The algorithm for ensuring the parts’ (assembly nodes, machines) reliability based on the theory of risk

V E Kasyanov, A A Korotky, E V Egelskaya, E E Kosenko*
Don State Technical University, 1, Gagarin sq., Rostov-on-Don, 344010, Russia

E-mail: a123lok@mail.ru

Abstract: currently existing technical systems are created for a certain service life with a limited number of work cycles and are out of order after some time. At the same time, there are such failures that cause life loss, damage at various levels. Therefore, there is a need to use the “risk” concept of an adverse event (excluding damage). The considered risk exceeds the failure probability by the safety factor value. The article presents an algorithm for ensuring the reliability of the parts associated with negative consequences, based on the risk theory, which considers the patterns (Figure 8 - Figure 10), due to six scientific principles.

Introduction
The first GOST 13377-67 in terms of reliability (terms) was introduced on July 1, 1968, i.e. 50 years ago.

In accordance with the dictionary of the Russian language [1], the theory is based on the scientific principles and patterns of processes in parts (assembly nodes, machines).

The concept (term) of risk was introduced in GOST R 51901-2002 17 years ago, along with several new GOSTs for reliability [2-4].

An analysis of the literary sources regarding the concept “risk” shows that risk is practically a failure probability (excluding damage) associated with negative impacts on human and environment. This point of view was supported by A.P. Sinitsyn [5] and by the foreign scientists E.J. Henley and H. Kumamoto [6].

Main part
In accordance with Federal Law No. 184-FL “On the Technical Regulation” in Article 2 the basic concepts are noted as “Risk is the probability of harm to life or citizens’ health, damage to individual or municipal property, the environment, life or health of animals and plants, also taking into account the severity of this harm” [7].

In A.P. Sinitsyn’s monograph [5], devoted to the risk theory application for the structural calculations, in our opinion, numerous mathematical solutions (analytical calculations) to determine the forces acting on various building structures and objects, including risks are provided.

However, any theory is based on scientific principles and laws governing processes, for example, in machines, building structures and objects.

When considering the theory of risk, it is necessary to take into account not only the sampling, but most importantly the aggregate of the final volume as the principles’ part. The first principle: the
totality is usually many times larger than the sampling, which is reflected in the relative scope of the totality, significantly larger than the sampling (Figure 1).

![Figure 1. Differential curves: 1 – sample group; 2 - totality, 3 - the minimum totality value, 4 - the minimum sample value.](image)

To approximate the sample group and totality distribution in the region of some parameters’ maximum values, the Fisher – Tippet law is used with the restriction on the right. The following probabilistic laws can be used in the curves shown in Figure 1: normal \((-\infty + \infty)\), exponential, Weibull with two parameters with \((0 + \infty)\) limits, which do not reflect the real loads and strength of the objects under consideration and introduce the significant errors into the calculations.

Curves 1 and 2 on Figure 1 are approximated by the Weibull distribution with three parameters. Points 3 and 4 of the minimum values in Figure 1 show a large discrepancy in the parameter values and, of course, point 3 will allow avoiding major errors in calculating the failure probability and resource of the parts, etc.

Another scientific principle (second) is the safety factor, which allows moving the part’s failure moment from the risk value. In our opinion, the failure probability should be less than the risk by the amount of the stock (safety factor). This coefficient needs to be quantified.

Risk is a possible danger [1]. In relation to the national economy and society, the concept “risk” is a concept, long ago legalized by the regulatory acts, which is defined as the probability of an event multiplied by the amount of damage caused by this event. There can be no other terminology, because it is “truth”.

If to admit an assumption and the damage extent from a negative event is not taken into account, then the risk can be considered as the adverse event probability (failure with consequences).

Possible danger is the failure possibility, the failure probability.

\[ R \text{ is the risk; } Q \text{ is the failure probability.} \]

\[ Q = 5 \cdot 10^{-8} \]

\[ R = 10^{-7} \]

![Figure 2. Risk interdependence and failure probability](image)

Risk is the limitation of the event associated with a part’s (node, machine) loss of operability due to its failure. The risk extent is \(10^{-2} - 10^{-7}\), sometimes less. The greater the loss, the less risk should be and, accordingly, the less is the failure probability:
This inequality should be ensured with some margin.
The lower the Q, the greater is the margin relative to risk R.
Taking the margin into account, the formula (1) takes the form
\[ R > K_s Q, \] (2)

where \( K_s \) is the stock, \( K_s < 1 \).

Minor risk \( (10^{-5} – 10^{-7}) \) is major loss (costs); it is obtained due to the low failure probability. Such a probability requires large expenses for its provision in the design and manufacture of a part (node, machine), and also as a failure result, significant damage is possible (life loss, damage to the machine, downtime for repair, etc.).

An increase in strength and (or) a decrease in the existing stresses in the dangerous section of the part and, accordingly, a decrease in the failure probability and its life increase will be required to ensure the necessary margin when assigning a risk value (see Table 1, Fig. 2-4).

The risk is major or minor.

Example.

The tire is slightly inflated, i.e. the bus will not drive 500 km; emergency condition is possible - the risk is major: \( R = 0.999 \) (for example).

The tire is normally inflated, i.e. the bus will drive 500 km; the risk of an emergency is minor: \( R = 0.001 \).

The failure probability of bus is \( Q = 0.0001 \). Then \( R > (Q = 0.0001) \).

| Car | Failure probability (FP) | Damage | Allowable Risk |
|-----|-------------------------|--------|----------------|
| - fire | \( 10^{-7} – 10^{-5} \) | Death of people, extensive economic losses | Minor R=Q=10^{-5} - 10^{-3} |
| - ambulance | | Possible damage | |
| - police | | Possible, acceptable | |
| - head complex | | Diagnostics is not possible or costly | |
| - load-lifting | | | |
| - moon rover | | | |

| Node (Assembly Unit) | | |
| - engine | | |
| - control system | | |
| - braking system | | |

| Part | | |
| - sudden failure | | |
| - gradual failure | | |
Task:
1. Determine the risk and failure probability (FP) for cases:
   1.1 Death of people;
   1.2 Extensive damage (economic);
   1.3 Acceptable damage;
   1.4 Minor damage.

   For 20 thousand hours, the planned resource.

   The value of $Q$ for 1.1 should be less than the planned $R$.

There is no risk

The risk is

Risk – is a failure probability for the totality $N_c=10^8$
Figure 6. Risk - failure probability for a set of parts (assembly nodes, machines) with margin

Actual risk $10^{-7}$ is accepted as planned.
$R > Q; Q = 7 \cdot 10^{-8} < 10^{-7}$.
Example: sample group $n = 50$; totality $N = 10^4$;
the number of samples $m = 200$; resource = 20,000 hours

Figure 7. The risk ratio - lower confidence limit (LCL) for the failure probability

1 - the sample groups’ distribution
LCL is the lower confidence limit for the minimum distribution 1 value.
Risk $R = 10^{-7}$;
PF: $Q = 3 \cdot 10^{-7}$ (LCL), death of people is possible.
$T_{PR} = 20$ thousand hours.
Principles (continued):
3. The magnitude of the risk is mainly affected by the part’s (assembly node, machine) failure probability – i.e. causing harm to the life or health of citizens.
4. It is also necessary to take into account the failure effect on the damage extent when performing any work using equipment.
5. The failure risk is affected by the failure probability (this is the third principle), depending on many factors, necessitating the use of experimental data, the failure probability expert determination results and the implementation of its optimization.
6. The equipment failure probability optimization is necessary in case of damage at different levels.
Consideration of these principles allows to graphically represent the risk theory laws (Fig. 8 - Fig. 10) thereby outlining the risk theory basics.
Figure 8. Risk and failure probability (FP) for various aggregate parts’ resources

The graph (Figure 8) shows the relationship of the resource, risk R and failure probability Q in the presence of a fatal outcome and in its absence. Along with this, this graph demonstrates the pattern for R and Q and Tp resource.

\[
R_1 = 10^{-7}; \quad Q < 10^{-7}; \quad Q = 7 \cdot 10^{-8};
R_2 = 10^{-6}; \quad Q < 10^{-6}; \quad Q = 7 \cdot 10^{-7}.
\]

Figure 9. An example of a correct arrangement of R and Q.

There are two different risk values and failure times with some margin in the graph (Figure 9):
- risk \( R_1 = 10^{-7} \); BO \( Q = 7 \cdot 10^{-8} \); resource \( T_{p1} = 24 \) thousand hours more than 20 thousand hours planned;
- risk \( R_2 = 10^{-6} \); BO \( Q = 7 \cdot 10^{-7} \); resource \( T_{p1} = 19 \) thousand hours more than 17 thousand hours planned.

\[ R = 10^{-7}; \quad Q_1 = 5 \cdot 10^{-6}; \quad Q_2 = 3 \cdot 10^{-8} \]
The graph in Fig. 10 shows that for risk $R = 10^{-7}$ there are two values of failure probability for different resources.

Reducing the failure probability from $5 \times 10^{-6}$ to $3 \times 10^{-8}$ and increasing the life of the part from 16 to 24 thousand hours ensures the life loss exclusion for risk $R = 10^{-7}$.

However, the cost of a part with an increased resource increases.

Therefore, the graphs in Fig. 8, 9, 10 show the relationship of risk, the failure probability and the resource of a part (assembly node, machine), demonstrate the existing pattern, and as a result on the risk theory basis.

The algorithm for performing the calculations is composed (Fig. 11) of six blocks, which allows switching from the sample to the final volume aggregate and provide control over the failure probability and the resource, focusing on the planned risk.

1. Information gathering about the machine parts’ failures in case of fatal outcome according to the sample data
2. Approximation of statistical data by the Weibull distribution law with 3 parameters
3. Determination of lower confidence limit for the minimum value of the details’ assembly resource
4. The probability of a part failure for a planned resource is calculated
   \[ F(T_p) = 1 - e^{-\beta (T_p - LCL)/\alpha} \]
5. By changing the strength and (or) the operating voltage in the dangerous section of the part, the specified resource of the part is provided
6. If necessary, the value $Q < R$ (risk) is adjusted taking into account the margin

**Figure 11.** Algorithm for ensuring the parts’ (assembly nodes, machines) reliability in risk conditions

Such an experimental method gives the greatest objective result, but it takes a long time, especially for the risk values of 10-7 or less.

This problem can be solved by an expert method, but with low accuracy.
The risk extent determination is carried out by an expert method or by collecting and accumulating the statistical data on failures [8-15].

1. The expert method

The risk magnitude depends on the part’s (assembly node, machine) malfunction consequences. It is hardly possible to determine the risk magnitude analytically. Therefore, instead of collecting evidence, an expert method is usually used. For this, a group of 5-8 experts, specialists in the field of equipment creation and operation is formed. In the process of this work, the experts’ quality is checked using the concordance coefficient.

The risk extent is most often determined on the basis of statistical data accumulated in the operating organizations over the parts’ (assembly node, machine) life.

Typically, such information is considered as selective. The sample data can be obtained when, for example, an extensive economic loss occurs.

Information about the death of people is collected in the traffic police, the Ministry of Emergency Situations and it can be considered as a combination of the final volume.

If the graphical method of transition from the sample data to the products’ final volume aggregate data is applied, the accuracy of calculating the risk magnitude will increase.

Moreover, as the practice of calculations using the Weibull distribution law shows, this problem becomes solvable.

It is possible to increase the accuracy of determining the risk extent by using the lower confidence limit for the minimum risk extent in the aggregate.

Summary

Thus, the introduction of the term “risk” into GOSTs for reliability allows more accurate assessment of the situation, especially with regard to ensuring the trouble-free operation of a particular equipment (machine). An algorithm for ensuring the necessary uptime of the equipment based on the risk theory (the laws of processes and the six scientific principles of this theory) is considered.

References

[1] Ozhegov S I 1970 Dictionary of the Russian language (Sov. Encyclopedia, Moscow).
[2] GOST R 27.202-2012 2013 Reliability in technology (SWST). Reliability Management. Life cycle cost (Standartinform, Moscow).
[3] GOST R 27.607-2013 2015 Reliability in technology. Reliability Management. Reliability test conditions and statistical criteria and methods for evaluating their results (Standartinform, Moscow).
[4] GOST R ISO 2394-2016 2016 Building constructions. The basic principles of reliability (Standartinform, Moscow).
[5] Sinitsin A P 1985 Structural analysis based on risk theory (Stroyizdat, Moscow) 304.
[6] Henley E J, Kumamoto H 1984 Reliability of technical systems and risk assessment (Mechanical Engineering, Moscow).
[7] Federal Law "On Technical Regulation" dated 12.27.2002 N 184-FL.
[8] Egelskaya E V 2015 Human factor risk assessment in the system "personnel-lifting mechanisms-production environment" at engineering enterprises (dissertation of the candidate of technical Sciences, Rostov-on-Don).
[9] Korotky A A, Egelskaya E V 2015 Human factor risk assessment in the system “personnel-lifting mechanisms - production environment" at engineering enterprises Vestnik DGTU 15 (1)(80) 131-137.
[10] Korotky A A, Egelskaya E V, Kotelnikov V V 2014 The risk assessment of the human factor in the system "Man - technical system - production environment" at hazardous production facilities (for facilities that use lifting facilities) CHEMAGREGATES 4 (28) 39-41.
[11] Deryushev V V, Kosenko E E, Kosenko V V, Zaitseva M M 2019 Making technical decisions in conditions of uncertainty in the presence of risk Safety of technogenic and natural systems 2 56-61.

[12] Kasyanov V E., Kosenko E E, Kosenko V V, Kotesova A A 2019 Influence of volumes of general populations on the resource of automobiles in single and serial production Gruzovik 4 3-6.

[13] Kasyanov V E, Kosenko E E, Kosenko V V, Kotesova A A, Khvan R V 2018 Investigation of the influence of sample sizes and aggregates on the strength of automobile parts on their resource Engineering Journal of the Don 1 (48).

[14] Deryushev, V V, Panfilov A V, Zagutin D S, Kosenko E E, Arakelyan R M, Kopylov F S 2019 The risk assessment of making technical decisions under the uncertainty conditions AIP Conference Proceedings 2188, 050041 doi:10.1063/1.5138468

[15] Ivanov V V, Popov S I, Dontsov N S, Dieudonné E 2019 Zinc coating obtained in the result of the mechanochemical effects in vibrodynamic the setups of various types MATEC Web of Conferences 01003.