Intelligent elements in control systems and monitoring

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Abstract

A method is proposed for obtaining reliability indexes (RI) of control. Method is based on purpose control criteria (PCC). RI’s take into account the probability density of controlled parameter (CP) and its measurement precision. In the RI, methodical and instrumental components are distinguished. Methodical component corresponds to attainable limit of RI for precise measuring the object characteristic-of-interest.

Keywords: Reliability indices, purpose control criteria, methodical and instrument components

1. Introduction

Analysis of PCC is intended for control optimization of dynamic system’s and medico-technical parameters on trial stands for modeling the technical objects with prolonged circle of autonomous exploitation (including deep-underwater objects). The aims are the tracing of CP’s, data base on results of on-line registration of object dynamics, operative-tactical loads for tested men-operators on the modeled technical object [1-4]. OCP’s are the indexes of operator functional state (ECG, EEG, skin-galvanic reflex, speech indices), contamination levels (gas emanating from synthetic constructional materials in hermetic-object). Similar problems exist in monitoring of radioactive ejections in the field of AES.

Methodology for conclusions on object state quality using control principles and conceptual idea of PCC are seldom used now [5, 6], although proposed method is particularly important in the case of control system designing for training conditions with sub-extreme levels of men-influenced factors. Control traditional method based on principle “if OCP is lower than standard then it is good, if it greater, then stop”, does not provide decision problem in control [1, 2]. Similar situation is in the field of technical systems control. Aspiration to satisfy permit limits for all OCP results in requirement to interval widening for permissible deviations from standard or results in the operator-load lowering, shorten the list of permissible constructional materials, lowering the autonomous object exploitation, i.e. in whole, it lead to non-adequate estimation of quality of controlled object.

At the same time, the investigated conceptions and methods oriented on diagnostic control criteria formed by experts are absent [6-8]. Therefore, getting the new methodic approach to control optimization is acutely palpable in applied problems of ecological and radiation monitoring where the whole hierarchy of standardized limit-permissible concentrations and levels (LPC and LPL) exist [9].

Proposed methods are based on earlier investigations and papers [10].

2. Reliability indices

Our effectiveness index describes the lowering of probability of prescribed-problems realization under deviation of CP from its standardized quantity. Then, we get the estimations for probability of hyper- and hypo-diagnostics (that are termed as I and II type errors). Control condition optimization is realized by choice of OCP measurement precision and of control-level that correspond to required reliability indices and their relative ratio. Decision this problems is based on analytic and computer modeling.
Below in expressions (1) and (2) for false and insufficient diagnostics probabilities are used as \( P(\omega_1; \Omega_2) \) and \( P(\omega_2; \Omega_1) \) where \( \omega_1 \) and \( \omega_2 \) – subsystem (object) states being adequate and non-adequate to control problem; \( \Omega_1 \) and \( \Omega_2 \) – corresponding decisions on object state. So, \( P(\omega_1; \Omega_2) \) reflects false diagnostics probability (FDP), i.e. hyper-diagnostics, and \( P(\omega_2; \Omega_1) \) – insufficient diagnostics probability (IDP), hypo-diagnostics. Ratios include CP distribution type and the same – for error of CP measurement error, and also – measurement error interval \( \Delta=2\sigma_{C,\text{error}} \) calculated for limit error of CP measurement. Corresponding expressions have the form:

\[
P(\omega_1; \Omega_2) = \text{FDP} = \int_{Q^+\Delta}^{\infty} E(x) \cdot f(x) \cdot dx + \int_{Q^-\Delta}^{Q^+\Delta} E(x) \cdot f(x) \cdot \left[ \int_{Q^+\Delta}^{\infty} \phi(\delta) \cdot d\delta + \int_{Q^-\Delta}^{Q^+\Delta} \phi(\delta) \cdot d\delta \right] \cdot dx \] \tag{1}

\[
P(\omega_2 ; \Omega_1) = \text{IDP} = \int_{Q^-\Delta}^{0} \left[ 1 - E(x) \right] \cdot f(x) \cdot dx + \int_{0}^{Q^+\Delta} \left[ 1 - E(x) \right] \cdot f(x) \cdot \left[ \int_{Q^-\Delta}^{0} \phi(\delta) \cdot d\delta + \int_{Q^-\Delta}^{Q^+\Delta} \phi(\delta) \cdot d\delta \right] \cdot dx \] \tag{2}

In (1) and (2) \( E(x) \) is the purpose-control criteria (PCC) – functional dependence of probability of functioning desired level conservation on the quantity of OCP deviation from its standard value; \( f(x) \) – distribution density of OCP centered values; \( \phi(\delta) \) and \( \Delta \) – probability distribution density for OCP measurement error, and its variation interval.

The exponential-power-mode distribution (EPMD) is used for OCP distribution model. EPMD is characterized by three parameters: by mathematic expectation \( m_x \), root-mean-square deviation \( \sigma_x \) and form parameter \( \alpha \):

\[
f(x) = \frac{\alpha}{2\lambda\sigma_x \cdot \Gamma(1/\alpha)} \cdot e^{-\left| x-m_x \right|/\lambda\sigma_x} \] \tag{3}

Distribution function of EPMD is of the form:

\[
F(x) = \frac{x-m_x}{\lambda\sigma_x} \cdot \frac{\alpha}{2\Gamma(1/\alpha)} \cdot e^{-\xi(1/\alpha)-1} \cdot d\xi \] \tag{4}

Scale parameter of distribution is \( \beta=\lambda\sigma_x \); multiplier parameter \( \lambda=\Gamma(1/\alpha)/\Gamma(3/\alpha) \). Wide variation of probability distribution density allows to get them starting from nearly uniform (at \( \alpha=5,\ldots,8 \)) to sharp-peaked distribution (at \( \alpha<1.5 \)), and includes Gauss law as particular case (at \( \alpha=2 \)). EPMD is more perfect for statistical analysis, but it is not included in handbooks and well-known monographs.

3. Methodical and instrumental components of reliability

In probabilities FDP and IDP we separate instrumental component (conditioned by OCP inaccuracy of measurement \( -\sigma_{\text{ocP,\text{error}}} \)) and methodical component existing even under absolutely precise OCP measurement. \( P_{\text{met.}}(\omega_1; \Omega_2) \) and \( P_{\text{met.}}(\omega_2; \Omega_1) \) (FDP_{\text{met.}}; IDP_{\text{met.}}) are conditioned by PCC construction as function equal to probability of efficient object-state (the state that is adequate to control problem (ACPS)). Such approach to PCC construction is analogous to principle of fuzzy logic that consist in introducing the belonging-to function (probability) – to be a set member, in our case – to ACPS-multitude (ACPS-set).

It is justified that such separation of indices corresponds to expressions:

\[
P(\omega_1 ; \Omega_2) = P_{\text{met.}}(\omega_1 ; \Omega_2) + P_{\text{instr.}}(\omega_1 ; \Omega_2); \quad P(\omega_2 ; \Omega_1) = P_{\text{met.}}(\omega_2 ; \Omega_1) + P_{\text{instr.}}(\omega_2 ; \Omega_1) \] \tag{5}

\[
P_{\text{met.}}(\omega_1; \Omega_2) = \int_{Q^-\Delta}^{Q^+\Delta} \frac{E(x)}{Q} \cdot f(x) \cdot dx; \quad P_{\text{met.}}(\omega_2; \Omega_1) = \int_{Q^-\Delta}^{Q^+\Delta} \left[ 1 - E(x) \right] \cdot f(x) \cdot dx \] \tag{6}

For used EPMD of OCP, methodical components of control-reliability indexes in the form of erroneous decision probabilities of the type FDP and IDP have the form:

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\[ P_{\text{met}}(\omega_1; \Omega_2) = \int_0^\infty \frac{e^{-0.093(x/x_0)^n}}{2\sqrt{\pi/2}} e^{-1/(2x_0^2 \sigma_x^2)} \, dx \]  
\[ P_{\text{met}}(\omega_2; \Omega_1) = \int_{-\infty}^0 \left( 1 - e^{-0.093(x/x_0)^n} \right) \frac{\alpha}{2\sqrt{\pi/2}} e^{-1/(2x_0^2 \sigma_x^2)} \, dx \]  

RI \( P_{\text{inst}}(\omega_1; \Omega_2) \) and \( P_{\text{inst}}(\omega_2; \Omega_1) \) have more complex expressions therefore it is enough to use (5) conjointly with (1) and (2). Furthermore, it should be mentioned that opening of complex analytical expression, i.e. \( \Gamma \)-function, do not result in the significant preference, since it is easily to calculate double integrals directly means of special of program.

Collection of graphs and alignment charts serves as informational base of all RI. In the terms of PPC are interpreted such generalized indexes as functioning mean level for subsystem and hygienic quality level of environment.

4. Purpose criteria

Purpose criteria corresponds to 100%-efficiency for no OCP deviation (or for zero contamination – in the case of environment monitoring or radiation control) and then it decrease with different rate for OCP going away. PCC is selected as \( \exp[-0.093(x/x_0)^n] \), where \( x \) is current value of OCP; \( n, x_0 \) – form- and scale parameters. PCC construction includes two stages: expert estimation of efficiency lowering for different deviations of OCP from its normal level, and selection of form and scale parameters for OCP.

PCC for \( n=1 - 3 \), scale parameter \( x_0 = 1 \) is represented on Fig. 1, and sensitivity curves of PCC to OCP variation – on Fig. 1b. The sensitivity is determined as module of PCC derivative \( |E(x)/dx|_{x=\text{OCP}} \). PCC parameters serve for calculation of RI’s.

![Fig. 1](image.png)

Fig. 1. (a) Purpose control criteria (PCC, %) for different values of form parameter \( n = 1 - 3 \) (on Y) depending on controlled parameter value given in units of scale parameter (on X axes).

(b) Sensitivity of PCC (on Y) to OCP-value variation (on X) for \( n = 1 - 3 \).

5. Components of reliability indices

Methodical component of RI’s is decreased by increasing the measurement precision of instrumental control of OCP. But this component can not be eliminated because it is reflect the OCP probability distribution that exists even without OCP displacement and is caused by limits of measurement error. Dependence of reliability methodical component (of false diagnostics probability \( FDP_{\text{met}} \) and insufficient diagnostics) is shown on Fig. 2. Particular significance for increasing the control RI has instrumental component and its quota in general RI (Fig. 3). Increase of OCP measurement precision is really decreases the value of false-
Fig. 2. Dependence of methodical component of control reliability indices (false diagnostics probability and insufficient diagnostics probability) on mean square deviation of controlled parameter and on controlled parameter level. Controlled level (in units of OCC scale parameter) is on the curves. Mean square deviation of OCP in the same units is shown on X axes. Dependencies are calculated for OCC with form parameter n=5 and Gauss (normal) distribution of CP. On Y axes are shown: a) FDP_{net}; b) IDP_{net}.

decision probability. However it take place until the instrument component becomes essential lower than methodical component. When it take place, improvement of reliability indices slows down sharply, and the price for indices improvement due to precision increasing becomes too height.

Fig. 3. The quota (η) of instrumental component in resulting probabilities of false decisions on the controlled object state for different levels Q of CP control and CP measurement errors. Values of Q in units of OCC scale are shown at curves. Value of interval Δ for CP measurement error (on X axes) is given in units of CP control level (Δ/ Q).

a) η for IDP: \(\eta_{121} = \frac{P_{\text{instr}}(\omega_2; \Omega_1)}{P_{\text{result}}(\omega_2; \Omega_1)}\); b) η for FDP: \(\eta_{12} = \frac{P_{\text{instr}}(\omega_1; \Omega_2)}{P_{\text{result}}(\omega_1; \Omega_2)}\).

Not keeping such rule can result in unfounded high requirements to instrumental control. In the case of purely admittance (permission) control, that as consequence had resulted in unfounded high part of objects assigned to be served, and had resulted in the reduction of operator training based on medico-physiological control, or result in the cost operations for lowering the contamination on complex technology stages.
6. Application examples
Method of constructing the control RI’s based on PCC is adapted to the field of medico-
technical research, especially to training of operators for long-term autonomous exploitation
of technical object, so as diver stand complexes, deep-water transport apparatus with new
power-engineering, single objects of aero-cosmic technique. In such research the medico-
physiological control needs for men being in sub-extreme conditions: PCC types are of
peculiar specificity, and determine state relative efficiency for cardio and respiratory systems.
Elaborated expert conclusions on type and form of PCC take into account drill-training
duration and experience of experiments realized earlier. Using such principals we made
several types of PCC for external and internal exposure to radiation.

7. Resume
Method is investigated for purpose-control criteria (PCC). The probabilities of erroneous
decisions are used as reliability indices (RI’s). RI’s depend on PCC, OCP probability density,
its measurement error, and control level. Methodical and instrumental components of RI’s are
introduced and their proportion is determined. Some applications are discussed.

References
for sport trainer and informational testing of men-operator in bio-technical system.
Proc. of All-Union Conference “Adaptive systems and its Applications”. pp. 69-72 // M.:
2. V.A. Gusev, P.I. Lisenko, V.M. Malychin. Control methodology of men state in ergo-
technical system. Proc. of VII All-Union Symposium “Efficiency and quality of ergo-
Academy of Science. 1984.
complex structure for analysis of state and efficiency of men in conditions of hyperbolic
action on men’s organism”. pp. 129-135 // L.: Inst. of evol. physiol. and biochem. of
5. P.A. Arutyunov. Theory and application of algorithmic measurements. M.:
9. Y.S. Belle, V.M. Malychin, E.L. Mordberg, I.L. Shalaev. Plumbum-212 content in
miners as index of cumulative exposure of ranon daughter products. In: Dosimetry and
10. T.V. Donezkaya, G.F. Malychina. Technical efficiency criteria of automated control