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SYSTEM IMPROVEMENT OF THE COMPLEX TECHNICAL SYSTEMS ON THE BASE OF MULTILAYER FUZZY OPTIMIZATION

The problem of reconstruction (modifications) of the complex technical system is reduced to the multilayer fuzzy optimum task, the quasi-solution of which can be founded by the distributive solution of the interconnected optimum and inverse tasks.

Keywords - Theory of the large systems, optimization, inverse tasks, turbojet engines

1. Introduction

The algorithms of solution of tasks of quantitative analysis of the physical fields and processes in the elements of the complex technical systems (CTS), and also optimizations (synthesis of rational construction) take, as a rule, to NP-complete [1, 2]. These circumstances reduce to large calculating charges (main memory, running time) for receiving the solutions of CTS reconstruction (modification) task [3]. Besides, allotted time on formation of technical proposition, draft and working designing, are limited, this is determined by marketing situation. Therefore, new technique designers hasn't the possibility to hold a complete analysis of all possible variants CTS using existent CAD, CAE-systems. The most of real-world problems connected with necessity of decision making at input data in fuzzy area of parameters, availability of alternative solutions with different measure of significance and also in multicriteria statement, which brings to necessity of dissimilar criterions convolution. On the basis of aforesaid one could approved about urgency problem of designing an effective mathematical methods and algorithms of computational solution of CTS fuzzy optimization problems.

2. Mathematical model

The solution of CTS fuzzy optimization problems is found on next data: the definition of subject of inquiry, the availability of prototype, the reconstruction (modification) goal and the class of possible managements (methods and realizing devices) and the criteria of quality of project solutions.

We will formulate the task of the CTS reconstruction (modifications). Will be characterized the improvement object using different groups of parameters: operating and project Π°, which selected by designer, phase variables or condition variables Φ°, which are determined in the process of calculations on the set locking correlations, control or regulating variables U°, the choice of which is determined by the type of task.

Let us presents the original mathematical model (OMM) of test subject in the following Eq.1:

$$\Phi^0 = \Phi^0(\Pi^0, U^0) \qquad (1)$$

Vector Π^0 is located at certain fuzzy domain of definition

$$D_\Pi = \left\{\Pi^0 = (\pi_1, ..\pi_k, ..., \pi_{Kd}) : (\forall k \in [1...K_d]\, \pi_k \in \mu(\pi_k))\right\}$$

of area Π, where $\mu(\pi_i)$ - function of attachment of design parameters, vector U^0 is located at certain fuzzy domain of definition

$$D_U = \left\{U^0 = (u_1, ..u_m, ..., u_{Md}) : (\forall m \in [1...M_d], u_m \in \mu(u_m))\right\}$$

of area U, which compactly is given as $\Pi^0 \in D_\Pi \subset \Pi$, $U^0 \in D_U \subset U$.

An area $D_\Pi \subset \Pi$ is the area of the modes in being physical right, an area $D_U \subset U$ – the area of acceptance control. The vector Φ^0 is located at fuzzy domain of phase variables.

$$D_\Phi = \{\Phi^0 = (\phi_1,..\phi_n,...,\phi_{Nd}) : (\forall n \in [1...N_d]) \phi_n = \phi_n(\Pi^0, U^0)\}, \ \Phi^0 \in \mu(\Phi^0).$$

Here K_d is the total amount of operating and project parameters, M_d – total amount of control variables, N_d – total amount of phase variables.

Let us consider the Q = $\left\{ q_j^0 \Big/ \mu(q_j^0) \right\}$, q_j^0=(Π_j^0, U_j^0, Φ_j^0), j=0…J, which is the finite set of feasible project solutions with predetermined degree of value $\mu(q_j^0)$ (reasonableness subset). In respect to person of decision making (PDM), the quality of any solutions $q_j^0 \in$Q is defined relatively to criterions W={w_i}, i=1…I.

Let us consider, that for every solutions exists the fuzzy representation A: $q_j^0 \to W_j$, then value $A_i(q_j^0)=w_{ij}$ – evaluation of solution $q_j^0 \in$Q by criterion $w_{ij} \in$W.

Let us consider, that for criterions W={w_i} exists the fuzzy representation B: W→W°, W°={$w°_i$}, then the value $B_i(w_{ij})=w°_{ij}$ – evaluation of criterion $w_{ij} \in$W by standardized criterion $w°_{ij} \in$W°. Taking into account the entered transformations the OMM (1) is possible to represent as Eq.2:

$$W^0 = W^0\left(\Pi^0, U^0, \Phi^0\left(\Pi^0, U^0\right)\right) = W^0\left(\Pi^0, U^0\right). \qquad (2)$$

The mathematical model (2) with dimension $K_d \times M_d \times I$ by aggregation of variables and decomposition of general task on subtasks can take to the aggregated mathematical model with dimension $(K_d - K) \times (M_d - M) \times N \times I$ and great number of mathematical models of elements of the CTS with dimension $K_l \times M_l \times N_l$, $l = 1...L$:

$$W^0 : (\Pi_r^0, U_r^0, \Phi^0) \to W^0, \ N << K + M; \qquad (3)$$

$$\Phi_l^0 : (\Pi_l^0, U_l^0) \to \Phi_l^0 \qquad (4)$$

3. Raising of investigation problem

A problem of fuzzy optimization, as a special case of a decision making problems [4], can be represented by the tuple:

{ t, V, G, F, W } (5)

where t – statement of problem (for example, selection of the best alternative, selection of well-organized or unregulated subsets of the best alternatives and others), F – procedure of choice of rational project decisions from the great number of alternatives V in the system of preferences G, W – mathematical models of subject of inquiry.

The procedure of choice of rational project decisions is implemented a representation F: (V, G)→V, and result from their using is a subset $\tilde{V} \subseteq$V of reasonable alternatives, which compose an elements, which not dominated comparatively criterions W, which entering into applied system of preferences G=(W, R).

The CTS fuzzy optimization problem (5) mathematically may be formulate in the following form: we have the prototype v_0^0, fuzzy set of alternatives V={ v_i^0 } and fuzzy preference system G. It would be necessary to find such as possible control variables U°(Φ°) (U°∈D_U), which would be transfer the system from defined condition v_0^0 into other possible condition $\tilde{v}^0 \in \tilde{V}$ from preference system G.

In the multicriteria decision-making problem it is necessary to follow the principle of optimum of decision, which satisfies to the axioms of optimum on Pareto and equality of the rationed estimations of private criteria for internal subsystems, with priority of the first criterion.

4. Approaches to solution of general problem

Let us consider the CTS, that will be the subject to improvement as a system, which consists from L components, and every l-th component (l = 1...L) – from applicable elements of components. On the basis of principle of unco-operative equilibrium the general problem of the CTS reconstruction (modifications) can be reduced to the multilayer optimum task of multicriteria decision making (findings of the J.F. Nash points – points of unco-operative equilibrium) with a less dimension at every level for each of subtasks, on comparison with a general task.

Tasks for internal subsystems (the CTS components – subsystems of the first level, elements of components – subsystems of the second and below than levels), assume two raising – direct and inverse. In first case the search of the best alternative $€_l^0$ from set of rational alternatives $€_l^0 \in V€_l$ $(l = 1...L)$ is carried out by the direct methods of solution of tasks of multicriteria decision making. In second case the search of the best alternatives is taken to construction of quasi-solutions by the distributed solution of the interconnected optimum and inverse tasks [5].

As an example of realization of approach [5] we will consider the solution of task of modification of turbo fan engine. The solution of optimum problem for turbo fan engine cycle parameters was considered at the paper [6]. For the choice of optimum cycle parameters the method of the thermogasdynamics calculation for turbo fan engine without mixing of streams with a constant heat capacity was used. As control variables got out the values: $m, \pi_{FII}, \pi_{CI}, T_G$. The values of physical properties of gases, efficiency of subsystems, losses in channels and other entrance data were set as the constant parameters. As a criterion of the turbo fan engine quality the sum power-plant mass M_{PP} and the mass of fuel M_F, necessity for implementation of the set program of flight was chosen: $M_\Sigma = M_{PP} + M_F$. The M_{PP} was calculated by methods of fuzzy logic for approximation of data about analogues was used. The search of the optimum turbo fan engine cycle parameters was carried out by a genetic algorithm.
The results of calculations, got on a method [6], were accepted as initial data for the task of modification. As an estimation of the desired value of fuel specific mass flow C_R^* of engine we will choose the value $\Delta C_R^* = \frac{C_R^* - (C_R)_0}{(C_R)_0} 10^2$. By a similar appearance we will enter estimations of the desired phase variables of the turbo fan engine subsystems $\Delta w_{\ln}^* = \frac{\Phi_{\ln}^* - (\Phi_{\ln})_0}{(\Phi_{\ln})_0} 10^2$, where $\Phi^0 = \{G_I, \pi_{CI}, \eta_{CI}, \eta_{TI}, G_{II}, \pi_{FII}, \eta_{FII}, \eta_{TII}, R_{SP}, M_\Sigma\}$.

The modern turbo fan engine for the regional passenger aircraft was chosen as an object of modification. A few variants of modification are considered (see Table 1). The set of the sought phase variables of subsystems, used for every variant of modification, is marked in Table1 by the symbol «+». The solutions of tasks of modification for the external system were carried out by a genetic algorithm. The calculations were executed for ΔC_R^* = -3 at the chosen region of acceptability phase variables (see Table 2). The results of calculations are represented in Table 3. It is got, that at the chosen region of acceptability the sought phase variables the desired value ΔC_R^* is not attained. For achievement of the desired value ΔC_R^* further correction of high bound of region of acceptability phase variables is needed. The found values $\Phi€^0 = \{\Phi€_l^0\}$ can be used further for the solution of tasks of modification of the turbo fan engine subsystems – fan, compressor of high pressure, turbine of high pressure, turbine of fan.

TABLE 1

Variats of modification

Variable	Var. 1	Var. 2	Var. 3	Var. 4
π_{CI}	+	+	+	+
η_{CI}	+	+	+	+
η_{TI}	-	+	+	+
π_{FII}	-	-	+	+
η_{FII}	-	-	+	+
η_{TII}	-	-	-	+

TABLE 2

Region of phase variables

Variable	Minimal level	Maximal level
π_{CI}	25.0	26.5
η_{CI}	0.85	0.91
η_{TI}	0.89	0.91
π_{FII}	1.38	2.00
η_{FII}	0.89	0.92
η_{TII}	0.92	0.94

TABLE 3

Calculation resalts

№	ΔG_I^O	$\Delta\pi_{CI}^O$	$\Delta\eta_{CI}^O$	$\Delta\eta_{TI}^O$	ΔG_{II}^O	$\Delta\pi_{FII}^O$	$\Delta\eta_{FII}^O$	$\Delta\eta_{TII}^O$	ΔC_R^O	ΔR_{SP}^O	$\Delta M_{\sum}^O$
1	0,19	6,00	0,75	0,00	0,18	0,00	0,00	0,00	-1,06	-0,18	-0,95
2	0,28	6,00	0,00	1,45	0,28	0,00	0,00	0,00	-1,37	-0,28	-1,26
3	-0,23	6,00	0,00	2,14	-0,24	0,51	0,00	0,00	-1,88	0,24	-1,75
4	-0,33	6,00	0,00	1,98	-0,38	1,29	0,00	2,08	-1,99	0,33	-1,73

5. Conclusion

On the basis of principle of unco-operative equilibrium the main problem of the STS reconstruction (modifications) on the example of turbojet engine is resulted to the multilevel multicriteria multiparameters optimization task (findings of the J.F. Nash point – points of unco-operative equilibrium) with a less dimension at every level for each of subtasks, on comparison with a general task. The quasi-solution of put problem can be founded by the distributive solution of the interconnected optimum and inverse tasks.

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