Journal of Modern Technology and Engineering
Vol.10, No.1, 2025, pp.57-62
https://doi.org/10.62476/jmte.10157

OPTIMIZATION PRINCIPLES OF MECHANICAL TRANSMISSION OF LIFTING DEVICES

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Abstract. The article presents the basic principles of optimal design of mechanical drives of lifting units. It is noted that when optimizing the designs of machine and unit drives, only those characteristics of the object that have a significant impact on the optimization criterion should be taken into account. As it is known, depending on the choice of internal parameters of the designed technical objects, the constructions that characterize these objects receive different values. Economic indicators of the design, metal consumption, durability, reliability can be taken as the target function in matters of optimal design. In multi-criteria problems, the target function summarizes several factors simultaneously. Compliance with the criteria for the performance of the design (strength, rigidity, corrosion resistance, vibration and heat resistance) can be considered as constraints. An algorithm for an optimization problem using a computer is given.

Keywords: objective function, optimization, stress, gear transmissions, chain sprockets, wear resistance.
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Received: 22 October 2024; Revised: 2 December 2024; Accepted: 21 February 2025;
Published: 30 April 2025.

1 Introduction

Normalization of the optimization criterion. The choice of optimization criterion for drives of various machines and units is a complex problem, since the design of the unit must satisfy a number of conflicting requirements. The table provides a list of conditions that the design must satisfy and the characteristics corresponding to these conditions, which can be written analytically (Habibov & Mammadov, 2010; Akinsade et al., 2024; Semenyuk et al., 2023; Job & Galve, 2023; Sun et al., 2021)

The design tasks of lifting gear transmissions are as follows.

- Economic goals - mass or weight of the object (total and variable elements of the structure).
- Technical requirements
- moment of inertia of the moving element of the structure;
- mechanical efficiency of the drive;
- overall or main dimensions (e.g. inter-center distances of chain drives);
- generalized mechanical impact;
- wear in the main element of the object – minimization or maintenance of a given value of wear in a group of elements;

- durability of the main element – maximization or ensuring a given durability of a group of elements;
- stresses, including stress concentration – minimization or maintenance of a given value in various elements (e.g. the intermediate plates of drive roller chains);
- specific pressure – minimization or maintenance of a given value in various elements;
- generalization of the movement of the main element – minimization or maximization;

It is necessary to consider these conditions simultaneously and not allow the mutual influence of one condition on another. When optimizing the designs of machine drives and units, only those characteristics of the object that have a significant effect on the optimization criterion should be taken into account. In this case, it is advisable to form the optimization criterion in the form of a weight function. Moreover, when constructing the optimization criterion, it is necessary to either aggregate the characteristics that reflect the opposite requirements for the object, or, where possible, write them down as separate members (Huseynov, 2010).

2 Calculation of the object

The characteristics of an object with synchronous change, that is, when the application of one characteristic causes a similar change in another, should be taken into account as one complex (Aliyeva & Damirova, 2021). For an object with a homogeneous structure, the expression of the optimization criterion can be written in the following form:

$$\min_{x\in X} f\left(x,p\right) = \min_{x\in X} \sum_{j=1}^{r} \alpha_j \frac{S_j\left(x_j,p_j\right)}{S_{j_0}} \tag{1}$$

where the weighting coefficients satisfy the condition

$$\sum_{j=1}^{r} \alpha_j = 1 \tag{2}$$

x - vector of variables; p - vector of parameters; $S_j\left(x_j,p_j\right)$ - characteristics of objects; S_{j_0} - initial approximation of the j-th characteristic of the object, in other words, optimization of the function determined at the stage of the preliminary design of the project; X - set of admissible vectors x.

A graphical representation of the weight (multi-criteria) function is shown in Figure 1.

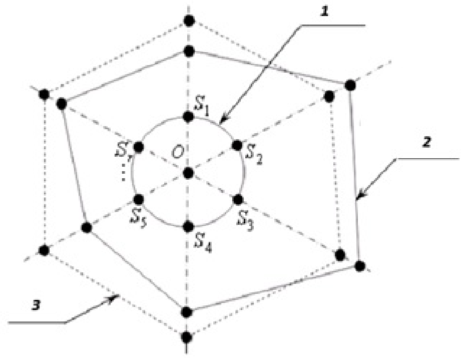

Figure 1: Graphical representation of the weight multi-criteria function

Here 1 - optimal value for a particular criterion; 2 - optimal value of the weight function; 3 - initial version of the project.

When forming a weight function in the form of equation (1), in some cases it is necessary to take into account the possibility of its unlimited change by introducing additional conditions (Karimov, 2002). For similar objects with a sequential structure, the vectors of variables and parameters can be specified in the form:

$$X = \{x_i\}, p = \{p_i\}$$

where $i = 1, 2, \ldots, r$ - object number.

In the current state of the theory of multi-criteria optimization, it is impossible to solve the problem of optimization of similar objects with a sequential structure in general. However, the search for an optimal solution can be implemented as a sequence of the following steps:

1. Selecting the optimal set of variables for a specific, uniform object.
2. Selecting a suboptimal solution taking into account the requirements determined by uniformity.

The analysis of kinematic diagrams of most mechanical drives, in particular drives of drilling rigs and lifting units, consists of the sequential interaction of gear and chain transmissions. In this case, the kinematic diagrams of the drives are determined by the number of lifting speeds, lifting capacity, productivity, traction motor power, etc. (Mammadov, 2001). The gear ratios of individual sequentially connected elements (gear wheels and chain transmissions) in mechanical drives of machines and units, determined in accordance with the specified speeds, will be:

$$u_i = \frac{1}{\Phi^{i-1}}$$

or taking into account the adaptability of the engine

$$u_i = \frac{1}{(K\Phi)^{i-1}}$$

The choice of a rational Φ series of machine and unit speeds in the form of a geometric progression with a denominator allows to carry out the synthesis of geometric parameters of chain boxes and gearboxes, ensuring the minimum cost of manufacture and the volume of the designed product. The purpose of the synthesis is to find the sizes of chain sprockets from the engagement equation and gear ratios, so that one or more of the following conditions are performed (Heydarov & Mirzayev, 2012):

1. Minimizing the size of the largest chain sprockets.
2. Minimizing the dimensions of chain gearboxes and reducers.
3. Minimizing the total cost of chain gearboxes and reducers.

The optimization criterion for minimizing the largest dimensions of chain sprockets can be mathematically formulated as follows:

$$objective\ function\ |z_1 - z_2| \to min$$

where z_1 and z_2 - number of teeth of the largest dimensions of chain sprockets.

It should be noted that the choice of the number of teeth of the chain sprockets depends on the pitch of the drive roller chain. Therefore, the value of the roller chain pitch will also participate in the minimization of the objective function.

Analysis of the gear ratio equations allows to estimate the smallest gear ratio as a function of independent parameters.

$$u = u\left(x_i\right)$$

and express the relative dimensions of other wheels through Φ, u and x_i. Then, considering a set of parameters x_i with known Φ and u, we can calculate the relative dimensions of the leading chain sprockets. Taking into account the above, when minimizing the dimensions of chain gearboxes and reducers in the drives of machines and units, the objective function will be taken as the minimum of the sum of the wheel diameters, that is, the sum of the distances between the centers of the shafts (in chain drives, the center-to-center distances depend on the pitch and number of rows of the drive roller chains) as a direct measure of the dimensions of the chain gearboxes and reducers (Mammadov, 1997a). Then, normalizing the wheel diameters relative to the base diameter, the objective function can be written in the following form:

$$\min\left|1 + \sum x_i\right|$$

Formulating constraints. Among the restrictions that are imposed on the design and determine the permissible design area, the following must be highlighted:

1. Constraints on static characteristics (e.g., on the strength and rigidity of the optimization object elements).

2. Constraints on kinematic characteristics (e.g., conditions limiting the operating speed and operating acceleration of the design object elements).

3. Constraints on dynamic characteristics (e.g., conditions limiting natural frequencies, i.e., depending on the needs, ensuring the operation of the chain drive before the occurrence of sprocket beating or vibration of the drive chain, limiting dynamic stresses when the chain links engage, the amplitude of chain vibrations and the fatigue strength of the drive chain elements).

4. Design conditions ensuring the dimensions of chain gearboxes and reducers.

5. Technological conditions associated with certain requirements for the processing of drive elements.

6. Conditions excluding collisions of drive elements.

7. Conditions reflecting the characteristics of the drives (e.g., ensuring the required output power and output torque), which will also be formulated if necessary.

All the specified restrictions imposed on the design must be formulated explicitly, which means writing them in the form of mathematical expressions.

Since the optimal value of all independent parameters must satisfy the engagement conditions, these equations act as restrictions in the optimal design of gearboxes and reducers in the drives of lifting units (Mammadov, 1997b; Mammadov et al., 2017).

Thus, according to the objective function and restrictions described above, the optimal dimensions of series-connected drive elements (gear wheels and chain sprockets) can be found.

To optimize the drive elements with the implementation on a computer of drilling rigs and lifting units intended for well repair, an algorithm for solving the optimization problem has been developed (Fig. 2).

1. Conditions reflecting the wear resistance of chain rollers.

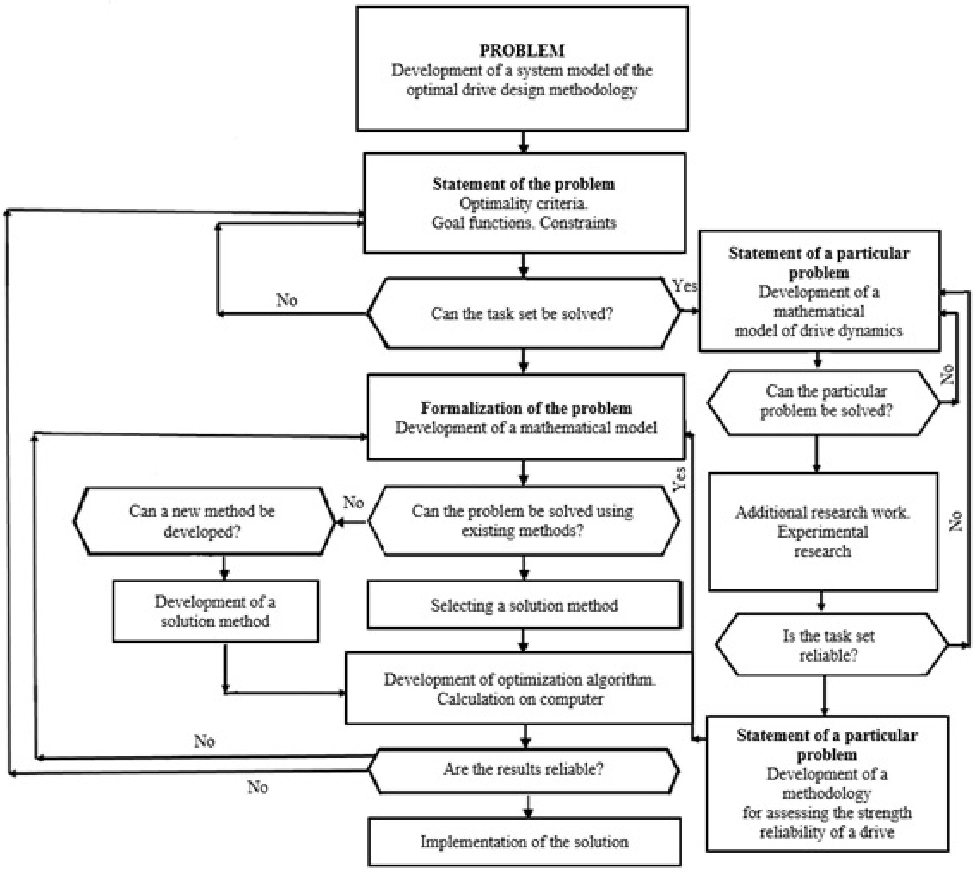

Figure 2: Algorithm of the optimization problem for solution on a computer

2. Conditions reflecting the fatigue life and safety margin of the drive chain and the fatigue strength of chain elements, for example, intermediate plates, characterized by a high value of the stress concentration factor.

3 Conclusions

The article analyzes the basic principles of designing gear mechanisms of lifting devices. An expression for the optimization criterion for calculating an object of a special structure is formulated. Vectors of variables and parameters for similar objects of a sequential structure are also expressed. Taking this into account, when minimizing the dimensions of chain and gear transmissions in machine and unit transmissions, the target function will be the minimum sum of wheel diameters, i.e. the sum of the distances between the shaft centers. Then, the target function was formulated by normalizing the wheel diameters in relation to the base diameter. As a result of the optimal solution, an algorithm for solving the optimization problem was developed on the computer.

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