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Regulation of tolerances of associated parts of mechanisms of livestock farms during repair

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Abstract. The paper considers an algorithm for optimizing the efficient distribution of resources that determine the cost of assembly work, subject to restrictions that ensure high quality assembly of livestock machines and equipment. To determine the required tolerance values for parts, one can use the known methods of parametric optimization. Therefore, the application to the solution of the problem of the method of Lagrangian multipliers as a result of the calculations obtained the optimal tolerances of the details of the angle. Upon completion of the calculations, the optimal assembly parameters of the node for various values are obtained; the result is presented in graphical form. There are various methods for calculating component tolerances of mating parts. Methods based on the statistical evaluation of tolerances and finding their root-mean-square deviations make it possible to reduce the degree of risk when expanding the tolerance limits for mating parts and reduce assembly losses. The correct assignment of tolerances allows one to achieve significant savings in material resources and reduce production costs. The most effective solutions may be those obtained by implementing optimization procedures that ensure the minimization of the quality criterion under the conditions of restrictions determined by the components of the assembly assembly process.

1. Introduction

One of The most important areas for improving the efficiency and quality of the overall range of work on the repair of machines and mechanisms of livestock farms is the improvement of assembly technological processes of both the nodal and general assembly [1]. In modern technological processes of machine repair, the volume of assembly work is quite large and can be up to 35–40% of their total volume in small-scale production [2; 3]. Carrying out repair work in conditions of resource shortage requires the development and application of optimization procedures, modern resource-saving technologies and computing environments at minimal cost for their implementation. Optimization of technological operations for assembling machines and mechanisms of livestock farms based on scientifically substantiated provisions, methods and models using effective technical solutions makes it possible to radically solve the problem of resource saving using operational technologies. Studies have shown that in the process of assembling mechanisms it is advisable to use algorithms and models of parametric optimization, efficient allocation of resources that determine the cost of assembly work while observing the restrictions that ensure high assembly quality.

2. Object and methods of research

Repair of parts, assemblies and assembly of mechanisms must be carried out in compliance with technical standards, tolerances and surface treatment technologies provided for by the relevant technological documents. If significant deviations from the requirements of the drawing are made in the process of manufacturing parts, then the necessary assembly of assembly units will not be ensured during assembly. Additional processing of parts or their rejection lead to an increase in the cost of production. In the case of tightening requirements for limit deviations, production costs increase, since with an increase in machining accuracy, the cost and time of manufacturing parts increase significantly. If there is no equipment that ensures high manufacturing accuracy, then sorting of parts and the transition to selective assembly are inevitable at the assembly.

The use of statistical control of the population of parts under the normal distribution law is based on the fact that the tolerance field is set by the parameter 6σ (“statistical tolerance”), where σ is the standard deviation of the normal distribution. In this case, the number of defective items from a batch of parts will not exceed 0.27%.

When pairing parts, the maximum deviations of their dimensions are calculated subject to the requirements for the tolerance of the assembly unit. It can be assumed that the total tolerance of the assembled assembly is equal to the sum of the individual tolerances of the parts included in the assembly.

Resource distribution models play an important role in solving the problems of creating operational technologies for improving technological processes in animal husbandry. These models allow, under conditions of limited resources in each specific situation, to use them with the least loss, which is achieved through algorithmization and the use of optimization methods and efficient computational procedures.

It should be noted that for a certain class of models, the problem of optimal assembly of a node according to a given total tolerance can be solved analytically. Suppose we need to assemble a assembly consisting of n different parts. Since the node tolerance should not exceed the specified value T units, and it is equal to the sum of the tolerances of n parts, the conjugation condition can be written:

$$T=t_1+t_1+...+t_n=\sum_{i=1}^{n} t_i=\Phi(t_1, t_2, t_3, ..., t_n), \quad (1)$$

where t_i is the tolerance *of the* i -th part ($i=1,2,3,...,n$).

Suppose that the cost of *the* i -th part $g_{i\ manufactured}$ consists of two components: the constant g_{pi}, representing the cost of the workpiece, and the variable c_i, depending on the complexity and quality of processing. In general, the variable component should be a non-linear function of t_i:

$$g_i = g_{pi} + c_i(t_i) \quad (2)$$

We will assume that the variable component $c_i(t_i)$ is inversely proportional to the tolerance t_i to *the* m -th degree and can be represented by the dependence

$$c_i(t_i) = \frac{K_i}{t_i^m}, \quad (3)$$

where K_i is a constant coefficient depending on the shape, dimensions and material properties of *the* i -th part; m is an integer. Then the cost of all parts included in the node is equal to

$$G = \sum_{i=1}^{n} g_i = \frac{K_1}{t_1^m} + \frac{K_2}{t_2^m} + ... + \frac{K_n}{t_n^m} + g_{p1} + g_{p2} + ... + g_{pn} = f(t_1, t_{2,} ..., t_n). \quad (4)$$

The problem is to minimize the cost of all parts G , included in the node, when constraint (1) is satisfied, if (2) and (3) are known. The search for the minimum G is carried out by varying the tolerances t_i . Of all the possible values *of* t_i included in (1), one should choose such values of tolerances of the assembly parts

$$t_1^* + t_2^* + \ldots + t_n^* = T, \tag{5}$$

so that the cost function (4) takes the minimum value.

Known methods of parametric optimization can be used to determine the required tolerance values for parts. In particular, consider the solution of the problem using the multiplier method Lagrange. According to this method, to find the extremum, it is required to solve the system of equations:

$$\begin{gathered} \frac{\partial f}{\partial t_1} + \lambda \cdot \frac{\partial \Phi}{\partial t_1} = 0, \\ \frac{\partial f}{\partial t_2} + \lambda \cdot \frac{\partial \Phi}{\partial t_2} = 0, \\ \ldots \\ \frac{\partial f}{\partial t_n} + \lambda \cdot \frac{\partial \Phi}{\partial t_n} = 0, \end{gathered} \tag{6}$$

where λ is the Lagrange multiplier.

Simple calculations of partial derivatives of functions (4) and (1) with respect to variables t_i allow us to write

$$\begin{gathered} -m \cdot K_1 \cdot t_1^{-(m+1)} + \lambda = 0 \\ -m \cdot K_2 \cdot t_2^{-(m+1)} + \lambda = 0 \\ \ldots \\ -m \cdot K_n \cdot t_n^{-(m+1)} + \lambda = 0 \end{gathered} \tag{7}$$

Let $\alpha = \frac{1}{m+1}$. Then from the first and second equations of system (7) we obtain the optimal tolerance of the second part t_2^* as a function of the optimal tolerance t_1^* of the first (base) part:

$$t_2^* = \left(\frac{K_2}{K_1}\right)^{\alpha} \cdot t_1^*. \tag{8}$$

Similarly, we write t_3^* in terms of t_1^*:

$$t_3^* = \left(\frac{K_3}{K_1}\right)^{\alpha} \cdot t_1^*. \tag{9}$$

For the chosen model (1)÷(4), if $1 < i < (n-1)$, by induction we obtain

$$t_i^* = \left(\frac{K_i}{K_1}\right)^{\alpha} \cdot t_1^*. \tag{10}$$

Optimal tolerance of the nth part:

$$t_n^* = \left(\frac{K_n}{K_1}\right)^{\alpha} \cdot t_1^*. \tag{11}$$

After substituting (9) ÷ (11) into equation (1), we will have:

$$T = S \cdot t_1^* \tag{12}$$

Where

$$S = K_1^{-\alpha} \cdot \left(\sum_{i=1}^{n} K_i^{\alpha} \right). \tag{13}$$

The optimal tolerance of the base part t_1^* is determined using a simple relationship

$$t_1^* = \frac{T}{S} \tag{14}$$

Tolerances of other parts of the assembly are calculated by formulas (8) ÷ (11). Let's select a subassembly consisting of five parts. Knot tolerance $T=0.022$ (mm). We estimate the cost of parts using formula (2) with the following values of the coefficients:

- *K_1 \u003d 0.0035; K_2 \u003d 0.0018; K_3 \u003d 0.00028; K4 = 0.0070; K_5 \u003d 0.0012;*
- *g_{p1} =120 ; g_{p2} =180; gp3 =47.5 ; g_{p4} =150; g_{p5} =250 (arb. units).*

The exponents in the formula (3) for all parts are the same and equal to m=2.

As a result of calculations by formulas (8) ÷ (14), the optimal tolerances of the assembly details are obtained, represented by the vector

$$t^* = \begin{bmatrix} t_1^* & t_2^* & t_3^* & t_4^* & t_5^* \end{bmatrix} = \begin{bmatrix} 0.0051 & 0.0042 & 0.0023 & 0.0066 & 0.0037 \end{bmatrix}$$

The minimum cost of parts was *Pm* =1280.2 arb. units

For comparison, the cost of parts was calculated with equal tolerances $t_i = \frac{T}{n}$. In this case, *P* =1459.3 arb. units Thus, the optimal distribution of tolerances of parts of the node allows you to reduce costs by 179.1 arb. units

The solved problem can be attributed to the class of simple problems of optimal resource allocation. An analytical solution is obtained by choosing m=2. In addition, the model has no restrictions on the elements of the state vector, etc. The resource is the parameter T , which is distributed over n processes in the most efficient way.

For functional dependencies $\Phi(t_1, t_2, t_3, ..., t_n)$, $f(t_1, t_2, t_3, ..., t_n)$ and $g_i(t_i)$ of a complex form, the complexity of calculations increases significantly. For example, for functions (3) with different exponents *m1÷m5* in the presence of linear and nonlinear constraints, as well as constraints on state variables, it is almost impossible to obtain solutions in an analytical form, and one has to use numerical methods and optimization algorithms. It is expedient to construct such algorithms using the tools of various computing environments. To solve a class of problems with unimodal cost functions (3), as well as a family of nonlinear problems that meet the Kuhn-Tucker conditions, a spline optimization method was used in the work, an algorithm was proposed, and a program was developed based on the use of the fmincon function of the MatLAB environment [3; 4]. A fragment of the program is represented by a file - the function s1.m and blocks of the script file:

- %s1.m
- % File is a function.
- % Optimal distribution of node access as a resource across processes.
- function L=s1(x)
- h1 h2 h3 h4 h5
- L=[ppval(h1,x(1))+ppval(h2,x(2))+ppval(h3,x(3))+ppval(h4,x(4))+ppval(h5,x(5))];
- The first block of the script is the file.

% Assembly of the mechanism according to the spline method.
% Initial data:

- h1 h2 h3 h4 h5

% Initial data for calculations:

- T=0.022; k1=0.0035; k2=0.0018; k3=0.00028; k4=0.0070; k5=0.0012; m=2;
- gp1=120; gp2=180; gp3=47.5; gp4=150; gp5=250; N=5;
- m1=1.9;m2=1.72;m3=1.85; m4=2.05;m5=1.73;
- Tmin=0.001; Tmax=0.008.

% Estimation of cost functions in (D+1) interpolation nodes:

- D=8;
- t=Tmin:(Tmax-Tmin)/D:Tmax;
- f1=k1./(t.^m1);f2=k2./(t.^m2);f3=k3./(t.^m3);f4=k4./(t.^m4);f5= k5./(t.^m5).

% Formation of matrices of initial data:

- g1=[t;f1];g2=[t;f2];g3=[t;f3];g4=[t;f4];g5=[t;f5].

% Construction of splines:

- h1=spline(g1(1,:),g1(2,:));h2=spline(g2(1,:),g2(2,:));
- h3=spline(g3(1,:),g3(2,:));h4=spline(g4(1,:),g4(2,:));
- h5=spline(g5(1,:),g5(2,:)).

3. Results of the study

According to the obtained calculated data, graphs of cost functions for five parts are constructed, shown in figure1. Interpolation nodes are represented on each characteristic as points. The optimal values of tolerances for parts with a variation in the tolerance of the node from 0.015 to 0.030 mm, as well as the minimum assembly costs, were obtained using the second block of the script file:

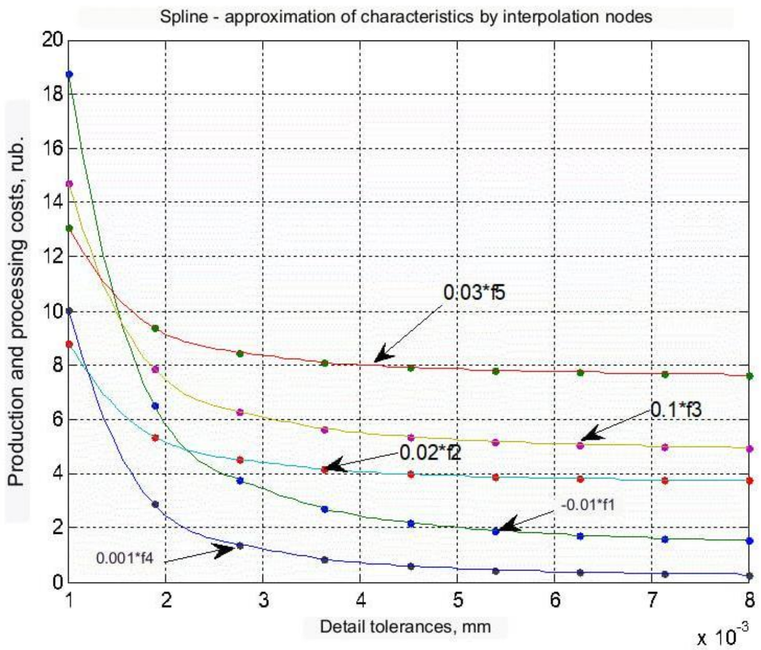

Figure 1. Functions of costs for the manufacture and processing of assembly parts.

% Implementation of the algorithm for the optimal distribution of resource T over n processes.
% Restrictions on state variables:

- lb=ones(5,1)*Tmin;
- ub=ones(5,1)*Tmax.

% Numerical optimization procedure:

- Aeq=[1 1 1 1 1]; beq=T;
- options=optimset('Display','Iter');
- [x,J1]=fmincon('s1',lb*4,[],[],Aeq,beq,lb,ub,[],options)

% Calculation results

- G=k1./(x(1).^m1)+k2./(x(2).^m2)+k3./(x(3).^m3)+k4./(x(4). ^m4)+k5./(x(5).^m5)+... sum([gp1 gp2 gp3 gp4 gp5])

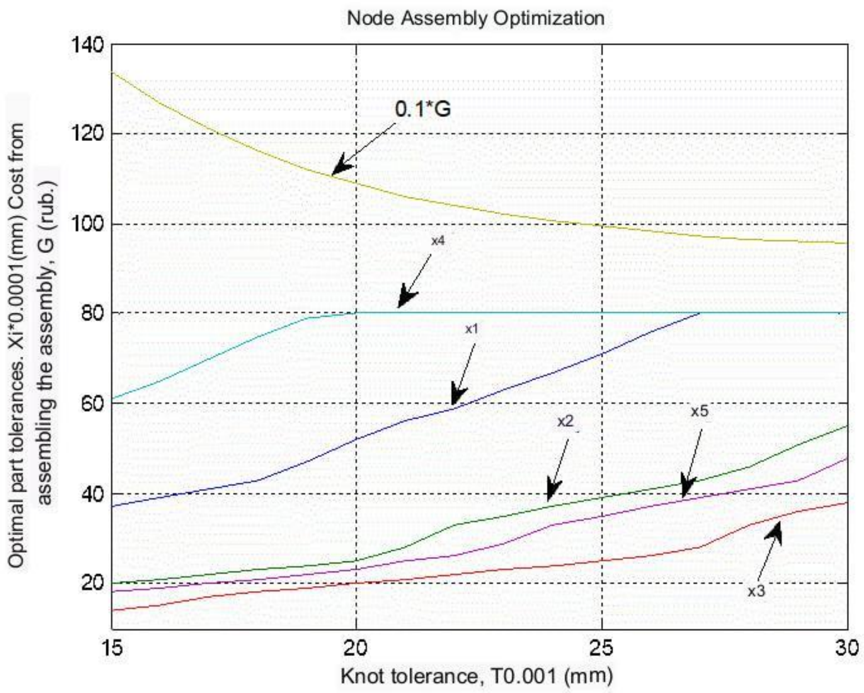

Figure 2. Optimization of the technological process of assembly of the mechanism.

Upon completion of the calculations, the optimal assembly parameters of the assembly for various tolerance values T were obtained. The results are presented in graphical form (figure 2). Calculations are performed with the introduction of restrictions on the state variables *x1÷x5* . It can be seen that the detail tolerance *x4* for values $T \geq 0.020$ mm takes the maximum allowable value determined by the boundary *ub* (see file fragment) and equal to 0.008 mm. The workpiece tolerance *x1* reaches the right limit if $T \geq 0.027$ mm. Minimum assembly cost *G(T)=G(0.015)=1335.8* c.u. As T increases, the cost of assembling the assembly decreases, and at T =0.030 mm it is *G(T)=G(0.030)=955.5 c.u.* . If the node tolerance is T =0.040 mm, then according to the right boundary , all part tolerances must be equal to 0.008 mm, and the variation of the state variables is not performed.

4. Conclusions

The input of initial data is connected with obtaining the structure and estimating the parameters of models (2), (3) and (4). Initial data preparation is the most time-consuming and responsible part of the solution and is usually based on an experiment. The advantages of the spline method are that the experimental data can be entered in the form of low-dimensional measurement vectors, without determining the structure and parameters of the input signals. There are no restrictions on the choice of the change discreteness step. Operations on the analytical representation of the initial characteristics according to the experiment are implemented in terms of spline approximations, using experimental points as interpolation nodes, which in practice ensures high accuracy and ease of calculations.

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