New method of achievement and maintenance of the reliability objective of mechanical engineering products on the basis of control actions

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Abstract

The system approach to the analysis, forecasting and maintenance of reliability of complex products on all life cycle is developed. The offered new method of achievement and maintenance of the given level of reliability is generalization of a known method and essentially specifies it due to introduction of additional two-parametrical function R(t; α; β) with piecewise constant values of parameters α and β. Advantage of a method and its novelty is, that the R(t; α; β) function used at a design stage can be specified in process of accumulation of the statistical data received during tests and operation. In addition this method actively allows to interfere in process of increasing of a level of reliability at a stage of creation and to provide the achieved level of reliability during a batch production and operation by control actions. The offered method of calculation and an estimation of reliability is confirmed with results of tests and operation for the long-term period of the expensive products and has given the big economic benefit for the country. The developed new approach on achievement and maintenance of reliability can be successfully applied in creation, in operation and in prolongation of terms of operation of expensive products of any industry.

Practice shows, that reliability of products of mechanical engineering till 70th years of XX century was provided with constructional ways by means of increase of margin of safety, stability, use of more expensive materials, due to change of time for maintenance service etc. Reliability evaluation for such products was expert, without use of quantitative methods, and it is justified for that period. Reliability of practically all products of mechanical engineering of that period was estimated so. In light of rapid technical progress and creation of rather complex technical systems the expert estimation became too subjective and inexact. Therefore at the end of 60th years of XX century there are the first theoretically developments of a quantitative estimation of reliability both at a stage of designing and calculation and in service. For that period the known method of calculation was based on a design stage only on one-parameter probability function of reliability P(t, λ), as exponential law of distribution of failures:

$$P(t, \lambda) = \exp(-\lambda t) \qquad (1)$$

t - an operating time of object (an element or a product);
λ = *const* - parameter of distribution which physical sense is intensity (frequency) of failures;
P (t, λ) - probability of survival (reliability) of object in time *t.*

In design calculation of reliability value of parameter λ is chosen from reference books, or received by results of tests or operation of an element (product) - analogue in the normal conditions determined by normative documents: an ambient temperature t°C = (20 ± 5) °C, pressure p = 760 millimeters of mercury, humidity of 65 %, load factor K = 1,0 etc. This approach was used at creation of products of all industries on which requirements on reliability were set.
Graphically changes of failure rate and function of reliability are shown on fig. 1. Scientific researches and experimental data testify, that failure rate of a product (element) is essentially various at different stages of life cycle from designing till removal from operation.

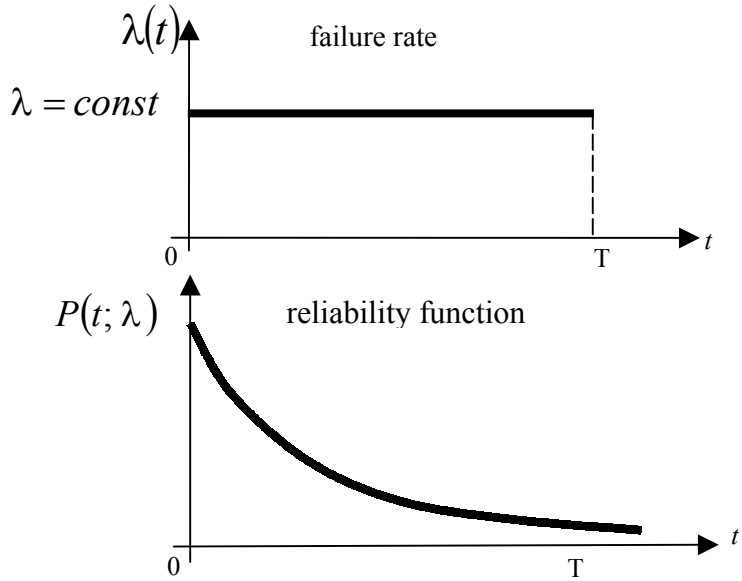
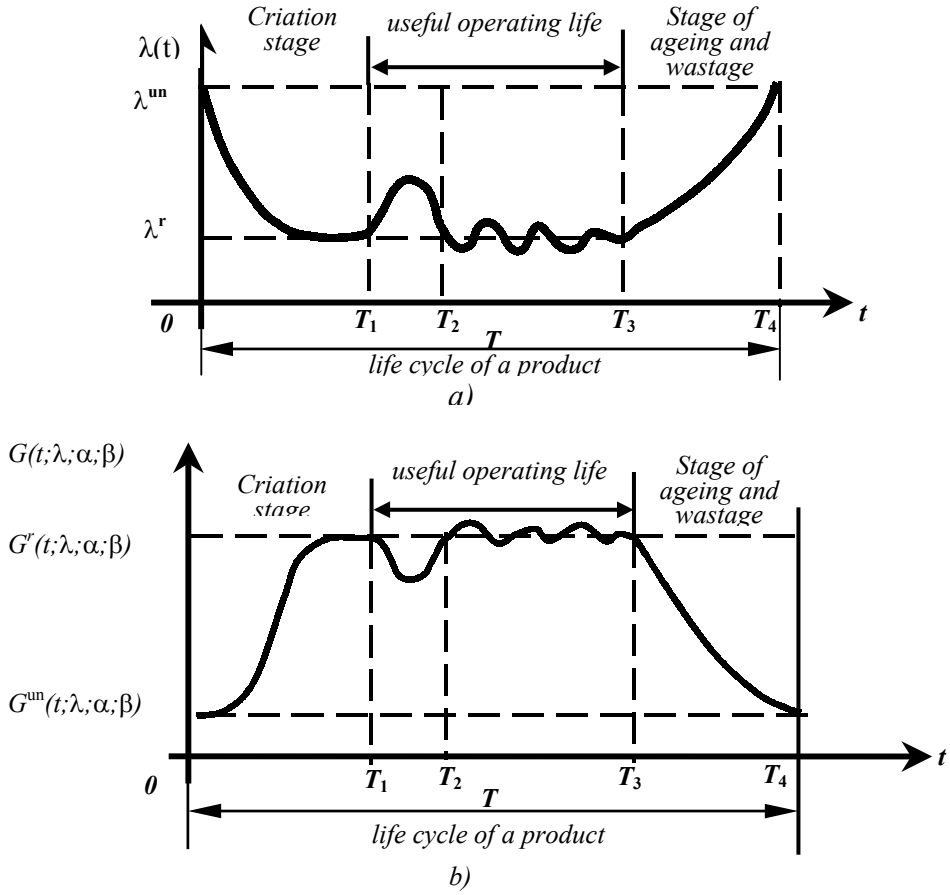


Figure 1: Changing of failure rate λ(t) and reliability function P (t, λ)



Fugure 2: a) Changing of failure rate of a product during the whole life cycle
λ^r – required failure rate, λ^{un} – unacceptable failure rate, (T1÷ T2) – shakedown period
b) Changing of reliability function of a product during the whole life cycle
$G^r(t;\lambda;\alpha;\beta)$ – required level of reliability function, $G^{un}(t;\lambda;\alpha;\beta)$ – unacceptable level

We carried out the work on achievement and maintenance of the given level of reliability at all stages of life cycle and results are possible to present as the generalized diagrams of changing of failure rate $\lambda(t)$ and functions of reliability $G(t;\lambda;\alpha;\beta)$, figure 2. This diagram visually shows, that function of reliability $P(t, \lambda) = \exp(-\lambda t)$ accepted before with constant value of parameter λ=*const* is too rough approximation having in view of all life cycle of a product, including stages of creation, useful operating life, ageing and wastage.
On the basis of these system researches it was suggested to use the new approach to calculation and reliability evaluation in which changing in time external influencing factors and characteristics of a technical condition of a product as a whole and elementwise are taken into account. For realization of this approach function of reliability $G(t;\lambda;\alpha;\beta)$ is represented as two multipliers. The first multiplier is the standard one-parameter function of reliability $P(t, \lambda)$ with constant failure rate λ = const on all period of life cycle of a product. The second multiplier $R(t;\alpha;\beta)$, has two parameters α and β which keep the constant values on each stage of life cycle, but changes from a stage to a stage.
The introduced parameters α and β take into account external influencing factors (operating conditions) and an actual technical condition of a product (element) on each stages of life cycle.
The physical sense of these parameters means the following. The parameter α represents the average failure rate (intensity) varied at each stage of life cycle because of influence of external conditions and a technical condition of a product, and the parameter β represents dispersion of failure rate about its average value (average of distribution), i.e. a dispersion:

$$\alpha = D[\beta]$$

So function of reliability of a product is defined by such correlation:

$$G(t;\lambda;\alpha;\beta) = P(t, \lambda)\, R(t;\alpha;\beta) \qquad (2)$$

$P(t, \lambda)$ - standard one-parameter function of reliability;
$R(t;\alpha;\beta)$ - additionally introduced two-parameter function, which specific expression is set at each stage of life cycle.

Thus, the offered new approach is based on probability function of reliability $G(t;\lambda;\alpha;\beta)$ depended on time t and three parameters $\lambda;\alpha;\beta$.
The choice of function $R(t;\alpha;\beta)$ is carried out from a class of known distribution laws: normal, lognormal or Weibull. These laws are two-parametrical and well describe failure distribution at all stages of life cycle of a product in view of adverse influences of external conditions and actual changing of a technical condition of elements in time. In particular for the Weibull distribution the formula (2) becomes:

$$G(t;\lambda;\alpha;\beta) = \exp(-\lambda t)\exp(-\alpha t^{\beta}) \qquad (3)$$

Having chosen the value of parameter λ beforehand and selecting values of parameters of distribution α and β at each stage of life cycle, it is possible to describe changing of failure rate of a product $\lambda(t)$ in time and function of reliability $G(t;\lambda;\alpha;\beta)$. It is necessary to note that after statistical data processing for the long-term period of operation of expensive products it was established that accepted additional function $R(t;\alpha;\beta)$ obeys the law of Weibull distribution.

This approach was used at creation and operation of a complex "Bereg" (Figure 3) and a complex of hydrobreak of a layer of oil wells (Figure 4)

Figure 3: Artillery complex “Bereg”

Figure 4: Complex of hydrobreak of a layer of oil wells

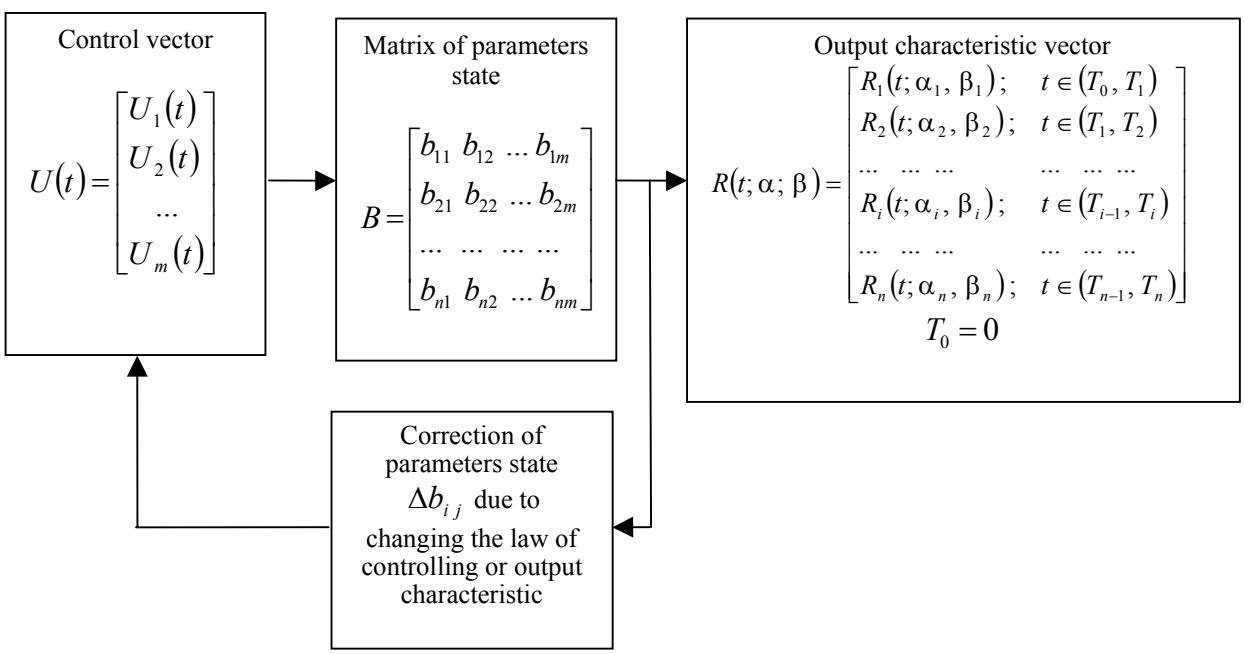


Figure 5: System of calculation the parameters of function R(t;α;β) on the basis of control actions

Function of reliability $R(t;\alpha;\beta)$ can be calculated and defined at a design stage both for a separate element and for a product as a whole on constructive, technological and operating parameters using a closed system of calculation and optimization on the basis of control actions (figure 5). As an input in this system we accept a vector of control actions $U(t)$ as constructive, technological and operational parameters filled the technical documentation. The output characteristic $R(t;\alpha;\beta)$ can be presented as failure rate, mean-time-between-failures, probability of survival or any other output characteristic (for example, cost, productivity, efficiency etc.). If the received output characteristic does not satisfy to required value than correction of paremeters state of a system must be carried out.

The same approach can be used at a stage of preproduction test and during exploitation of commercial product. Having defined statistical function of reliability $G(t;\lambda;\alpha;\beta)$ as a result of preproduction tests the latter is compared to function of reliability $G(t;\lambda;\alpha;\beta)$ constructed as a result of designing. By results of comparison it is carried out correction the parameters of the distribution law of design reliability function $G(t;\lambda;\alpha;\beta)$, i.e. this function regularly in process of accumulation of the statistical data is specified and is brought to required due to obvious controlling by changing constructive, technological and operational parameters filled the technical documentation.

The offered method remains formally identical at all stages of life. It allows to predict and provide not only required parameters of reliability, but also any output characteristics of technical system.