Necessity of creating digital tools to ensure efficiency of technical means

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Abstract. The authors estimated the problems of functioning of technical objects. The article notes that the increasing complexity of automation systems may lead to an increase of the redundant resource in proportion to the number of components and relationships in the system, and to the need of the redundant resource constant change that can make implementation of traditional structures with redundancy unnecessarily costly (Standby System, Fault Tolerance, High Availability). It proposes the idea of creating digital tools to ensure efficiency of technical facilities.

1. Introduction

To prevent significant damage in case of failures of equipment and control devices in automated control systems of technological processes - ACSTP (CAM, ACS, DCS, ICS, Process control system, C&I system), the redundancy is applied in the traditional ideology, which covers the duplication Standby System (the organization of unloaded redundancy), High Availability structures (carrying out redundancy replacement), and Fault Tolerance structures (constant redundancy) [1].

However, in the last decade, the use of traditional ideology of redundancy has been put to the test [2]:

• firstly, there is the complication of automation systems not only in new enterprises but also in the modernization of existing ones. This is associated with a sharp increase in elements of automation systems and the complication of connections and relationships (laws of transformation) between the components (increasing the number of sensors, actuators, control loops, the control circuits of accounting and planning). All this requires an increase in the redundant resource, which is actually proportional to the number of components and relations in the system;

• secondly, if earlier the requirement for high reliability was imposed solely on specific industries (explosive, chemical, nuclear power plants, power distribution systems, intelligent systems for buildings high-risk type tunnels, airports), since the 2000s, the economic environment has changed dramatically. Significant complications of general industrial facilities in connection with extensive automation and robotization of production processes actually have led to the need for a substantial increase in the overall level of reliability of ACSTP, which also significantly increases the redundant resource;

• thirdly, a dynamically changing economic and industrial situation in the regions leads to a dynamic change in the working environment of an enterprise, which often leads to a constant
change in relations, relationships and the component structure of automation. In case of the complication of automation systems and the reliability increase, the redundant resource increases in proportion to the number of components and relationships in the system. Then, taking into account the dynamically changing production environment, not only needs for the redundant resource permanent changes, but also the change of the number of standby-devices arise, and this can remind a hardware “combinatorial explosion”.

All this sets a judgment that the traditional redundancy structures Standby System, High Availability and Fault Tolerance, in the current trends in the industrial production development, can lead to unnecessarily costly solutions (Figure 1), and, in this regard, the research to find new tools to ensure the efficiency of technical means is required.

![Figure 1. Unwanted consequences of using traditional redundancy.](image)

2. Assessment of opportunities

The existing procedure of creating the automated control systems by an industrial enterprise is to develop a five-level (tier) structure of the automation system [3, 4]: ERP (Enterprise Resource Planning) for accounting and enterprise resource planning; MES (Manufacturing Execution Systems) for industrial process control; MMI (Men-Maching Interface) for operational control of technological processes; Control for the operational management of technological operations (so-called level local management); Input/Output as a tier of sensors and actuators covers various automatic control and regulation means. The latter three tiers (levels) are ACSTP.

For automation means of each of the ACSTP levels [5], the pattern of equifinality is particularly sensitive when they reach time-independent conditions under which the functioning of the means depends neither on initial conditions nor on external disturbances, and is determined solely by the parameters of the technical means [6, 7]. This means that during the device operation, a moment always comes when it ceases to fulfill its target function. The meaning of the indicators “a limit state” and “a limit state criterion” may be referred to close normative terms.

That is, after a certain time of the required functioning, inoperability may be fixed as a fact of failure of any of its functions, which are described in the operational documentation, as well as a fact of failure of several functions. Finally, there will be a clear disorder of the object operability as a whole, that is, the device impossibility to perform its target destination can be fixed (GOST 27.002-89, IEC 61508-5-1998). For example, it can happen in the form of the distorted output characteristics of the technological process, resulting in the release of defective products, or pre-fault conditions in the permissible boundaries of the system settings, or even the circumstances of the accident (emergency shutdown, destruction, equipment disposal or technological objects control).

Therefore, it is possible to say that the failure of the various devices or their components (as well as the system as a whole) is an expected and understandable event. At the same time, considering this
phenomenon as a natural one, it is imperative not only to be able to estimate a priori that the researched system (system, object) will be operable in the required time and then, possibly, for some subsequent interval of functioning, but also to have the tools to ensure operability.

Different characteristics can be used to assess operability (for example, GOST 27.002-89; GOST 15467-79). In the system plan, they are the following:

- the academic reliability indicator (in professor I. P. Bushminskii’s view, 1989 [8]) as the functioning ability to maintain operability of the whole system in case of failure of specific device components with all its actually derived notions of reliability, durability, maintainability, persistence, MTBF, failure rate, etc.;
- the vitality indicator (in prof. V. V. Denisenko’s interpretation, 2009 [5]) as the ability (of an object) to retain limited operability during a fault or failure of some components, including information technology (GOST 34.003-90), while understanding faults (GOST 27.002-89) as a state of the object at which it does not meet the technical requirements of at least one parameter (or defect according to GOST 15467-79);
- the availability coefficient (operational availability) as the probability that the device will be in working state at any time, except for planned periods, during which the device usage until its destination is not provided (and, from this moment, it will work reliably within a specified time interval) (GOST 27.002-89, p. 7) in specific valuation methods (for example, in prof. A. E. Alekseev’s formulations, taking into account the concept of stationarity (2004 [9]).

On the whole, it is generally accepted that without such tool as redundancy, which is aimed at ensuring operability, it is impossible to achieve high reliability in complex technical devices, even using elements with high reliability.

3. Conclusion: to the digital redundancy

As noted above, the most effective response to the possibility of the failure occurrence is measures for structural redundancy by introducing redundancy (unloaded redundancy – Standby System), redundancy substitution (High Availability) with their versions of loaded (hot), reduced and unloaded (cold) standby and the permanent redundancy (Fault Tolerance), provided with a majority redundancy with a scheme of “voting” without switching [10, 11].

Irrespective of the merits, the most common and well-known features and limitations are typical of the marked tools in terms of selected operability assessment.

Firstly, it is assumed [5] that the unloaded (including cold) standby has a low availability coefficient; the redundancy substitution is characterized by a high dependence on the reliability of switching devices; the permanent redundancy backup (as in hot standby) is characterized by a decrease in the resource over time. Hence, generally understood, the first group of problems relates to the lack of some “unified” tools for ensuring operability, which are deprived of unsuitable characteristics and limitations;

Secondly, as it has been noted, the growing complexity of the ACSTP structure means increasing the number of control objects, sensors, actuators; the complication of laws (conversion functions) of interactions (relations and relationships) in the system of management; the complication of relationships with higher tiers of the management hierarchy (ERP, MES) and with related structures within a single production (other MMI, Control, and Input/Output). The complication with the environment of interaction not only significantly increases the need for redundant equipment, including the fact that it provides the functional (mathematical, information, software and organizational support), but also leads to a sharp increase in the redundant resource.

So, inevitably there are problems associated with both the provision and maintenance of a large amount of redundant equipment in the structures of ACSTP, and with the complexities of the production processes in connection with the significant increase in the density of the redundant resource within the boundaries of the production capacities.

It is necessary to stick to the traditional understanding of logistics (prof. S. M. Rezer, A. N.Rodnikov, 2007 [12]). This logistics is understood as all the issues of planning, control and
management of transportation, storage and other tangible and intangible operations, which occur in the process of bringing (in this case) redundant elements (blocks, boards, modules, assemblies) to the place of production replacement of redundant components along with the solution to the problems of transmission, storage and processing of relevant information. Also when taking into account the strict time limits, within which any event dealing with redundancy should be carried out, it is possible to speak about the second group of problems. These problems are connected with the logistic difficulties, associated with attempts to resolve issues, which are caused by the redundant equipment “combinatorial explosion” and by a substantial increase of their density in the production structure. Apparently, this group of problems can limit, or even make futile any approaches to ensuring the required levels of reliability of complex automation systems (that is, in fact ACSTP) by means of the traditional redundancy.

It is not surprising that the solution to the problems of both groups, ultimately, will be reduced to the replacement of the “old” by the “new”. But in this case, it is essential how this process will be conducted: with high material, financial and labour costs in an “emergency” mode with the (temporary) cessation of the enterprise target activities, or with the appropriate consistent optimization of losses and retention of the required level of the production and technological process efficiency.

The first group of problems is caused by the need to use traditional structures of unloaded redundancy, redundancy substitution and persistent redundancy, burdened with the uncertainty of selecting or constructing required tools to ensure operability. This group allows offering, in a sense, a systematic approach to the solution, for example, of constructing a predicate evaluation of the circumstances of equifinality. Besides, it enable the substitution of pre-emergency components for new or operable samples and based on the results of the assessment of the predicate application in advance, without any interrupt of the enterprise target activities.

But the solution to the issues related to a significant increase in the redundant resource and, as a consequence, a substantial increase of density in the production capacities of industrial enterprises in the modern paradigm of redundancy, may be either unreasonably costly or impossible. In this respect, the solution to the issues of the second group is possible only in one direction – transpositions of the functions of the failed (or failing) component to other operable structures of the device.

Undoubtedly, the infinite arrangement is impossible, and the total equifinality is inevitable. But in this case, requirements to perform the entire range of logistics activities – starting from the search, acquisition and other activities and ending with a significant weakening of the requirements for the time of replacement and putting a redundant resource into operation – are significantly reduced.

Most likely in turn, the transposition of the functions of the failed component from the system point of view can be viewed in two ways. First - as a reinforcement in the construction solutions of the hardware variability of the device structure, in which a priori, there is the standby redundancy or operational formation of the required (reserved) functions. Second - as a creation of a structure that is able to fix, to recognize and to store the current states of redundant components so that in case of equifinal conditions (e.g., pre-emergency), to enter correctly the testing of functions of the process, in which the failing part of the device is involved.

The first representation (the embodiment of a variable structure) has not gone far from duplication and is not far from removed redundancy, from standby, subjected to the risk of the “combinatorial explosion”, although it smooths its effects slightly. The second representation is impossible for analog equipment, because any converter is structurally (and hardware) unique at least in its system and physical and technical characteristics if not in its own type. Besides, it is fundamentally not adapted to the implementation of the recognition, the maintenance and alteration of its transformation laws.

At the present level of the technology development, this is possible only when using digital algorithmic devices in the model of computing machines of discrete action with its well-known arithmetic and logical capabilities [13 – 16] and information technology of the artificial intelligence [17 – 19]. In other words, at the present stage of technological development, the transposition of the functions of the failed component to other parts of the device (system) structure is possible only with the use of digital calculating machines (DCM). Taking into account the weight and dimensional
parameters of control means and their number in ACSTP, it is undoubtedly possible in a miniature version.

Since there is no methodology of digital redundancy, the creation of digital tools to ensure operability of technical means of control is urgent.

4. Acknowledgment
The development of this topic is supported by Orel State University named after I.S. Turgenev, Order No. 7-n / 26 of 23.10.2013.

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