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Research Paper

Definition of area and center of technological safety in space of conditions of the production system

S. R. Bakasov [1] *, A. E. Prorokov [2], Yu. N. Matveev [1], V. N. Bogatikov [1], B. V. Palux [1]

[1] Tver State Technical University Russia Novomoskovsk Institute (branch) of the Federal state budgetary educational institution of higher education "Dmitry Mendeleev University of Chemical Technology of Russia
**Corresponding author E-mail:*

Abstract

Abstract. Realization of system of diagnostics of states and management of technological safety in space of states is considered. The technique of definition of the center of safety on the basis of the solution of a problem of linear programming and the two-level system of decision-making on ensuring technological safety is offered. At the first level the center of safety is defined, at the second level the problem of stabilization of process in the field of safe functioning is solved.

Keywords: *State Assessment; Safety of Technologies, Area of Safety; Center of Safety; Linear Programming; Preparation and Decision-Making.*

1. Introduction

The methodological principles of creation of system of diagnostics of states and management of technological safety are based on the final and finite-difference mathematical models, which are a kernel of system of diagnostics of states [1]. Decision-making on management of technological safety of the production systems functioning in semistructured and badly formalizable environments,on the basis of the diagnostic multilevel analysis is carried out taking into account the possible predicted conditions of technological process, information on a condition of the external environment and subjective ideas of production personnel of a condition of technological situations [2].

2. Technique

Formations of area of safety. The main objective of industrial systems of diagnostics is timely detection of violations, which lead to non-staff situations. For identification of possible violation at an early stage of his development, assessment of technological safety formed with use of quantitative and qualitative information is necessary. It assumes use when developing a technique of assessment of technological safety use of a mathematical apparatus of the theory of indistinct sets.

Definition of area of safety for a class of continuous technological processes can be carried out by method of division of states. Finally by this method we receive the system of linear restrictions:

$$(Xiq<, z) < 0, (i =1, I) \quad (1)$$

$$(Xiq>, z) > 0, (i =1, I) \quad (2)$$

Or for quasi-dynamic regimes:

$$(Xiq< (k), z (k)) <\Delta x (k+1), (i =1, I) \quad (3)$$

$$(Xiq> (k), z (k)) >\Delta x (k+1), (i =1, I). \quad (4)$$

These restrictions define safe area in space of conditions of parameters of system.

Restrictions (1), (2), (3), (4), in this case, are linear.

Definitions of the center of safety at linear restrictions comes down to a problem of nonlinear programming in which it is necessary to maximize the sum of distances from a point to area borders

$$\sum_{i=1}^{i=I}|d_i(\bar{z})| \longrightarrow \max \quad (5)$$

At restrictions (1), (2) or (3), (4).

Algorithm of definition of area of the center of safety.

First step

Determination of ranges of values of coefficients of matrixes A and free members of b, in whom restrictions (1, 2) are carried out for xik(min) < xi <xik(мах), (i=1, 2, …, I; k=1, 2, …, Ki).

Statement of the problem

In case of the given restrictions x (min) and x (max) to find the ranges of change of coefficients of the aij (min) and aij system (max) (i=1, I; j=1, I) and also bi(min) and bi (max) (i=1, I) so that the system of restrictions was executed (1, 2).

Decision The offered method of the decision realizes search of restrictions with search with a variable step. The initial provision of system is for this purpose set and the minimum value of a step is defined. Search takes place in two stages – at first the matrix of the maximum values of coefficients, and then minimum is created.

Consider the algorithm of search of the minimum values. The maximum values are defined similarly. Elements of an initial matrix A (min) are defined by originally set coefficients. Then consistently changes each coefficient (decreases) by the step size determined by the corresponding value of a matrix of steps dA (for each coefficient of system the step pays off, thus, the efficiency of an algorithm significantly increases).After change of each coefficient check is carried out whether the decision (1) has exceeded the limit of required range (how this check becomes, it will be told below). In case check does not givepositive result, the reference value is appropriated to this coefficient. Further the new step for the current coefficient – increase twice is calculated if check has been undergone successfully, or reduction twice otherwise. The new value of a step registers in dA matrix. In case the step has appeared less than the set minimum value, the value of the current coefficient is remembered. After all coefficients of a matrix of A (min) are counted, the program analyzes a matrix of steps and checks whether there were elements which haven't reached a limit. If such elements are found, process repeats for these elements. If all elements have reached a limit, the program passes to the following stage.

Check on accessory of the solution of Ax+b=0 to range (2) is made for coefficients of a matrix of A and vector of b calculated on the next iteration as follows. Repeatedly the system of coefficients of a matrix of A and vector of b from the current range is in a random way generated. If in each case of the solution of system are carried out restriction (3) and (4), check is considered successfully passed. If at least in one of attempts there was a release of solutions for admissible range, the procedure repeats.

At rather large number of tests, reliability is 95%÷97% that for many practical cases it is quite enough.

Second step

Formation of function of the purpose. Formation of function of the purpose consists in the following [3]. From analytical geometry it is known that a point deviation (h1, at 1, z 1) from the plane, written down in a rated look

X cos [alfa] + y cos [beta] + z cos [gamma] + [rho] = 0, it will be equal:

$$d = x1 \cos [alfa] + y1 \cos [beta] + z1 \cos [gamma] – [rho] \quad (6)$$

In our case, coordinates of a point are formed by coefficients of a matrix Aand the free terms b, and constant coefficients are the preset minimum and maximum values of state variables in advance.

In formulas (1), (2) (Xiq<, z) < 0, (i =1,...,I) и (Xiq>, z) > 0, (i =1,...,I): variablesXiq<are formed by the minimum and maximum values of state variables; variables z are formed by coefficients of a matrix A.

In the previous algorithm ranges of coefficients of a matrix A and, respectively, z vector are defined. Not to solve a problem of nonlinear programming that is connected with need to look for the sum of absolute values of deviations, the following algorithm of formation of criterion function is offered (5):

1) Choose a point from the possible range of variables z;
2) Coercion of the equations of restrictions to a normal look is carried out;
3) Determine the deviation of the d_i point from the i boundary;
4) If the deviation of d_i is negative, coefficients with which this function is included into criterion change the sign to opposite. Thus, in target function not the amount of deviations, but the amount of distances is created;
5) If the deviation of d_i is positive, signs of coefficients with which this function is included into criterion are left without changes.
6) Points (3-5) repeat, signs of deviations to all boundaries will not be defined yet.

Thus, the objective function automatically takes into account the fact that the search is made for the sum of the distances of the point from the constraints $\sum_{i=1}^{i=I} |d_i(\overline{z})|$.

Third step

On this step the solution of a problem of nonlinear programming is carried out [4]: $\sum_{i=1}^{i=I} d_i(\overline{z}) \to \max$, under the constraints: (1), [2-6].The received decision will determine coordinates of the center of safety in case of equivalence of borders. If borders are not equivalent, it is necessary to enter weight coefficients for

Sarin, soman and V_x

$d_i(\overline{z})$.The organization of work of a control system of safety on the basis of stabilization of parameters of processes in the neighborhood of the center of safety, realizes the principle of balance of Nash.

Main part

Main stages of a technique of practical definition of area and center of safety.

The possibility of creation of model of states in the form of the ordinary differential equations or the differential equations in private derivatives is put in a basis of the technique offered in this work.

The technique consists of the following stages:

- Creation of mathematical model in the form of the equations of states is carried out [5];
- On the basis of the equations of states the system of restrictions (1) – (4) [6] is under construction;
- Development of an algorithm of determination of center of safety for the current situation as tasks of the linear programming is executed [7];
- Functions of a level of accessory to the appropriate linguistic variables for each of the revealed parameters for further computation of levels of indistinct switching on and indistinct equality of statuses are built [8];
- Algorithms of determination of a level of indistinct switching on of indistinct equality of values of the current values of technological parameters concerning safety center are developed for determination of the index of safety [9].

For realization of an algorithm of definition of the center of safety it is possible to use, for example, an approximate neural network algorithm of the solution of a problem of linear programming [10]. However, use of neural network basis at the initial stage demands considerable resources on training of system though the efficiency of decision-making can be reached by achievement of overlapping of work of neural networks. In this work, it is offered for the solution of a problem of definition of the center of technological safety to use a simple method of linear programming.

We will consider application of the offered technique for technological process of the destruction of chemical weapon (DCW). The function chart of the automated process control system (APCS) of a subject to destruction of sarin, soman and $V_x$is submitted in fig. 1.

In fig. 1: 1 – operation of a detoxication of the toxic substance (TS); [2] – operation of ripening of the reactionary mass (RM); 3 – operation of neutralization of RM; 4 – operation of obtaining bituminous and salt weight (BSW).

Variables of the functional diagram [11]:

X_0 – mass of OV loaded in the detoxication reactor;
U_1 – reagent mass for TS detoxication;
X_1 – the reactionary mass (RM) after TS detoxication;
U_2 – reagent mass for ripening;
X_2 – RM mass in a dozrevatel;
X_3 – RM mass in the collection E1;
X_4 – RM mass in the collection E2;
U_3 – mass of hydroxide of calcium (GOK) for neutralization ofsarin and soman;
X_5 – mass of the neutralized RM of sarin (soman);
U_4 – bitumen mass;
X_6 – the summary mass of the neutralized PM (NPM) and bitumen coming to the rotary-film evaporator (RFE);
X_7 – distillate mass (the evaporated solvents and inert);
X_8 – BSW mass.

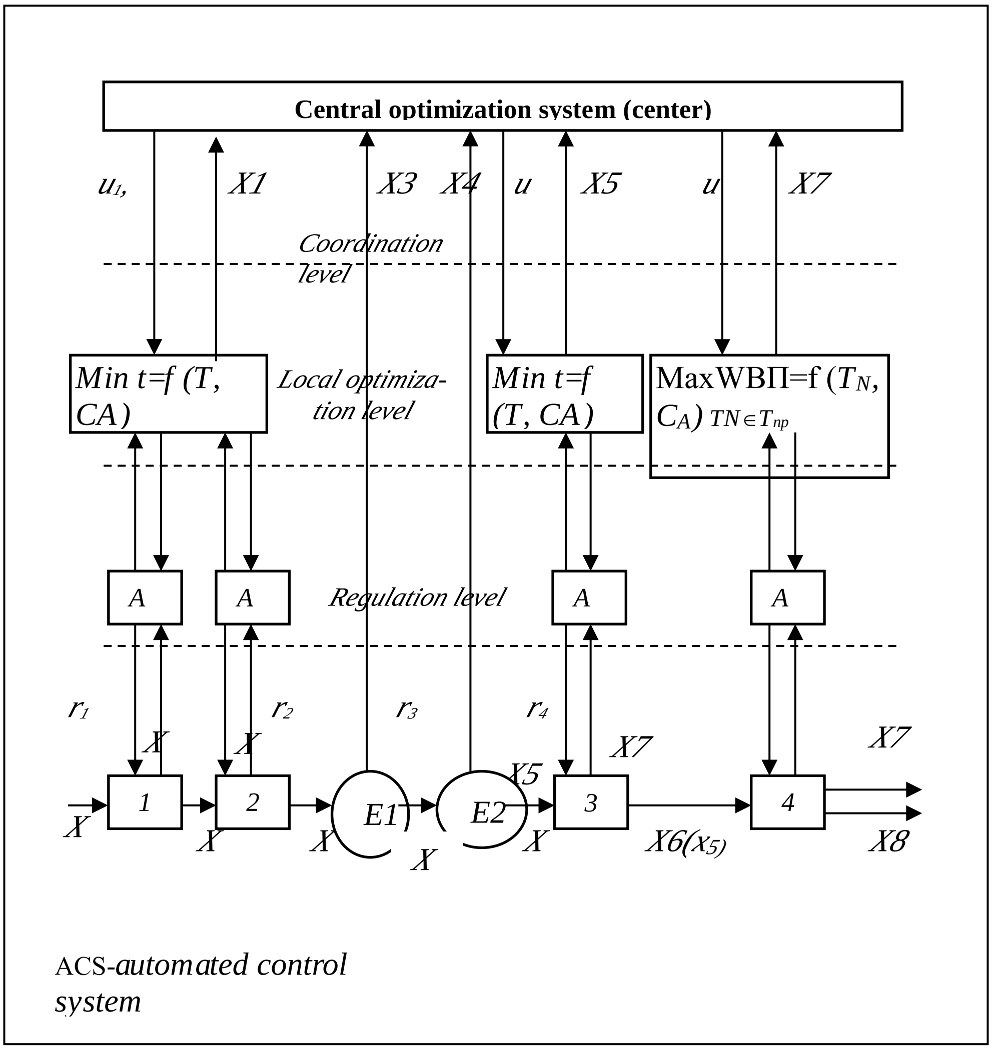

Fig. 1: Functional Scheme APCS for the Complex of DCW For.

The central system of optimization (CENTER) functions on the following algorithm [12]: The operator-technologist enters into the system of value of coefficients a1÷a6,(for sarin a_1=1,1; a_2=0,05; a_3=0,31; a_4=1,64; a_5=1,05; a_6=1,0; for soman a_1=1,1; a_2=0,05; a_3=0,26;a_4=1,64;a_5=1,0;a_6=1,0; для V_x a_1=2,0; a_2=0,05; a_3=0,26; a_4=1,64; a_5=1,0; a_6=1,0) [13], and also numerical value of mass of x_0 toxic agent which arrived on operation of a detoxication [14]. The system calculates the controlling influence – u_1 (reagent mass for a detoxication of toxic agent) and gives u_1 value on the operator-technologist's monitor. Upon completion of operation of a detoxication the operator-technologist enters into system data on results of the performed operation of a detoxication x_1 (the number of reactionary mass) [15]. The system on x_1 value calculates the controlling influence – u_2 (reagent mass for ripening) and gives u_2 value on the operator-technologist's monitor. Upon completion of ripening operation, the operator-technologist enters into system data on results of the performed ripening operation – x_4 (the number of reactionary mass in the collection). The system on x_4 value calculates the controlling influence of u_3 (amount of hydroxide of calcium for neutralization of reactionary mass) and gives this value on the operator-technologist's monitor. Upon completion of operation of neutralization of reactionary mass the operator-technologist enters into system data on results of the performed neutralization operation – x_5 (the number of the neutralized reactionary mass). The system makes calculation of the controlling influence – u_4 (amount of bitumen for bituminization of reactionary mass) and gives its value on the operator-technologist's monitor. Upon completion of bituminization operation, the operator-technologist enters into system data on results of the performed operation – x_6 (the summary number of the neutralized reactionary mass and bitumen which comes to the rotor and film evaporator). The system considers x_7 – distillate mass (the evaporated solvents and inert) and x_8 – the number of bituminous and salt mass [16].

At the level of coordination according to the accepted criterion of management (an efficiency indicator), restrictions and communications tasks for management of the sequence of operations are formed. In turn, at the level of local optimization tasks to the corresponding regulators (for example, maintenance of temperature in the reactor on the maximum value) are formed by the accepted criterion of management, restrictions and communications (for example, minimization of time of carrying out operation), [17]. After completion of technological process by results of his carrying out adjustment of parameters of mathematical model according to criterion of management, restrictions and communications is made.

The main purpose of the APCS - increase in productivity of a complex of destruction of chemical weapon at the level of danger (risk) in the normal mode of functioning, not exceeding value, standard for an object. The structure of the chemical-technological complex DCW (HTK DCW) - (a detoxication and bituminization) is consecutive: separate stages of process – TS detoxication, ripening of the reactionary mass (RM), neutralization of RM (only sarin), bituminization of NRM (for Vx bituminization of RM), evaporation of the bituminous and salt weight (BSW) – are connected in such a way that an exit of everyone previous is an entrance of one of the subsequent. Detoxification, ripening, neutralization, bituminization, evaporation of poisonous substances will be considered as a complex system in which each i-e poison substance will be denoted by K_i. Then the change K_i is a sequence of functional actions FD_{ij} (j- is the operation number). At j = 1, a poisonous substance of the i-e type is loaded into the detoxification reactor.

We will designate process parameters through x_i (i = 0, 14),

Where:

X0 – the mass of toxic agent for a detoxication (m_{ts})
X1 – the mass of the reagent necessary for a detoxication (m_{r1});
X2 – the number of reactionary weight, which arrives in a dozrevatel (m_{rm1});
X3 – the mass of reagent, which arrives in a dozrevatel (m_{r2});
X4 – the number of reactionary weight, which comes from a dozrevatel to the collection (m_{rm2});
X5 – the number of reactionary weight which comes to the collection E1 (m_{rm3});
X6 – the number of reactionary weight, which arrives on neutralization (m_{rm4});
X7 – the mass of hydroxide of calcium, which comes to the reactor converter (m_{gok});
X8 – the number of reactionary mass of V_x, which comes to the reactor-bitumator (m_{rmVx})
X9 – the number of the neutralized reactionary mass of sarin and soman (m_{nrm})
X10 – the mass of bitumen, which comes to the reactor-bitumator (m_{bit});
X11– the number of the bituminous and reactionary mass (m_{brm})
X12 – the average size (quantity) of the bituminous and reactionary mass coming to RFE
X13 – the average size (quantity) of solvents and inert which come to condensers;
X14 – the average size (quantity) of fusion of bituminous and salt weight.
The task of static optimization of management of HTK DCW is set in a general view as follows:
Identify

$$\sum_{i=0}^{14} c_i x_i + \sum_{j=1}^{5} d_j u_j \to \min \quad (7)$$

At

$$x_2 = f_2(x_0, x_1, u_1),\ u_1 \in U\_1 \quad (8)$$

$$x_4 = f_4(x_2, x_3, u_2),\ u_2 \in U_2 \quad (9)$$

$$x_9 = f_9(x_6, x_7, u_3),\ u_3 \in U_3 \quad (10)$$

$$x_{11} = f_{11}(x_9, x_{10}, u_4),\ u_4 \in U_4 \quad (11)$$

$$x_{14} = f_{14}(x_{12}, x_{13}, u_5),\ u_5 \in U_5 \quad (12)$$

$$x_5 - x_4 = \Delta_1,\ x_6 - x_5 = \Delta_2,\ x_{12} - x_{11} = \Delta_3 \quad (13)$$

$X_{imin} \le x_i \le x_{imax}$, i =1,2,3,4,5,6,7, 8,9,10,11,12,13,14. (14)
The economic index of control (7) is the most widespread index of operation of production – prime cost. This index is the linear function of two variables x and u. Coefficients of c_i and d_j are specific prices of the entering substances and energetic flows which define operation modes of technological stages. The equations (8) - (14) are models of technological operations. These models, generally speaking, are described by the known functions of input loadings and regime parameters and, as a rule, are non-linear functions of variables. Areas of admissible values of the regime U_1, U_2, U_3, U_4, U_5 parameters are known initially and do not depend from each other. The equations of balance of capacities define dependences of the material flows of different technological operations, which are connected through these capacities. Values Δ_1, Δ_2 and Δ_3 which are set, determine the permissible deviations of material flows. Restrictions (14) set the range of loadings, which provide normal functioning of technological operations.
The linearization of a task (7)-(14) considered in [18] has allowed presenting a problem of static optimization (a task of operational management) of a complex of destruction of chemical weapon as a problem of the linear programming (LP):
Identify

$$W = \sum_{i=0}^{14} c_i x_i \to \max, \quad (14)$$

At

$$x_2 - x_0 - a_1 x_1 = 0 \quad (16)$$

$$x_4 - a_2 x_2 - a_3 x_3 = 0 \quad (17)$$

$$x_9 - a_6 x_6 - a_7 x_7 = 0 \quad (18)$$

$$x_{11} - a_6 x_6 - a_7 x_7 = 0 \quad (19)$$

$$x_{11} - a_8 x_8 - a_{10} x_{10} = 0 \quad (20)$$

$$x_{14} - a_{12} x_{12} - a_{13} x_{13} = 0 \quad (21)$$

$$x_5 - x_4 = \Delta_1,\ x_6 - x_5 = \Delta_2,\ x_{12} - x_{11} = \Delta_3 \quad (22)$$

$$x_{imin} \le x_i \le x_{imax},\ i = 1,2,3,4,5,6,7,8,9,10,11,12,13,14. \quad (23)$$

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