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THE PROBLEMS OF OPTIMAL DESIGN IN THE AUTOMOTIVE INDUSTRY

Ivan Dyakov

Department of Foundations of Car Designing and Construction, Ulyanovsk State Technical University, Severny Venetz Str. 32, 432027 Ulyanovsk, Russia

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Abstract. The paper considers the general problems of optimization of parameters of a vehicle at the design stage. The approaches to the solution of the task are set out. The questions of a choice of the objective function and the system of limitations are in focus, as the problem of optimization makes sense, if there are several possible variants of its solution.

Keywords: optimization; objective function; mathematical model; limitations; modeling; additive criterion; neural technology.

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Introduction

Optimization of the technological process of designing wheeled machines is the main objective of the constructor, who seeks to create a mathematical model of a separate element, a device or a system with certain properties (Dyakov 2003, 2007, 2012; Dyakov, Denisov 2005; Dyakov *et al.* 2007; Demokritov *et al.* 2007; Xu *et al.* 2007; Dyakov, Prentkovskis 2008; Pan *et al.* 2011, etc.). Different requirements are specified to a wheeled machine depending on its purpose; they are formed in the terms of reference. The most important ones are process-ability, unification, and qualitative operational indicators such as: fuel efficiency, off-road capability, control, reliability, safety, easy maintenance and repair, and low cost of manufacturing and operation (Duggirala *et al.* 1994; Lin, Lin 2001; Xu *et al.* 2007; Sekulski 2009, 2010; Khoei *et al.* 2010; Karkauskas, Popov 2011; Collignan *et al.* 2012; Gottvald, Kala 2012; Kou *et al.* 2012, etc.).

However, taking into account all these requirements at the design stage it is usually difficult even with the use of CAD, as at the designers' disposal there is a large number of methods, and which one will be able to help in solving the problem – the question is not easy. For example, when building models of bearing systems, the equations of the finite element method, boundary conditions and consumer properties with a certain mathematical structure are used. Since the finite element method is the main method of modeling, it is included as a core part of the method of the optimization of the project (Ermakov, Zhiglyavskij 1987; Lin, Lin 2001; Zhang *et al.* 2012; Goremikins *et al.* 2012, etc.).

1. Some considerations

When presenting any method of optimization, firstly, some idealized systems and elements are introduced, on which the substance of the method is based and its applicability in practice is demonstrated. For the solution of practical tasks of designing vehicles, the methods of optimization are modified with regard to special tasks. Therefore, the focus of this work is the problem of a choice of the method of optimization of the parameters of vehicles, and not just the theory of optimization.

The scientific concept of designing of vehicles was offered by domestic and foreign scientists, whose works are devoted to the theoretical and applied issues of the optimal design of mechanical systems.

At the present time, research on the algorithms of optimization is being conducted. As a result, it can lead to improved numerical methods of optimization.

Corresponding author: Ivan Dyakov
E-mail: i.dyakov@ulstu.ru

The optimization of the parameters of a vehicle is, in essence, the main goal of the engineer, who seeks to create a separate element of a device or a system to meet some of the needs of the consumer.

However, the implementation of this goal is usually difficult, because the designers have a small number of standardized methods at their disposal. The main problem of setting the task of the optimization is to select the objective function. The complexity of the choice of the objective function is that any technical object has a vector character (multiple criteria), and the improvement of all of the final parameters is a complex task. Minimization of the multicultural task to the single-criteria one is called the convolution of a vector criterion.

The best variant (making the best decision) can be chosen in different ways. If the choice provides for a quantitative analysis of the situation by the comparison of different options with the help of some of the quantitative assessment, then it is considered to be necessary to solve the problem of the optimization (*optimus* means the best). From all that, it follows that the task of the optimization makes sense, if there are several possible variants of its solution. Then it is necessary to formulate the optimality criterion, i.e. to define the attributes and preferences, which should be taken to make a comparative evaluation of the alternatives and to choose the best one among them from the point of view of the given goal of the optimization.

From this point of view, we can answer the question: what exactly do you need to improve? That may be the improvement of the throughput of the vehicle, reducing its weight or the cost of production and operation, etc. For that, it is necessary to have a mathematical model of the object of the optimization. Such a model describes the object with the help of the relations between the values, characterizing its properties. Variable values during the optimization, included in the mathematical model of the object of the optimization, are called optimization parameters, and the ratios which establish the limits of the possible changes in these parameters are called constraints. These constraints may be specified in the form of equalities or inequalities.

If the objective function and constraints are linear in terms of the optimization parameters, then the linear programming problem is used. The nonlinear programming problem is used in case of the nonlinear dependence of the objective function or constraints on the optimization parameters. A strategy of the automotive industry growth can be developed on the basis of the parametric optimization theory including the protection of the environment, the consumer demands, the use of alternative energy (electricity, hydrogen, biomass, and renewable energy), control of exhaust emissions (vehicle with zero toxic effect), reduction of the noise level of the vehicle, the use of intelligent transport systems (interactive data exchange, "thinking" vehicle).

Research will only be effective when it is possible to increase the efficiency of the vehicle while operating it. The systematic approach is the most reliable to that; it allows considering the influence of such fundamental factors as the operator's impact on the vehicle and the environment. Methods, which are used for the achievement of the effective construction, are considered to be general in the essential features (criteria and limits) with the use of mathematics (linear, nonlinear, and dynamic programming and differential and variational calculus, etc.).

The basis of any of the design process is the information about what the designer actually wants to get, and what is his purpose (or more accurately to say, a multitude of goals), which provides the international standards requirements in this field. The process of goal-setting precedes the procedure of design: between the purpose and the object, generally speaking, there is an interrelationship; the goal influences the choice of the object, and the object determines the nature of the goal. This interdependence of the purpose and the object is connected with the fact that the designer can not formulate the goal, not having at least some preliminary (a priori) representation of the object, in which this objective should be implemented.

Therefore, to test the technical feasibility of goals it is necessary to know, what would happen to the vehicle while it is operating? This means that in the process of goal-setting, we should have a fairly clear idea about the loading of the vehicle in operation.

It is known that not every vehicle always meets the design goals completely, i.e. we cannot achieve all of the formulated goals with the available resources both in the field of design and in the field of manufacturing technology. The scientific results achieved in the world practice are not always used in these spheres. This fact usually forces us to correct the purpose of design, and it inevitably changes the technical and operational characteristics of the vehicle. That is why the goal does not occur separately from the object. Probably, the designer thinks over various ways for achieving the objectives and the object at the same time, they are interconnected and actively interact. Answering the question: "what is better?" – it is necessary to formulate a *criterion of optimality*, i.e. to define the attributes and preferences, which should be taken into consideration when comparing the alternatives and then choosing among them the best from the point of view of the concrete goal of optimization. Sometimes *a clever additive criterion* is used, when there are two groups of the output parameters. The first group are the parameters, which are being increased in the process of the optimization: the throughput, the probability of trouble-free operation, maximum speed, etc. and the second group are the parameters which are being reduced. Such an approach does not give any positive results. Here you should use only relative values and enter restrictions. It is from this point of view, you can answer the following question: what is specifically needed to be improved? So, that to answer, it is necessary to have a mathematical model of the object. It should describe the object with the aid of the relations between the values, characterizing its properties.

The parameters of the mathematical model, which are changing during the optimization, are called *parameters of the optimization*, and the ratio of establishing the limits of the possible changes in these parameters, are called *constraints.* They may be specified in the form of equalities or inequalities. However, from the methodological point of view, it is better to divide these processes, i.e. the synthesis of objectives should be considered regardless of the process of isolation of the object from the environment; although in reality they are parallel. So, for example, after the manufacturer's testing on the ground, the vehicle goes into operating mode, where, basically, the requirements of the manufacturer are not carried out. Here, it is appropriate to remind that the designer's properties of the vehicle are stated in the operating conditions' instruction. Note, that the vehicles can be operated not only by one person (a driver), but a large group of people (the repair personnel, maintenance services, engineering, and technical employees). Therefore, the management should be regarded as the active system, whose interests should be reflected in the designed vehicle (the vehicle is created for their sake).

2. The formulation of the problem

Let the consumer have a $[k]$ set of different needs (to increase profitability, average speed, reliability, etc.), each of those we will characterize as the number α_i – the degree of its urgency and relevance. It is obvious that demands are changing during the time depending on the condition of the vehicle (the consumer demands and the environment conditions where it is located). As the methodological base of the set for constructing the model of differentiated assessments of vehicles, we suggest to apply the genetic algorithm, which demonstrates real parameters when solving complex tasks of optimization.

Suppose the consumer has a system of realization of the set of the given goals; then, the designer's actions will be limited to the formulation of the control objective and to the achievement of that goal, i. e. to the implementation of the equality $z = \dot{z}$ with the help of control. Let's imagine that z is the status of the vehicle (object), as described in the objectives $\{\dot{z}\}$. Translation from one language to another is carried out with the help of the function f, i.e. $z = f(y)$, where $f(y)$ is the given function, defined on the status of the object.

The designer must have the measures of the quality of the objective $\mu(z)$, i.e. a peculiar function of non-comfort (non-optimality) of the construction, which is determined by the set of all possible objectives $\{\dot{z}\}$. This function allows to compare two objectives $\dot{z}_1$ and $\dot{z}_2$ as follows:

– if $\mu(\dot{z}_1) \le \mu(\dot{z}_2)$, then the objective $\dot{z}_1$ is preferable to the objective $\dot{z}_2$;
– if $\mu(\dot{z}_1) = \mu(\dot{z}_2)$, then the objectives are equivalent.

The choice of the optimal objective is reduced to the solution of the problem:

$$\mu(\dot{z}_1) \to \min_{z \in \{\dot{z}\}} \Rightarrow \ddot{z}.$$

The measure $\mu(\bullet)$ can be defined as a clever ("weighted") sum:

$$\mu = \sum_{i=1}^{k} b_i \cdot a_i,$$

where: $b_i > 0$ is the constant coefficient ($i = 1, 2, \ldots, k$); a_i is the "weight", characterizing the significance of the appropriate requirements of the consumer. These values are determined with the help of the expert estimates.

Implementation of the selected objective must change needs in the direction of the improvement of the used model (functional or structural):

$$M_1^{\dot{z}} = M_2,$$

where: $M_1^{\dot{z}}$ is the initial state of the original model; M_2 is the model obtained as a result of the implementation of the objective $\dot{z}$.

Of course, in this case the model:

$$M_2 = \frac{n!}{r!(n-r)!}$$

would represent the minimum of the objective function, where n is the number of repair impacts; r is the number of conducted services.

For that you need to establish the connection in the form of the dependence:

$$M_2 = f(M_1, \dot{z}, s),$$

where: s is the situation in the environment by the time of the selection of the objective $\dot{z}$. In the simplest case $s = (x, y)$, i.e. that is the state of the environment (the modes of loading, the frequency of service, the way to store, the road conditions). This dependence should be known, then, substituting it in the measure $\mu(\bullet)$, we will obtain the desired function $\mu(\bullet)$, minimization of which would clearly determine the optimal goal of the consumer.

The described mechanism, derived from the optimal goals of the impact, can be put in a basis of the creation of formal criterion of the optimality. However, for this purpose it is necessary to have at the disposal two models: $\mu(M_{1\dot{z}})$ and the generalized model $(M_{2\dot{z}})$, providing the changing demands of the consumer $f(\bullet, \bullet, \bullet)$ as a result of realization of the objective $\dot{z}$.

The model is considered to be adequate if it reflects the examined properties of the vehicle according to the given accuracy. The latter is estimated by the degree of matching of the output parameters of the model with their true values. The accuracy of the model ε_m is calculated for the totality (m) of the considered output parameters:

$$\vec{\delta}_i = (\delta_1, \delta_2, ..., \delta_m);$$

$$\left|\vec{\delta}_m\right| = \max_{\varepsilon_m \in |1:m|} \left|\delta_j\right|,$$

or

$$\left|\vec{\delta}_m\right| = \sqrt{\sum_{j=1}^{m} \delta_j^2},$$

where: δ_j is the relative error of the model of j-output parameter:

$$\delta_j = \frac{\bar{y}_j - y_j}{y_j},$$

where: $\bar{y}_j$ is j-output parameter, which is calculated on the basis of the designed model; y_j is the value of the same parameter, found while the testing the vehicle in the controlled test conditions.

If the maximum permissible error of simulation $\delta_{\lim}$ and you can select the pane in which $\delta_{\lim} > \delta_m$ it is considered to be an adequate model. The universality of the model is characterized by the number and composition of its internal, external, and output parameters taken into consideration. The more of them the model has, the more universal it becomes, but that can significantly increase the cost of finding of the coefficients and constant parameters. When making the mathematical model, the decomposition of the overall structure of the vehicle according to the hierarchical levels can be carried out.

Implementation and experimental-performance testing in terms of production have confirmed that carrying out technical maintenance more than 12 times a year does not give positive results when using a vehicle in mixed traffic conditions; the length of a driver's work experience less than 10 years administers the decrease in reliability of the vehicle by more than 15%, and the quality of traffic conditions – more than 30% than the length of a driver's work experience.

Conclusions

The scientific innovation of the presented work is to develop a mathematical model of spatial set of the parameters of vehicles, when the variety of situations and indicators are participating in the sphere of exploitation and taking into consideration service staff, together, they form neural technology.

The basis of many methods of searching for the optimal technical solutions is considered to be Zwicky's method, which is based on the opportunities of sorting the parameters; every of them can have several values.

By combining different values of the parameters we can obtain different variants of the decision.

Such a method of solution to the problem does not produce the desirable results at increasing characteristics of a consumer's vehicle.

A more complete approach finding solution to the problem can be provided with the system analysis based on neural technologies that allows the designer to predict changes of the parameters in the terms of operation of the vehicle.

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