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A. V. Abramova,
D. I. Konotop

ONTOLOGY APPLICATION FOR ESTIMATION OF COMPLEX TECHNICAL OBJECT CHARACTERISTICS

Antonov ASTC, Ledi_annet@ukr.net, Konotop.dmitriy@gmail.com

In this article authors have described methodology of using intellectual technologies such as ontology and processing of the statistical data on the initial stages of the design of complex technical object on example of aircraft.

Keywords: ontology, complex technical object design, weight design, weight estimation, plural calculation method.

Introduction. Complex technical object (CTO) design is appeared the developed hierarchical structure with the large number of elements and internal connections. New information technologies (IT) which gives provide possibility of system approach and optimized design decisions are widely used in the CTO design. This article describes a methodology and features of automatization provided in the CTO weight design domain. In this article aircraft acts for an example of the CTO.

Stages of the CTO design. It is known that CTO design process includes four main stages [1 – 3]. The first stage is formulation of requirement specification (RS) which includes the requirements and recommendations to the CTO basic technical data. The second stage is the development of master-geometry model (MGM) of the CTO, which is formed on the basis of requirements defined in RS. MGM is intended for definition of the base coordinate systems of theoretical surfaces and locations of the basic power elements of the CTO construction. The third stage is the designing of objects allocation model (OAM), which contains 3D-models of construction, systems and equipment according to MGM. Objects allocation model includes stages of preliminary and engineering design. The fourth stage is development of the complete productdefinition model (CPM), which correlates with the stage of the detail design. The final result of the CPM design is an automatized preparation of working documentation and forming of the programs for modern computer numerical control (CNC) machine tools. Complex technical object design process is possible to present as the iteration procedure.

$$\to \{a\}_0 \to M_1 \to M_2 \to M_3$$

$$\{a\}_{i+1},$$

where $\{\alpha\}_0$ – is an initial data for designing (RS), M_i is the geometrical model on the stages of MGM (M_1), OAM (M_2) and CPM (M_3), $\{\alpha\}_{i+1}$ are new (changed) parameters, which appear as results of the subsequent stages and than could make changes on the previous stages.

Geometrical model M_i on different stages is possible to present as:

$$M_i = \bigcup_{k=1}^{N} m_k, \quad (1)$$

where m_k are models-components of construction, systems and equipment of the CTO geometrical model (GM) on the appropriate design stage, N is a GM amount.

Component of CTO construction, systems and equipment is possible to present as a following functional dependence: $m_k = f(X_k)$, where X_k is a parametric managing model of the appropriate CTO component, which can be presented as follows: $X_k = \bigcup_{j=1}^{S} x_j$, where x_j is a component of parametric managing model, S is an amount of parametric managing model components.

In general, based on (1), CTO model-component of construction, systems and equipment is possible to present in a following view: $m_k = f^k(x_j,\ j = 1...S)$, where: x_j is a component of parametric managing model, particularly: based points of affixment, based and guide lines, planes. The parametric managing model is a managing structure, which intended for support of initial data inheritance at all CTO design stages in CAD/CAM/CAE- system. Besides the geometrical model other models are also developed at the initial design stages, particularly: weight, aerodynamic, model of arrangement, etc.

The CTO weight model includes a system of weight limits for CTO as a whole and for its components. Today there are many different approach to the calculation of any components of weight limit [1; 4]. There are many attempts to bring automatization in the tasks of aircraft weight design such as creation of interdependence tables, graphics of relation between aircraft mass and its aerodynamic parameters, computer program. There is a row of products automatizing the decision of some tasks from weight design domain, but great amount of aircraft types, modern materials and advanced methods cast doubt on exactness and completeness of classical weight estimation.

Aircraft design ontology. Modern practice of the CTO design is based on an application of row of functional principles and correlations. It needs a concerted collaboration of engineering departments and specialists in different industries as well as simultaneous decision of plenty of technical and economics tasks, handling of large project information content, realization of opportunity of returning on the previous design stage to introduce clarity into design results.

That's why complete automation of the design process is impossible, however many tasks in the CTO design could be decided by applying intellectual technologies. An ontological bases of knowledge could present information of design process as a well-organized structure with well-defined connections between different components of the design process, also makes link between various project information, organizes connection between the different stages of planning, contains the real project data and conditions of application of different calculation methods in its structure, closely linked them. Ontological scheme of aircraft design, which describes the basic relations between parts of design process, is shown on fig. 1.

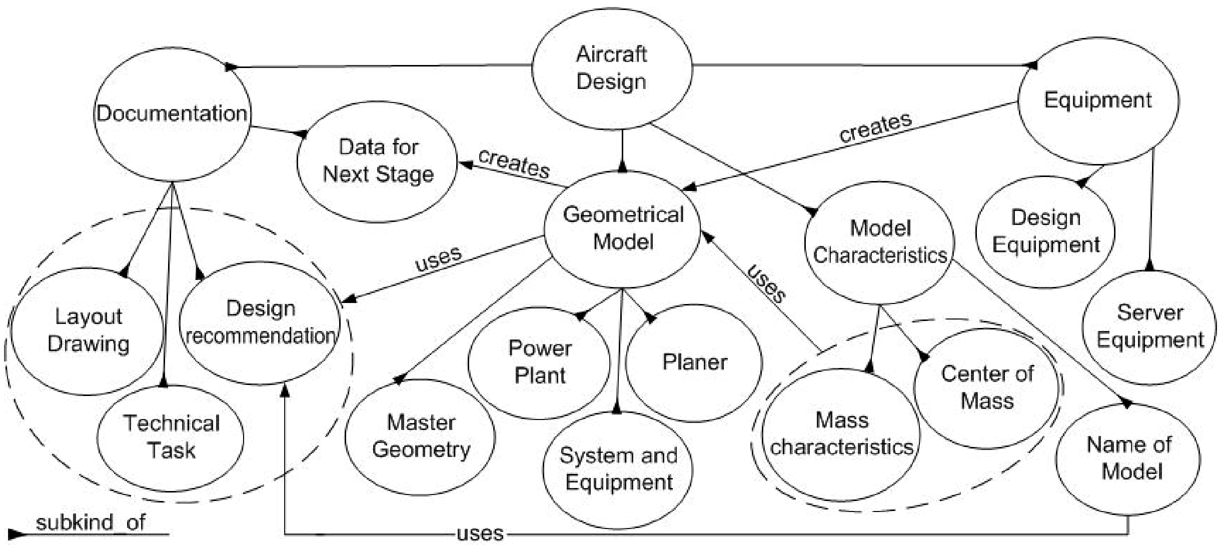

Fig. 1. Aircraft design ontology

Aircraft design ontology is the conceptual ontology but for solving of different task in aircraft design domain ontologies are built. Weight design defines the distance and maximal flight height, fuel efficiency, technical and economical aircraft efficiency. Weight factor plays an important role in a choice of aircraft sizes and parameters and for achievement of the best flight-technical characteristics.

Ontology of weight design domain. The main task of the weight design is creation of the weight limit system that makes possible optimization of the CTO construction. Main conceptions of the weight design domain are shown on the fig. 2.

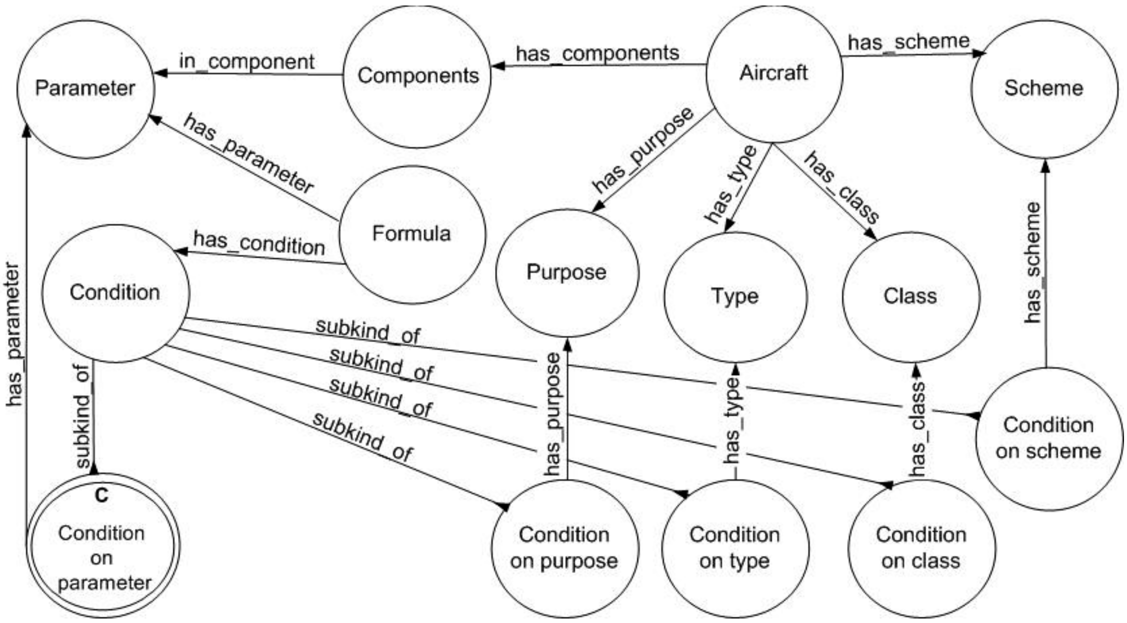

Fig. 2. Ontology of the weight design domain

For the preliminary calculation of CTO components mass different gravimetric formulas are offered, which expressed by dependences between masses sizes, geometrical parameters and operating loadings. These dependences are determined analytically on the basis of different pre-conditions.

The automated system of the aircraft weight design allows carrying out the estimation of weight limits on the different stages of aircraft design. For this purpose the formulas knowledge base and method of the plural weight calculation are created. Today there are the great number of formulas and methods of weight estimation of the airplane. These formulas carry out estimations with different exactness. Exactness of the weight estimation of aircraft depends on the great number of parameters and characteristics of the airplane. At providing the choice of weight estimation method it is necessary to take into account the parameters of airplane, its features of construction, planning terms, purpose, class and type. The initial level of classification of weight formulas is presented on the fig. 3. For the optimum weight estimation it is necessary to operate with different methods of calculation on the different stages of the airplane design.

Objects of the classes represented on the fig. 3 have next characteristics that could be presented by means of Elaboration language [5]:

(forall(?x)(=>(instance-of ?x Specialized_formula)(exists(?y)(and(instance-of ?y Condition_on_type) (has_condition ?x ?y)))))

((forall(?x)(=>(instance-of ?x Multi-purposed_formula)(not exists(?y)(and(instance-of ?y Condition_on_type) (has_condition ?x ?y)))))

(forall(?x)(=>(instance-of ?x Statistical_formula)(and(I5-has-property ?x has_parameter)(I5-relation-arity has_parameter ?k)(k>1)(k<4)(I5-has-property ?x has_result)(or (and(has_result ?x ?y)(instance-of ?y Aircraft_mass_parameter))(has_result ?x Mass_of_constraction_planer) (has_result ?x Mass_of_system_and_equipment)(has_result ?x Mass_of_Propulsion_system))))) (forall(?x)(=>(instance-of ?x Rough_calculation_formula)(and(I5-has-property ?x has_parameter) (I5-relation-arity has_parameter ?k)(k>2)(k<5)(I5-has-property ?x has_result)(or(has_result ?x Mass_of_fuselage) (has_result ?x Mass_of_landing_gear)(has_result ?x Mass_of_wing)(has_result ?x Mass_of_empennage)))))

(forall(?x)(=>(instance-of ?x First_grate_formula)(and(I5-has-property ?x has_parameter)(I5-relation-arity has_parameter ?k)(k>7)(k<12))))

(forall(?x)(=>(instance-of ?x Second_grate_formula)(and(I5-has-property ?x has_parameter)(I5-relation-arity has_parameter ?k)(k>25))))

(forall(?x)(=>(instance-of ?x Aircraft_formula)(exists(?y)(and(instance-of ?y Aircraft_parameter) (has_result ?x ?y))))

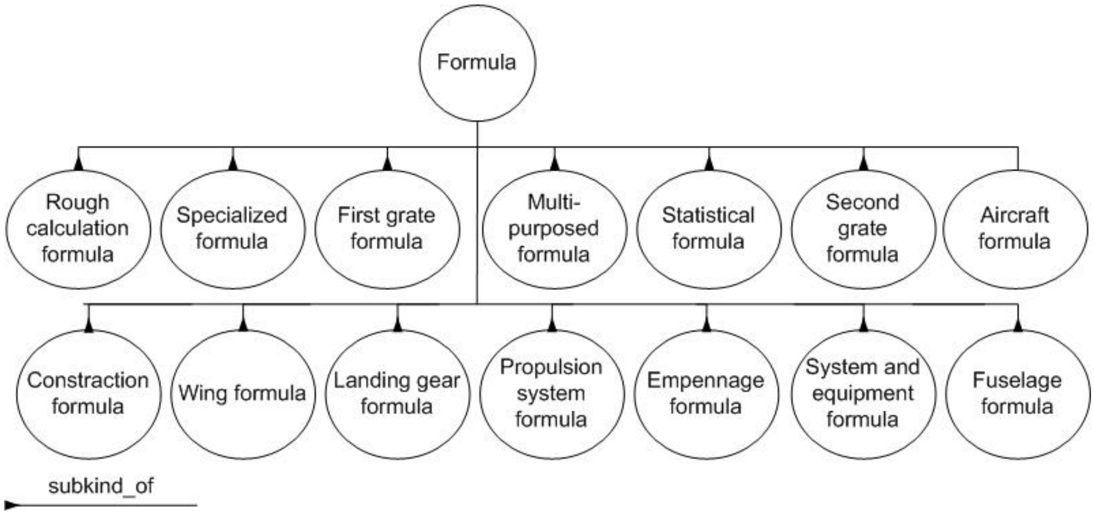

Fig. 3. The initial level of formulas classification of the weight design

The system of classes, subclasses, attributes and relations, which realized at OWL language as well as interpretation functions and rules of choice, realized by Java with the use of Jena and Pellet libraries, present the knowledge base and decision-making system of weight design. The structure of knowledge base of the weight design is represented on the fig. 4.

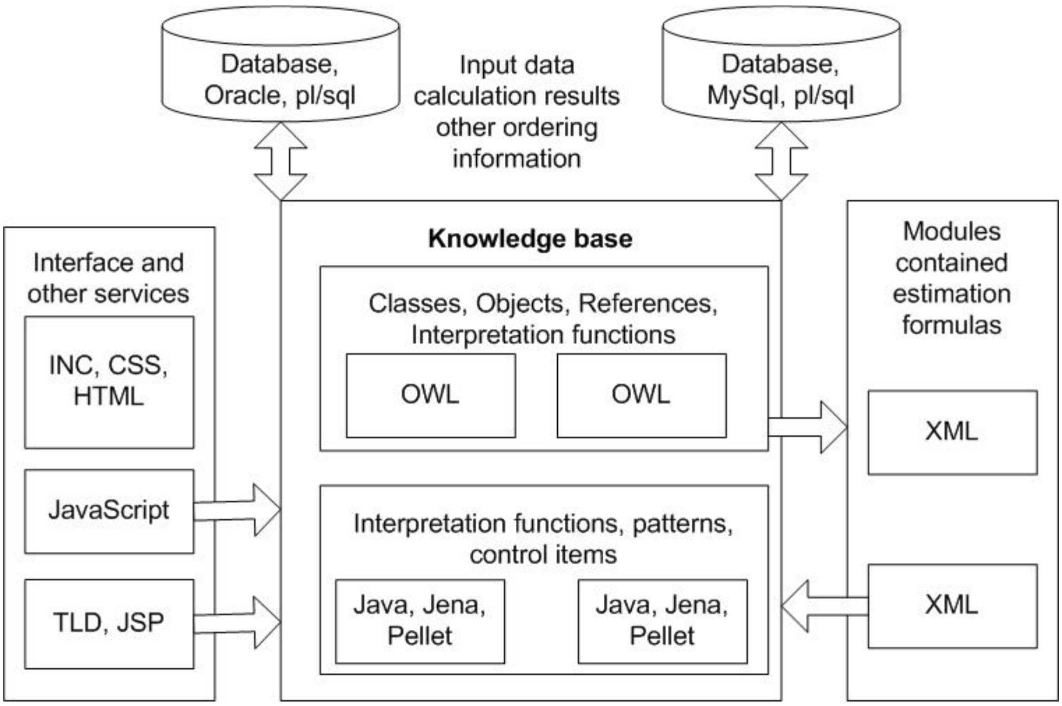

Fig. 4. The knowledge base structure

The main programming means are instruments of JAVA SE6. Information of weight calculations and basic data for conducting of weight control are kept in the Oracle base. The formulas of weight estimations are kept as XML-files, which contain the order of implementation of actions. There is a reference on these files in the ontology of the weight design. After the choice of one of formulas program realizes the processing of the XML code and calculation of result is made with the use of chosen from the database parameters. If it is necessary the user can edit one of formulas or add new. After the record of the formula program commutates an order of actions in the calculation, than generate the XML-code and write a new file. The automated system of the weight design carries out a choice between a few methods of calculation, provide weight estimations that depend on the aircraft parameters, purpose and features of the constructed airplane, allows taking into account new tendencies in the area of weight design and correcting the method of weight estimation by adding of new formulas in the knowledge base or changing existing.

The program makes the calculation of weight limits of the airplane by the set of formulas, after that it conducts their optimization by the Sheynin's method of plural calculations.

Plural calculations method. The method of plural calculations leads to exactness maximization in the mass estimation of the CTO components. This method consists in determination of the mass parameter of the CTO or its components on a few compatible between itself formulas with following acceptance as a final decision of their arithmetical mean on the condition of exclusion of falling out results.

The base formula of Sheynin's method algorithm of mass calculation is cited below:

$$m_{av} = \frac{m_1 + m_2 + \ldots + m_{n\text{-}i}}{n_p - i_{for}}, \tag{2}$$

there m_i is a mass of the part of airplane calculated according to the one of the mass formulas; n_p is a complete number of calculations or number of the applied formulas; i_{for} is a number of falling out results.

The algorithm of Sheynin's method proposes next sequence of actions:

a) Choice of several formulas on the principle of compatibility on the basis of verification of their exactness by the construction of probability distribution of estimation errors, found from statistical data;

b) Calculation of component mass – m_i;

c) Determination of falling out results;

d) Finding of an arithmetical mean value on the condition of exclusion of falling out results.

Different analytical and graphic indexes of exactness are used for the analyses of formulas. Exactness of estimation is characterized by the absolute and relative estimation error. The relative error does not depend on mass values of component and characterizes the systematic and random estimation error. A probability or P (A) is the measure of possibility of event realization. As it applies to this method such event will be appearance of the random error in the mass estimation. A probability density function is used to describe a probability distribution of some random value. The probability density function of relative error distribution gives exhaustive information about exactness of mass formula.

The non-equivalence of mass formulas provides different exactness at calculation the same mass values of CTO components with the use of different formulas. The measure of exactness of the formula or in other words the probability of appearance of the random error in the calculation characterizes such parameters of probability density function as dispersion and average square-law deviation (s. d.). The error theory distinguishes systematic and random errors. The first arise out of inexact (in our case) account of parameters influence on mass of the construction, second appears because of large number of different causes. The formula of estimation error looks like $\Delta = \Delta_s + \mathring{\Delta}$, where: Δ_s is the mathematical expectation of error or systematic error; $\mathring{\Delta}$ is a random error with zero expected value. In the random errors distribution the deviation of the mathematical expectation from a zero value in any direction marks a systematic error. A systematic error could be eliminated by input of correction coefficients.

$$m_{av} = \frac{\sum_{i=1}^{n_p - i_{for}} k_i m_i}{n_p - i_{for}},$$

where k_i are the converting coefficients on the CTO prototype.

For the optimum integration of a few independent mass estimation results that calculated mass value for the same component it is suggested to use the maximum likelihood estimation method instead of the arithmetic mean [6].

On the basis of this method a mean value is found as

$$x_{av} = \left(\frac{x_A}{\sigma_A^2} + \frac{x_B}{\sigma_B^2} \right) \Big/ \left(\frac{1}{\sigma_A^2} + \frac{1}{\sigma_B^2} \right), \quad (3)$$

where σ_A and σ_B are the s.d. values of measuring results cause the standard uncertainty has the sense of square-law deviation.

A formula (3) can be written down more compactly, if to define influence parameter.

$$w_A = \frac{1}{\sigma_A^2}, w_B = \frac{1}{\sigma_B^2}.$$

Putting in (2), will receive:

$$m_{av} = \frac{\sum_{i=1}^{n_p - i_{for}} w_i m_i}{\sum_{i=1}^{n_p - i_{for}} w_i}, \quad (4)$$

where $w_i = \frac{1}{\sigma_i^2}$ is the influence parameter of the mass estimation result received by using of the i formula, σ_i is the square-law deviation of probability density function of mass estimation random error that is built using the statistical parameters of CTO, which mass limits are known. Square-law deviation of the relative error distribution characterizes exactness of mass formula and can serve for the calculation of its influence parameter at finding of component mass mean value.

Taking into account the presence of correction coefficients that compensate the systematic error the formula (4) acquires a next appearance.

$$m_{av} = \frac{\sum_{i=1}^{n_p - i_{for}} w_i k_i m_i}{\sum_{i=1}^{n_p - i_{for}} w_i}.$$

The choise of the weight estimation formulas. The choice of formulas for the weight estimation of certain airplane component from the knowledge base is carried out taking into account the purpose of airplane, its class and type. By the EL language the operation formula choosing can be described as a next expression:

(setofall(?x)(and(I5-is-of-kind ?x Formula)(I5-has-property ?x has_result)(has_result ?x mass_parameter) (or(and(has_condition ?x ?y)(has_purpose ?y air_purpose)) (not exists(?y)(and(has_condition ?x ?y)(has_purpose ?y ?z)))) (or(and(has_condition ?x ?y)(has_class ?y air_class)) (not exists(?y)(and(has_condition ?x ?y)(has_class ?y ?z)))) (or(and(has_condition ?x ?y)(has_type_of_control ?y air_type_oc)) (not exists(?y)(and(has_condition ?x ?y)(has_type_of_control ?y ?z)))) (or(and(has_condition ?x ?y)(has_type_of_runaway ?y air_type_or)) (not exists(?y)(and(has_condition ?x ?y)(has_type_of_runaway ?y ?z)))) (or(and(has_condition ?x ?y)(has_type_of_speed ?y air_type_os)) (not exists(?y)(and(has_condition

?x ?y)(has_type_of_speed ?y ?z)))) (or(and(has_condition ?x ?y)(has_type_of_takeoff ?y air_type_ot)) (not exists(?y)(and(has_condition ?x ?y)(has_type_of_takeoff ?y ?z))))))

The formulas which probability functions form a narrow area on graphics satisfy the terms of compatibility to a full degree [4]. Mass formulas has large number of parameter that have complex mutual influencing so according to the central limit theorem and researches of carves of probability functions they are approximately normally distributed. For every mass formula with probability functions distributing $F_j(x) = P(X < x)$ verification of normality of distributing is carried out, and also mean value ($\bar{x}$), D и σ are determined. Pearson's chi-squared test could help to make a distinction between the empiric distributing and normal, observing whether empiric frequency distribution n_i differs from a theoretical frequency distribution $n1_i$:

$$\chi^2 = \sum_i \frac{(n_i - n1_i)^2}{n1_i}.$$

Theoretical frequencies are calculated on the followings formulas:

$$n1_i = \frac{nh}{\sigma}\varphi(u_i), \quad u_i = \frac{x_i - \bar{x}}{\sigma}, \quad \varphi(u) = \frac{1}{\sqrt{2\pi}} e^{-\frac{u^2}{2}},$$

where n is the sample size, h is a step (difference between two nearby variants) [7].

Distribution will approximate to the normal if the condition $\chi^2{}_{emp} < \chi^2{}_{cr}$ is satisfied. There $\chi^2{}_{cr}$ is a table value of critical point for the set significance level and number of degrees of freedom. A base formula to which other formulas are compared for determination of compatibility is defined according to next conditions

$$\chi^2_{emp\,j} < \chi^2_{cr}, \; M_j(x) = M_{\min}, \; D_j \approx D_{\min}, \; j \in 1 \ldots n.$$

The next step is choosing among other formulas and finding formulas with distribution near to base. For distribution that approximate normal a comparison with the base is made with the Student`s test and F-test [7]. For distribution that doesn't approximate the normal comparison with the base formula is carried out with the test of Kolmogorov-Smirnov (or *k*-s test) which is nonparametric and allows estimating on a point with the biggest sum of divergences of the accumulated frequencies between two samples [7].

Determinations of falling out result carried out on the basis of middle step of deviation S_{av} and maximal deviation of component mass from its mean value. The exclusion condition:

$$S_{av}(n_p) > S_{av}(n_p - i_{for})$$

where $S_{av}(n_p)$ is the middle step of the deviation at the complete number of calculations n_p.

$$S_{av}(n_p) = \frac{(m_{\max} - m_{\min})n_p}{(n_p - 1)m_{av}}, \quad S_{av}(n_p - 1) = \frac{(m1_{\max} - m1_{\min})n_{p-1}}{(n_p - 2)m1_{av}},$$

where $m_{\max}$, $m_{\min}$ are maximal and minimum values of mass at consideration of all of the got results; $m1_{\max}$, $m1_{\min}$ are maximal and minimum values of mass at consideration of results from a number calculations $(n_p - 1)$. Research on the basis of statistical probability distribution of random error in weight formulas and the using of maximum likelihood method allows obtaining the maximal exactness and including the results of all conducted weight estimations in searching of mean value of mass of the component of complex technical object.

Conclusions. Using of ontology and the method of plural calculation in the automatized system of weight design allow to take into account classic and innovative methods of weight estimation, combining them in accordance with their exactness at the calculation of mass limits. The received system of weight limits serves as theoretical basis used for creation of parametric managing models in CAD/CAM/CAE-system.

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А. В. Абрамова, Д. И. Конотоп

Применение онтологии для прогнозирования характеристик сложных технических объектов

Описано применение интеллектуальных технологий, таких как концепция онтологии и математические методы обработки статистических данных к автоматизации проектирования сложного техничного объекта.

Г. В. Абрамова, Д. І. Конотоп

Застосування онтології у прогнозуванні характеристик складних технічних об'єктів

Описано застосування інтелектуальних технологій, таких як концепція онтології та математичні методи оброблення статистичних даних до автоматизації проектування складного технічного об'єкта.