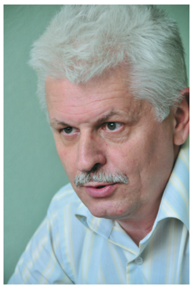

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ABOUT THE PHILOSOPHICAL ASPECT OF RELIABILITY EXAMPLIFIED BY UNIQUE MISSION-CRITICAL SYSTEMS

The article deals with the philosophical aspect of reliability exemplified by unique mission-critical systems for which it is impossible to apply probabilistic and statistical methods of reliability theory.

Keywords: *unique mission-critical systems, reliability, failure-free operation, property, ability, parameter, index.*

Introduction

For engineers there hardly is anything more indefinite than the number of nines in reliability indices. When you have no real possibility to feel and measure these nines, it becomes so tempting to give it up and write the wanted reliability figure in the technical assignment expecting that the life will judge. That is probability, indeed!

From the outlook of a classical reliability theory, probability of failure-free operation (FFO) equal to entity seems absolutely impossible, that is why in order not to tease the orthodox devotees, the requirements for failure-free operation are set as being equal close to entity. But as a whole the point does not change. There is a class of technical systems – unique mission-critical systems (UMCS), for which the requirements of FFO probability are set on the level of four nines and more, and in each particular case of application, the functional tasks are implied and expected to be accomplished for sure [1]. Such systems include large transformable mechanical systems (LTMS) of spacecrafts (SC) [2], for instance, the opening sections of solar panels (SP). Any failure in such systems means not just failure to fulfill the reliability requirements but also enormous, sometimes even thumping damages and losses impugning the practicability of their creation without any reliability assurance.

Meanwhile, verification of failure-free operation at the level of three-four nines for the products produced only in a single copy is much an open scientific problem [3]. And by the way, one could hardly find an engineer able to detect the construction part of a specific UMCS which should be practically changed to increase its reliability, for example, from three nines to four nines. Besides, the emphasis shall be certainly put on the lack of statistics, i.e. in fact on the lack of source data (as the case is about systems produced in a single copy). However, if the same question is asked in relation to UMCS strength improvement, there will be an immediate enumeration of definite methodological ways to solve the problem (singularity of object makes no obstacle here, and nobody is confused). Certainly, the reliability indices of technical systems can, and in some cases must be measured by statistic means. But what can be done if there is no statistics ready at hand, or it is not possible to receive, or if the object behavior can not be postulated in the form of statistic hypotheses?

It was V.V. Bolotin who made the first consideration of real environmental factors, system properties, technological, operational and other requirements for reliability problems of mechanical systems, instead of notions and methods of formal reliability theory [4-6]. His theory of mechanical systems reliability describes reliability as evolution of trajectory of quality elements with time within the limits of acceptable states of quality space, and failure – as a surge of trajectory of any element beyond the limits of acceptable states. The reliability is an objective degree of possibility of event occurrence, which depends not on the frequency of reproduction of some or other events, but on the selection of specific materials, design solutions taken, technologies and production methods, terms of interaction with environment.

In such perception of reliability the nines of UMCS reliability index do not reflect statistics, but objectivity, and on this basis an engineer needs to learn the methods of analysis and estimation of reliability, vivifying the figures of reliability indices by means of visualization of "trajectory of quality elements with time". To vivify the nines means to fill them with meanings and therefore the philosophy here is a kind of multipurpose "scalpel" for dissection of meanings one could hardly do real work without.

It should be noted that this article is by far not the first effort to penetrate deep into the philosophy of reliability [7, 8], but this time, however, you are suggested to consider the philosophical aspect of reliability on the examples of unique mission-critical systems, for which it is mostly impossible to apply probabilistic and statistical methods of reliability theory.

Approach to philosophical understanding of reliability

Considering that any science with any subject studies things, their properties and relations, let us refer to the paradigm of their trinity proposed by A.I. Uyomov [9]. As per this paradigm, the properties are one of the philosophical categories closely linked to and merging into each other – the things as the relation of properties, the properties as the relation of things, and the relations as the properties of things. The properties are exceptionally related to the things, they express any of their sides and do not exist without the relation of a thing to other things.

To avoid "junk" perception of things let us agree to refer the notion "thing" to a synonymic row signifying an article: object, product, system, etc., in other words let us use this notion in the technical meaning.

Any things as a class of physical elements of material world – atoms, molecules, materials, objects or systems – are in continuous relations of mutual arrangement, interrelation and interaction, occurred in their properties. The things have an internal structure in the form of the set of elements with a definite spatial location and interrelations: chemical, mechanical, geometrical, kinematical, stiffening, etc. – it keeps the things cohesive, with reference geometrical sizes and forms, it helps keeping a certain manner functioning, with occurrence in these or those properties. At the same time, the properties of things occur in a different way, by change or supplement, if considering not only their internal structure, but also the terms and processes of interaction between the elements: mechanics, wear and tear, electrochemical corrosion, creeping, crumple, fatigue – modes of coexistence and functioning of internal elements.

Based on the unity of principles for construction of material systems, the properties appeared in mutual arrangement, interrelation and interaction of the elements inside a thing do likewise appear in mutual arrangement, interrelation and interaction with other things. As the result, relations of the things, the properties of every thing are detected as a summary total different from the properties of things separately, in other words they appear in a different manner rather than alone ones. Therefore, the properties are always specified doubly: by internal substance of a thing, as a combination of mutual arrangement, interrelation and interaction of its elements, and by the relations with external things. Any thing is a set of properties, each of which makes it to be an integral whole to a certain degree. For instance, based on its sense bearing notions – such as permanence, constancy, certainty, trusted functionality, the notions that you can rely on, – the reliability is expressed by a thing on the part of stability. Stability here means *steady state able to keep long-term existence with preservation in time.*

In fact, the reliability is one of the properties of things, but what is the essence of this property?

As per the given paradigm, the relations of properties are the thing which is possible to consider as the system of properties of the "ordinary-significant" hierarchy. A set of ordinary properties is clustered around a stable integral unity of the thing – which is a significant property showing any important part of the thing. The color, for example, is an ordinary property. Combination of colors and shades, composition and style of pictures prints, proportions of the object, form lines, etc. – are a significant property reflecting the thing's esthetics.

The set of ordinary and significant properties of the thing makes the main significant property – a quality that determines the thing's specific nature, distinguishing it from a number of other things. The quality as a philosophical category is a property expressing the thing on the part of its integral unity, it is a boundary of the thing, and with no quality this things becomes another thing. The difference between the quality and other properties is that without any properties the thing can still exist, and destruction of the quality will destruct the thing, though it will not annihilate it, but turn it into another thing with a different quality.

It is important to distinguish and to generalize a quality as a philosophical category, and a produce property as a *"set of produce properties, determining its feasibility to satisfy the demands in accordance with its purpose"* [GOST 15467-79, article 3]. For example, the "Zhigul" and "Mercedez" are the cars in philosophical perception of the quality are autos, and they cease to be autos only when their repair is impossible or unreasonable. From the position of the produce quality these are different autos – but only in consumer's perception. From the position of philosophy they still remain autos as man-controlled self-moving machines.

If the quality is a property describing the integral unity of a thing, then there must be a property describing the preservation of the integral unity of a thing in time. By definition, such property is the reliability because the properly functioning thing in case of failure loses quality after some time. After the repair carried out the quality could return, but in case of unrecoverable failure the quality is lost irreversibly.

Consequently, the reliability is a property to keep the quality in time (for comparison: *the reliability is one of quality aspects depending on time* [ISO 8402:1994, article 2.5, note 2], or *the reliability is the quality expanded in time* [10]). Considering that quality is a set of the thing's properties, the reliability then can be regarded as the property to keep the stability of the thing's properties (for comparison: *the reliability is the object's preservation in a given time interval within the limits required and sufficient for its functional capability at workloads* [11]).

By analogy, the reliability is a property to keep the quality in time, or the property to keep the stability of the things properties.

Based on the foregoing, a set of all properties of the thing, including the reliability as an integral part of it, makes the quality with an achievable level. The reliability, meanwhile, expresses the achieved quality as an integral whole on the part of its time preservation. Thus based on philosophical understanding, the reliability reflects the achievability of specific quality level, and simultaneously, defines the preservation of quality preservation in time.

The first effect of the philosophical aspect of reliability

In view of the delivered philosophical understanding it becomes obvious that reliability as a property is appropriate only to material objects (according to A.I. Uyomov, the property is the relation of things). Looking at the terminology we can see that this is how it is reflected in the modern term "reliability". *The reliability is the property of an object to keep all parameters for support of the ability to function in the prescribed modes and conditions of application, maintenance, storage and transportation* [GOST 27.002-89, table 1, article 1.1]. Since according to GOST 25866-83 the modes and conditions of application, maintenance, storage and transportation are together the operational conditions, the reliability is understood as the ability to keep (within prescribed limits) technical object parameter values in terms of operation only.

Inspired by the definition of "reliability" it is implied that from the beginning and till the end of operation there may be a certain recession of the level of parameter values affecting reliability. Therefore, to provide target reliability in the end of operation it is implied that at the beginning of operation the object should have the maximum possible necessary initial level of reliability. And the initial level of reliability is a priori higher than the current one. Hence there occurs the rhetorical question – what value should the index of FFO probability have for UMCS at the beginning of operation so that it will be close to one at the end of operation?

It is well known that operation is the part of a product's life cycle following the stages of development, production engineering and the cycle of manufacture. At the stages of development and production engineering there is no material object yet – we can only speak about various models of the object. It is produced within the manufacturing cycle, but before putting into operation the material object does not exist de facto.

In relation to UMCS there occurs a paradox. There is no product as a material object, but at the same time its expected reliability must be extreme close to one. Practically it means that by the beginning of operation the state of UMCS as regards reliability must be ideal, there should be no engineering, manufacturing and operational near failures, i.e. as it is passing the life cycle phases its failure-free operation shall not deteriorate due to:

– imperfections of engineering and design methods, engineering errors, breach of the requirements of normative and technical documentation, breaking of engineering rules and regulations;

– imperfections and errors in the applied technologies;

– defects and errors of manufacturing, assembling and installation, troubles with technological processes of production, friction joints burn-in, degradation of parameters after tests required by the manufacturing cycle.

Here is the conclusion already mentioned in the other words: reliability is not just the property, but the ability to show this property (terminologically, *the ability is a property allowing somebody or something to do an action*).

Such aspect gives the opportunity at the early stages of a life cycle before the operation to consider one more important factor for reliability. It is nothing else but discrepancies and errors at the creation of models during the development and production engineering, as well as unauthorized actions in relation to a physical object during installation and maintenance in form of probability of unmistakable actions of people involved in the UMCS development and creation.

Possibility to consider the reliability as the property and as the ability depending on the life cycle stage allows eliminating mismatch of reliability terms highlighted by A.S. Pronikov. The native literature describes the term reliability mostly as the property, but the English-language references determinate it as the ability of a product to keep the prescribed functionality in time [8]. The question arises then if the reliability is the ability (assertion by the American school of reliability), or the property accepted by the Soviet and Russian science? By the philosophical aspect of UMCS reliability under consideration, the reliability is simultaneously the property and the ability. When operating the objects it is by all means the property. On "prior-to-material" stages of the life cycle including waiting for operation, it is certainly the ability.

It was A.N. Tupolev who paid attention to the consideration of object reliability on "prior-to-material" stages of the life cycle: "The further from the developer board the unreliability is detected, the more it comes at a price".

The same idea was expressed by V.I. Kurenkov by the correlation formula of correction expenses at the design stage 1:10:100:1000 (design: development: batch production: operation) [10]. For correction of the specific error, provided it is early detected, the amount of expenses will be equal to the "amount" that leads to its occurrence. At the following life cycle stages, the elimination of design errors causes considerable increase in expenses.

For UMCS it becomes even more serious due to the total price of rocket vehicle and spacecraft. Severable or complete breach of the operating capability of the latter because of the failure of a "pennyworth" element of the opening sections is the luxury which is unnecessary, and sometimes even – inadmissible. In particular, with a failure of mechanics opening the solar panels, for instance, due to the malfunction of only one locking clamp, the financial consequences are measured not by the net cost of the defected element, but by the damage evaluated by the base value of transport delivery system, which for the spacecrafts like "Express-AM5", "Express-AM6" as part of the rocket vehicle "Proton-M", amounts to 8,35 bln. rub.

For the indicated reasons the UMCS state as the ability allowing to wait for the reliability property occurrence before the start of operation, is deterministic, as any error at the first stage of a life cycle defeats the purpose of further activity. A good example is the Chinese spacecraft Sinosat-2, spaceborne on October 29, 2006. After the orbital insertion SP sections and telecommunication antennas did not open due to some design and technological errors, and as the result the spacecraft was lost never starting the operation.

The second effect of the philosophical aspect of reliability

The paradigm by A.I. Uyomov determinates the thing by the relation of properties. The set of relations makes the system which can be regarded as the system of properties of quality or, taking into account the system's hierarchical pattern – as the set of subsystems of the quality properties. Accordingly, the reliability property of UMCS is proposed to be considered as the system of finite number of quality properties changing with time.

Any properties giving instability with time can be detected by methods of system analysis, distinguished qualitatively and specified quantitatively by means of values [12]. For a rotary gear of the shaft of spacecraft magnetometer under operation [1], there performed a detailed analysis of such properties, including the property to provide angular freedom of a rotating joint in any angular position of the shaft, the property to provide energetic sufficiency for the shaft's rotating by the full angular orientation, the property to provide unobstructed movement of the shaft on the prescribed trajectory, etc.

It is important to note that this philosophical aspect gives the possibility to consider not only the properties which could be specified by means of parameters, but also the properties which can be specified by nothing else but indices, or which can be specified by both – parameters and indices. Parameters here are the values, intensity of which can be measured directly by technical devices or calculated (length, strength, moment, etc.), and indices are the calculated colligating data to check the state of the property under or parameters (contingency factor, factor of moving torque, FFO probability, probability, etc.). Operating with parameters and indices allows choosing the values useful for qualification of properties, for instance, for determination of properties of contingency one can use:

– values of current loads (parameters) if these are enough for estimation of stressed-strained state;

– values of current stresses (parameters) if it is necessary to distinguish states of strength;

– contingency factors (indices) in case of complex stress.

Using indices it is possible to consider the properties which can be distinguished only in a quality manner in "binary" form: "zero-one", "yes-no", or which can be specified solely by reliability indices, for example, FFO probability.

Considering the above, the set of properties can be expressed by a certain space of UMCS parameters as the system of indices and parameters (1):

$$F = f(X_1, X_2, X_3, \dots X_k), \quad (1)$$

where $X_1, X_2, X_3, \dots X_k$ are the indices and parameters specifying the UMCS quality properties; k is a total number of UMCS quality properties.

UMCS condition is considered as operating in case its indices and parameters are within the area of admissible states of quality space. The limits of operating condition of UMCS are specified by set of constituent elements of the quality property (1), each of such elements meets the requirement for indices and parameters to be within the limits of their maximum permissible variations:

$$D_x = \left\{ X_i \,\middle|\, X_{\min(i)} \le X_i \le X_{\max(i)} \right\}; \; i = 1, 2, 3, \dots k, \quad (2)$$

where X_i are the values of indices or parameters of the i property; $X_{\min(i)}$, $X_{\max(i)}$ are the maximum permissible limits for the values of indices or parameters of the i property.

Formula (2) fully describes UMCS quality. UMCS reliability, as it was noted above, is the property to keep the quality with time, and it is determined by the probability for the element of the $X_i(\tau)$ set to be within the limits of permissible quality space D_x during the time interval $0 \le \tau \le t$:

$$H(t) = P\left[X_i(\tau) \in D_x; 0 \le \tau \le t\right], \quad (3)$$

where $P(A)$ is the probability of event A.

For UMCS, elements of which are normally the points of a single failure, formula (3) can be transformed into formula (4):

$$H(t) > \prod_{i=1}^{k} P_i(t), \quad (4)$$

where $P_i(t) = P\left[X_{\min(i)} \le X_i(\tau) \le X_{\max(i)};\ 0 \le \tau \le t\right]$.

Formulas (2) and (4) indicate that at early stages of UMCS life cycle it is already possible to form such engineering and technological requirements for the development process that provide the performance of the target quality and reliability indices. Methods and application examples of such requirements in relation to UMCS are described in papers [1, 13]. The design-engineering activity on the provision of target reliability, as per the described philosophical approach comes down to the following algorithm:

– determination of necessary and sufficient requirements to the design, ensuring its functional capability in the given area of permissible states of the quality space;

– basis for probability of keeping of the specified requirements with time under the given operational conditions;

– administrative, technical and methodological measures to fulfill the requirements;

– control of the fulfillment of the prescribed requirements at all stages of a life cycle.

Findings

1. The suggested approach to the reliability perception based on the considered philosophical aspect exemplified by unique mission-critical systems does not contradict with general prevailing notions and methods of theory and practice of reliability, and simultaneously, it enables to solve the reliability tasks without probabilistic and statistical methods of calculation of reliability indices.

2. As per GOST 27.002-89 the currently accepted term “reliability” does not fully reflect the specific features of UMCS task solving in terms of application of the notions “property-ability” and “parameter-index”. At the same time, the ability to distinguish the above mentioned notions gives essential advantages for the assurance of UMCS reliability. In particular, it conduces:

– regular distribution of the attention of UMCS developer among the stages of life cycle to achieve the initial level limit of reliability and to reduce various near failures at the very early stages of a life cycle;

– consideration of UMCS properties which can be estimated only by the trustworthiness of their performance by means of probability of the “binary” event in “yes-no” form. It is important, for instance, when estimating the property to provide unobstructed movement of the revolute construction elements on the prescribed trajectory. The timely consideration and appropriate estimation of this property could certainly have prevented from the mesh of solar panels of “Soyuz-1” with the blanket foam pads, that could have enabled the unobstructed opening of the panel;

– consideration of the properties of UMCS elements, which could be determined based on statistical samples. For instance, it is pyrotechnics that is used as initiator of primary actuation of LTMS. The basic elements of the pyrotechnics are the pyrotechnic squibs – large tonnage products with specified values of reliability factors, which could be used in formulas (1-4);

3. The philosophical understanding of reliability as the property to keep the quality in time makes it possible to build a logical bridge between an expected reliability factor of UMCS and separate indices and parameters of quality properties. It offers a number of opportunities which were unavailable earlier:

– by varying the values of particular FFO probabilities, descriptive of the values of indices and parameters of any given properties to be within the limits of admissible range, it is possible to achieve the FFO probability target values of the system as a whole. The task to find out what essentially should be changed in the design of the particular UMCS in order to raise its failure-free operation for example, from three nines to four nines, deduces the certain solution algorithm based on formulas (1-4). In order to do that, based on the value level of particular FFO probabilities, a “weak component” has to be found in the system of properties of the object’s quality, as well as reinforcement measures have to be taken. For example, to reconsider the engineering and technological requirements of failure-free operation with adjustment of the range limits of indices or parameter values, to change, when possible the constitution model of reliability, to quash the constructive decisions, etc.;

– engineering evaluation takes up its niche in the methodology of reliability as the system analysis of the quality properties changing with time calls for the necessity or feasibility of any engineering evaluations eliminating the human factor in selecting. Reliability calculations are assimilated to additive consideration of the results of engineering evaluations to keep the quality properties with time. Failure to carry out one or another engineering evaluation when developing UMCS causes the ambiguity of trustworthiness of the final figure of reliability;

– a designer could provide the timely specification of any requirements being aware of their influence on the specified reliability requirements.

Conclusion

This paper describes the philosophical approach to the solving of practical problems of UMCS failure-free operation based on the theory of reliability of mechanical systems by V.V. Bolotin [5, 6] considering a certain specific character – unavailability of probabilistic and statistical methods of decision.

Unlike with the theory of reliability of fail-safe systems by A.M. Polovko and S.V. Gurov [3], who denied the possibility of calculations for technical systems with the FFO probability which is more than 0.999, the philosophical understanding of reliability gives the key to quantitative evaluation of UMCS reliability. These evaluations shall be used as the analysis procedures for confirmation of sufficiency of measures taken to provide reliability followed by practical conclusions vital for solving daily problems faced by designers.

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