized in table 1, where S_{min} is the smallest quantitative characteristic of risk; λ is the failure rate; τ is the time value of the period between maintenances; U/C is the ratio of costs in case of a sudden failure to the cost of maintenance. KAMAZ–4308 truck is selected as an example.

Table 1

The results of the problem solution of optimizing the duration of the period between the planned maintenances of KAMAZ–4308 truck

τ, h	U/C	Frequency of maintenance T_{opt}, h		
		$\lambda=10^{-8}\ h^{-1}$	$\lambda=10^{-7}\ h^{-1}$	$\lambda=10^{-6}\ h^{-1}$
10	10	9992	3154	992
	100	3152	990	307
	1000	990	306	91
	10000	306	91	23
20	10	14126	4456	1398
	100	4453	1395	428
	1000	1394	428	123
	10000	428	123	29
50	10	22321	7031	2196
	100	7022	2188	660
	1000	2187	659	179
	10000	659	179	37
100	10	31543	9920	3083
	100	9902	3066	907
	1000	3064	905	232
	10000	905	232	41

Thus, given $\lambda = 10^{-6}$ h^{-1} and $\tau = 100$ h, the cost ratio is U/C=100. Taking into account the final probabilities of states, the value of the minimum technogenic risk $S_{min} = 0.0613$ and the optimal periodicity of maintenance $T_{opt} = 907h \approx 2$ months.

The optimization of the probability of no-failure operation of machines according to the criterion of "total unit costs" can reduce the injury rate in the production of works with technical objects, thereby increasing industrial safety. Justification of indicators and reliability criteria in the framework of increasing the reliability of works leads to a decrease in failures, reduction of losses for repair and recovery of equipment.

Conclusion. Improving the equipment safety and reliability will lead to injury reduction, reliability increase, reduction of the cost of its repair and recovery.

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