About problematic peculiarities of Fault Tolerance digital regulation organization

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Abstract. The solution of problems concerning estimation of working capacity of regulation chains and possibilities of preventing situations of its violation in three directions are offered. The first direction is working out (creating) the methods of representing the regulation loop (circuit) by means of uniting (combining) diffuse components and forming algorithmic tooling for building predicates of serviceability assessment separately for the components and the for regulation loops (circuits, contours) in general. The second direction is creating methods of Fault Tolerance redundancy in the process of complex assessment of current values of control actions, closure errors and their regulated parameters. The third direction is creating methods of comparing the processes of alteration (change) of control actions, errors of closure and regulating parameters with their standard models or their surroundings. This direction allows one to develop methods and algorithmic tool means, aimed at preventing loss of serviceability and effectiveness of not only a separate digital regulator, but also the whole complex of Fault Tolerance regulation.

1. Introduction

It is obvious that every deliberate transformation of a device structure (its elements, components, parts, relations and connections between them or media) must not at least worsen assessment indicators of its functioning quality in the process of redundancy. The ability of the device to perform the required functions will be at the core of the indicators for assessing the quality of functioning because:

1) “redundancy is a way to ensure reliability of an object through usage of additional means and (or) opportunities, redundant in relation to the minimum necessary for performing required functions” (SS (state standard) 27.002-89, p. 7);

2) “reliability is an object property to preserve the values of all the parameters in time and stated limits (borders). These parameters characterize an ability to perform required functions in predetermined regimes, conditions of usage, technical application and transporting” (SS (state standard) 27.002-89, P. 2).

Normative notion of fault (SS [GOST] 27.002-89, P. 2), including the term defect (according to SS [GOST] 15467-79), is defined as an action of a serviceability violation of an object, provided that operation state of an object (serviceability) implies a special state of an object. In this state, the values of all the parameters, characterizing the ability to accomplish (complete) predetermined functions, correspond to the demands of normative-technical and (or) design (project) documentation, including
the documentation, concerning information technologies (SS (GOST) 34.003-90). Therefore, fixation of a fault or the “pre-fault state” is possible only with a current (in a function tact) verification of the fact of the serviceability violation, which requires check-up of “the values of all the parameters, characterizing the ability to complete (perform) predetermined (preset) functions”.

The selected phrase “the values of all parameters that characterize the ability to perform specified functions” can be interpreted with varying degrees of detail and interpretation. However, it is obvious that for the noted term “working capacity” it is difficult to single out all the parameters characterizing the ability to perform certain functions and take into account all parameters in the design documentation. Perhaps this is even unrealistic. In any case, the parameters will reflect a certain limited set of states, properties, features or their combinations. Perhaps in the targeted plan such parameters must, first of all, reflect representatively not only functioning of the object, but also its laws of development (changes). Such parameters can be chosen in different ways. As a rule, the choice is based on the theory of signals and the theory of identification [1 - 7]. However, there are still difficulties in assessing the health of the system as an integral object. In this plan of the research, the use of system analysis and systems theory is considered as reasonable [8].

This article discusses the problems associated with the organization of digital fault tolerance regulation related to the assessment of operability in a systemic aspect and the prevention of disruption situations.

2. Scientific problem

Since the object (system, device) functions exclusively in accordance with its structure $S$, a description of the structure that provides a workable state can actually express the essence of operability. To do this, let us use well-known variants of constructing the definition of L. von Bertalanffy, V.I. Vernadsky, U.R. Gibson, M.G. Gasa-Rapoport, A. Hall, P.K. Anokhin, M. Mesarovic, V.N. Sagatovsky or Y.I. Chernyak [8].

Moreover, structurally simple descriptions can also be successful in the form of:

$$S \equiv \{\{a_i\}, \{r_j\}\}, \quad a_i \in A, \quad r_j \in R$$

or

$$S \equiv \{A, R, Z\}, \quad (1)$$

and structurally complex descriptions - in the form of:

$$S \equiv \{A, Q_A, R\}$$

or

$$S \equiv \{A, R, Q_A, Z, T, N, G\}, \quad (2)$$

where $a_i$ – elements of the structure; $r_j$ – connections and relationships between elements; $Q_A, Z, T, N, G$ – properties, goals, time interval, observer and description language $S$.

However, it is obvious that not all components of both simple description (1) and complex description (2) are structured. That means that they allow “adequate” formalization and thus allow the construction of formal models of all those parameters (characterizing the device’s ability to perform specified functions), for which the relevant requirements of normative and technical and (or) design (project) documentation will be established and formulated.

In connection with this, it is meaningless to build up (construct) and use approximated or even abstract (simplified, abstract by some components and relations) assessment of serviceability with operational evaluation of function quality, accompanying it, with a help of which, the events of serviceability violation may be marked. This means that methodological and algorithmic support, oriented to approximation or abstracted estimates, in reality can lead to erroneous fixation of a failure (“pre-failure” state) or erroneous confirmation of operability.
With regard to digital control circuits, this state of things may be typical not only of the project (design) level, when there is sufficient time resource (limit) for correction, but may also appear in the process of functioning, which can demand correction of regulation algorithms in the process of functioning. That can demand an operative correction of that part of the control algorithms which provides fault tolerance (if the predicates of the evaluation of operability violation can be a priori formalized).

Since there is no methodology for operational evaluation of operability in the theory of regulation, the issues of adjusting the control algorithms in the process of functioning are an important scientific problem.

3. Methodological approach

With the aim of overcoming the obstacles of the uncertainty of the sets of “all parameters” from the point of view of their usefulness for assessing performance, it is pragmatic to base on the classical concept of a diffuse (poorly organized) system. It involves the representation of the device without taking into account all its components, but with a concomitant set of certain patterns of functioning.

Digital regulation circuits (for deviation) can be represented, for example, as a combination of components: “An object of regulation”, “a sensor – anti-aliasing low frequency filters (ALFF) – an analog-digital converter (ADC)”, “setting impact – ALFF – ADC”, “the scheme of computing the controlling impact (hybrid signal processor)”, “a digital-analog converter (DAC) – smoothing (burnishing) low frequency filters (SLFF) – An operative mechanism”.

For the circuit of digital regulation as an object of investigation with electromagnetic, structural, operational features, with features of the realization of its components, the representation in the form of a separate diffuse system is likely not enough.

Numerous features that can not always be noted and appreciated require the representation of circuit of digital regulation in the form of the combination of several diffuse systems, each of which displays different components of the device with the corresponding patterns of functioning. Or they can be represented as a composition of such diffuse systems, in each of which there will be its representative set of parameters, through which it is realistic to assess the violation of operability.

At the same time, it is natural for the composition of diffuse systems to have either a common predicate for estimating an operability violation characterizing the integrity of the device or a hierarchically weighted evaluation sequence. These structural variants and their various combinations can be attributed to the problematic features of the organization of fault-tolerant digital regulation, since they, when performing an important function of fixing the disruption of operability, do not predetermine and do not prevent or rectify the malfunction.

4. Prevention of the situation of inoperability: transformation of the structure of majority reservation

The basis for the organization of fault-tolerant digital control is the synthesis of the analogue control circuit and the principle of permanent redundancy (Fault Tolerance), expressed by the majority reservation with a “voting” scheme without switching (Figure 1). After that, the structure of the regulator and the values of its adjusting parameters provide the required supply stability in the boundaries of digital control circuits.

A widespread practice of redundancy covers all the components of control means from analog input modules and sensors, sensors and modules of discrete signals input, analog output modules, modules of discrete output and load, CPU (processor) modules, networks with voicing, redundancy (reservation) of power (supply) source till a complete redundancy (reservation) of industrial networks in compliance with IEEE Std 802.1Q-2005 and IEEE Std 802.3 standards [9]. As a rule, redundancy (reservation) of computational tools, including reservation in regulators, comes down to reservation of processor plates (cards) and its arithmetic-logic core (ALC) with subsequent special implementation into chips (integrated circuits) [9, 10].

However, it should be noted that the main difficulties are connected not exactly with Fault
Tolerance principles for an organization of Fault Tolerance regulation, but with an implementation of special opportunities, which appear and become available with the transfer to the digital regulation. The idea of regulating fault tolerance (Figure 1) does not solve the problems of preventing a malfunction. If two burned out chips of three (Figure 1) show similar results with zero or maximum possible potential (power), then the main element will output exactly these values in the control circuit and the error will not be fixed.

Meanwhile, transfer (shift) to a digital regulation may entail considerable changes. If incorporating digital circuit of regulation into the structure of Figure 1, the functional of Fault Tolerance digital regulation of a new structure (Figure 2) acquires new features and qualities:

1) in the classical structure (Figure 1), the current values of control actions $U_j(t_i)$ ($j=1,2,3$) are estimated. In the new structure (Figure 2), numerical values of not only control actions $U_j(t_i)$, as in the classical case of Figure 1, but also adjustable parameters $x_j(t_i)$ and residuals of the regulation $\Delta x_j(t_i)$ loop itself, can be taken into account. Then, Fault Tolerance may be organized in accordance with the conditions of choice of any combinations from collection $\{U_j(t_i)\}$, $\{x_j(t_i)\}$, $\{\Delta x_j(t_i)\}$ ($j=1,2,3$) (Figure 2). In other words, the choice of controlling impact in a new major scheme may be made not only according to assessment $\{U_j(t_i)\}$, as it has been mentioned previously, but also in accordance with corresponding group conditions of assessment (the predicates):

$$\left\{\{U_j(t_i)\},\{x_j(t_i)\}\right\}, \left\{\{U_j(t_i)\},\{\Delta x_j(t_i)\}\right\}, \left\{\{U_j(t_i)\},\{x_j(t_i)\},\{\Delta x_j(t_i)\}\right\} (j=1,2,3);$$

2) the classical structure of fault tolerance organization (Figure 1) is the structure of the “point” comparison of the current values of control $U_j(t_i)$ influences at given moment $t_i$. And the new structure (Figure 2) is oriented to comparison of processes, i.e. comparison of the dynamics of a parameter that undergoes regulation or the dynamics of errors (faults of closures, faults) or the dynamics of the controlling influence, oriented at all, for example, three branches of the structure. In other words, the new structure allows one to compare curves $x_j(t)$, $\Delta x_j(t)$, $U_j(t)$ ($j=1,2,3$) in the entire interval of $[t_0,t_1,...,t_{i-1},t]_i$ from initial $t_0$ to current time $t_i$ or permanently in limited time window $[t_{i-k}, t_{i-(k-1)}, t_{i-(k-2)},...,t_{i-1},t]$, where $k<i$. In this case, value $k$ may vary depending on predicates specific to the process of providing fault-tolerant regulation;

![Figure 1. Major reservation (redundancy) in accordance with a principle “2 out of 3”, where 1, 2, 3 – reservation, stand-by (redundancy) branches of “identical” regulators; “1&2”, “1&3”, “2&3” – formation of conditions of choice; $\Delta x(t)$ - an error (a misclosure) at the moment: $\Delta x(t) = x_0(t) - x(t)$, $x(t)$ – a regulated value, $x_0(t)$ – a setting (a set point); $U_j(t_i)$ – evaluated controlling influences ($j=1,2,3$); $U(t_i)$ – control action at $t_i$ moment: $[t_0, t_1, ..., t_{i-1}, t_i]$.](image-url)
3) the introduction of majority branches of the redundancy of digital regulators lays the groundwork for preventing the situation of the inoperability of not only a separate digital regulator (a separate branch) but also the entire chain of fault-tolerant control (Figure 2).

5. Conclusion: some directions (approaches) and prospects
The idea of preventing the situations of serviceability loss may be determined by the system law of equifinality [8, 11], characterizing an ability of a system to achieve a special condition and state. That depends neither on time nor on initial conditions and even nor on external disturbances, which is determined by the parameters of the system. This means that the regulation has lost the ability to perform desired function $x(t)$, for example, of the required type in a certain time window: $[t_{i-k}, t_{i-(k-1)}, t_{i-(k-2)}, ..., t_{i-1}, t_i] (k < i)$.

In connection with this, setting a standard curve (function) of the regulated parameter or its aperture and entering a definite, particular time limit, metric of proximity, an error of deviation between current and standard functions of the parameter, undergoing regulation, one can always a
priori set an expected moment of loss of serviceability of a regulation (control) system. Doing this, one can guarantee the possibility of taking measures for supplying an “absolute” Fault Tolerance of the regulation means.

Transfer to digital regulation and usage of microprocessor equipment (hybrid signal processors and microcontrollers) give additional opportunities for solving complicated problems of serviceability assessment and possibilities of prevention of its violation at least in the following directions:

- creating methods for presenting control loops in the form of combining diffuse components, recommending the selection of a set of macroparameters and the regularities of each of the components, and forming an algorithmic tool for constructing performance assessment predicates separately for components and control loops as a whole;
- creation of methods of Fault Tolerance (redundancy) reservation in the process of complex assessment of current values of controlling influences, errors and regulated parameters:

\[
\langle \{U_j(t_i)\}, \{x_j(t_i)\} \rangle, \langle \{U_j(t_i)\}, \{\Delta x_j(t_i)\} \rangle, \langle \{U_j(t_i)\}, \{x_j(t_i)\}, \{\Delta x_j(t_i)\} \rangle (j = 1, 2, 3)
\]

- creation of methods of comparison of the processes of controlling influence change, errors and regulated parameters \( x_j(t) \), \( \Delta x_j(t) \), \( U_j(t) \) \((j = 1, 2, 3)\) with their standard models or their surroundings for creation of methods and algorithmic and tool means, aiming at prevention of serviceability loss not only of a separate digital regulator, but also of the whole complex of Fault Tolerance regulation (control).

6. 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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