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Preliminary note

COMPARATIVE ANALYSIS OF ANALYTICAL CALCULATION AND OPTIMIZATION ON GEARBOX DIMENSIONS AND VOLUME

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Abstract: *For the purposes of this research analytical and numerical calculations of gearboxes have been done. In the process of numerical calculation optimization was implemented. Optimization was done according to four different criteria: length, width, height and volume, whose values are compared to the analytical calculations according to the aforementioned criteria individually. This approach shows better gearbox performance which vary from 3% to 47% depending on the analytical calculation. The analytical calculations were conducted using suggestions from ISO standards, Petrisevic, GOST standards, and Kudrijavcev. For optimization, the Complex Box method has been used and an original software has been developed for these purposes. All real constraints have been taken into account in order to have the optimal results be usable in real applications.*

Key words: *gearbox, calculation, optimization, comparative analysis*

1. INTRODUCTION

Gearboxes have a widespread practical application, and represent a current research interest. Modern research is oriented on achieving optimal characteristics of these gearboxes and increase their efficiency. In order for these benefits to be achievable, it is necessary to include optimization in the gearbox design process.

For a successful optimization it is necessary to completely understand the operations and behavior of gearboxes. The interaction between optimization and the construction is achieved through a complex formulated mathematical model [1-2]. Detailed knowledge of the problem, such as analysis of clearances and deformations [3] of gearboxes enables the creation of a mathematical model for optimization. In order to optimize, it is necessary to use an optimization method. Some authors [4] using genetic algorithm methods have optimized the mass of a two stage coaxial gearbox, while other authors [5] have automated the design process of two stage reducers. Volume is one of the more important criteria for optimization of multistage gearboxes. Many authors [6] have worked on minimizing volume from the aspect of toothing parameters or with simultaneous maximization of stiffness of gear pairs [7-8]. For optimizing geared transmissions in use are also other optimization algorithms, a minimization is done according to various criteria [9-10-11]. Certain authors worked on generating general mathematical models for usual gear rations [12] or constraint functions in the mathematical model [13]. This approach enables flexibility in the optimization process.

The field of optimization of gearboxes opens a vast research space. This research is oriented on achieving optimal gearbox characteristics in terms of length, width, height and volume of the gearbox and comparing them to analytical calculation results. Optimization represents an alternative to designing gearboxes of desired characteristics. For this specific case optimization of a two stage gearbox has been done using the Complex Box method, and achieved values have been compared to analytical calculation results.

2. CALCULATION METHODS

Designing gearboxes represents a complex task due to the large number of influencing parameters on their work. Design solutions can be achieved analytically and numerically. For the purposes of this research analytical calculations according to suggestions based on ISO standards [14], suggestions according to A.I. Petrusevic, according to GOST standard [15], and according to suggestions by Kudrijavcev [16] have been done. A numerical calculation which included an optimization process was also completed.

The idea is to achieve beneficial characteristics of the gearbox, achieving an optimal length, width, height, and volume of the gearbox in question. Analytical and optimal solutions have been compared in order to show the measure of improvement in the design process. Input/output parameters for all calculations, numerical and analytical, are identical. For this set of input values all four analytical calculation methods give different design parameters due to the variance in determining the partial gear ratio, resulting in each calculation giving a different set of gears for the same input/output parameters. Optimization looks for the same input/output characteristics as analytical calculations with simultaneous minimization according to dimension parameters. The optimization used a Complex Box method for the purposes of this research has been

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conducted using four independent criteria, length, width, height and volume. An original specific software has been developed for the purposes of numerical calculation and optimization of geared transmissions.

3. CALCULATION PROCESS CONDITIONS

In order to show the advantages of this approach calculations for a specific input/output of a gearbox have been compared. The input data is shown in table 1.

Table 1. Input parameters

Name	Label	Value
Material	34CrAlNi7	
Input power	P_i	25 kW
Input shaft rotation per minute	n_i	2800 min^{-1}
Transmissions ratio	u_R	12.5

For the minimal safety factor against tooth bending and tooth breakage $S_{Hmin} = S_{Fmin} = 1.2$ have been adopted. The verification of the safety factos has been done in Audodesk Inventor software [17] for the analytical calculation.
In order to achieve realistic dimensions of the reducer, technical clearances must be taken into account. Values of technical clearances which are covered by all calculations are given in table 2.

Table 2. Technical clearances

Description	Label	Value
Distance between gear face and bearing	c_1	15mm
Distance between outside gear diameter and reducer housing	c_2	15 mm
Distance between outside diameter of the biggest gear and reducer housing bottom	c_3	50 mm
Distance between gears	c_3	15 mm

For calculating dimensional criteria for the gearboxes the same equations are used. Gearbox parameters which are calculated in all cases are length *L*, width *B*, height *H*, and volume *V*.
Optimization constraints are as follows:

- Stiffness of the tooth root;
- Stiffness of the tooth faces;
- Statics load capacity of the tooth root;
- Tooth meshing continuity;
- Accurate tooth meshing;
- Gearbox ratio deviation and
- Geometrics constraints.

Figure 1 shows gearbox dimensions as well as technical clearances. Parameters which are used as optimization objective functions length, width, height and gearbox volume, are also shown in Figure 1.

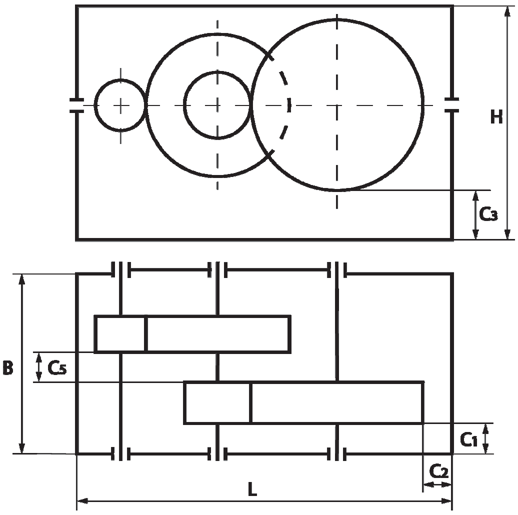


Fig.1. Gearbox dimensions

For the optimization process objective functions and constraints have been created. There are four objective functions corresponding to each of the optimization goals respectively.

4. RESULTS

Based on analytical calculations gearbox transmission specifications are given in table 3.

Table 3. Gearbox parameters according to analytical method

Value	ISO	Petrusevic	GOST	Kudrijavcev
$m_{1,2}$	1.75	1.75	1.75	2
$m_{4,3}$	3.75	3.75	3.25	3
$u_{1,2}$	4.309	4.488	3.15	2.5
$u_{4,3}$	2.901	2.785	4	5
z_1	24	24	24	24
z_2	103	108	76	60
$b_{1,2}$	38 mm	38 mm	38 mm	43 mm
z_3	18	18	18	19
z_4	52	50	72	95
$b_{3,4}$	61 mm	61 mm	53 mm	51 mm

Specifications for the optimized gearboxes according to criteria are given in table 4.

Table 4. Gearbox parameters according to optimization objective function

Value	OPT-L	OPT-B	OPT-H	OPT-V
$m_{1,2}$	2	2.5	1.75	2
$m_{4,3}$	2.25	3.5	2.25	3
$u_{1,2}$	3.1	3.5	3.087	4.15
$u_{4,3}$	3.810	3.286	3.875	2.913
z_1	20	20	23	20
z_2	62	70	71	83
$b_{1,2}$	64 mm	20 mm	65mm	35.6 mm
z_3	21	21	21	23
z_4	80	69	81	67
$b_{3,4}$	74 mm	28 mm	73.5mm	30 mm

Values are:
$m_{1,2}$, $m_{4,3}$- Modules;
$u_{1,2}$, $u_{3,4}$ - Gear set ratios;
z_1, z_2, z_3, z_4 - Numbers of teeth;
$b_{1,2}$, $b_{3,4}$ - Gear set widths.

Analytically calculated gearbox lengths have been compared to optimal results achieved numerically. This comparison is shown in figure 2.

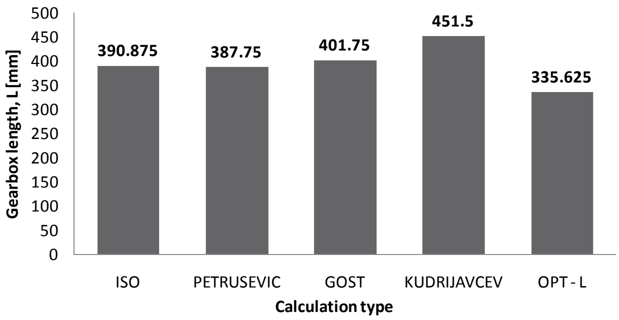


Fig.2. Gearbox lengths

Analytically calculated gearbox widths have been compared to optimal results achieved numerically. This comparison is shown in figure 3.

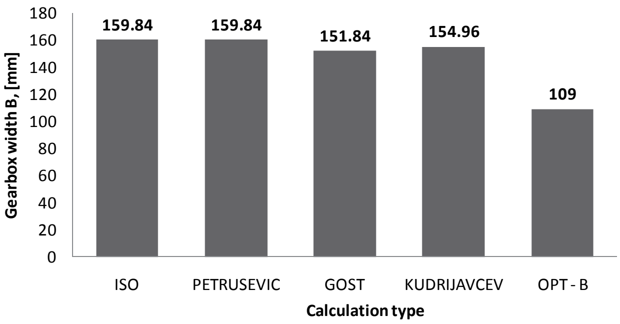


Fig.3. Gearbox widths

Analytically calculated gearbox heights have been compared to optimal results achieved numerically. This comparison is shown in figure 4.

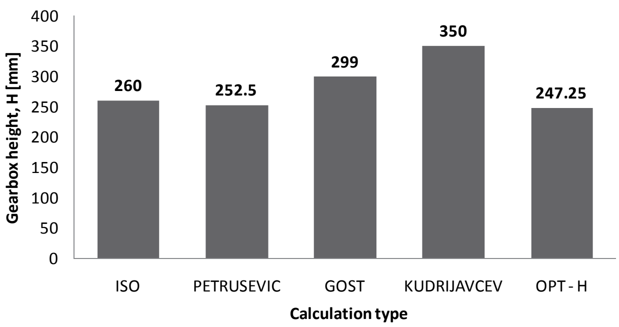


Fig.4. Gearbox heights

Analytically calculated gearbox volumes have been compared to optimal results achieved numerically. This comparison is shown in figure 5.
Significance deviations in the results can be noticed for the different types of calculations. Optimization gives results for all specific criteria separately, and using these results in practice can achieve numerous benefits.

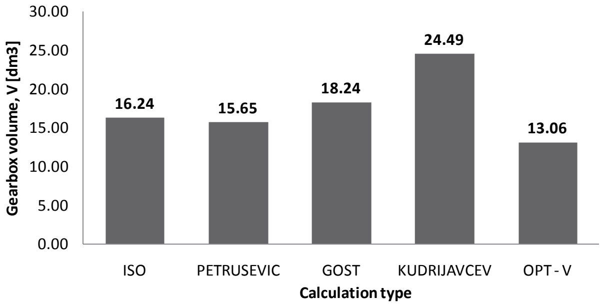
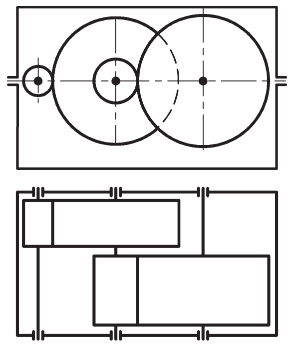
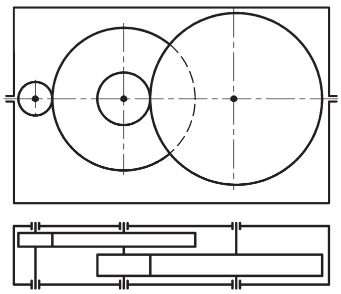
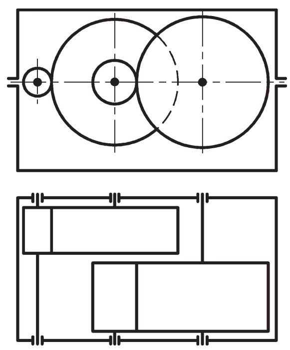
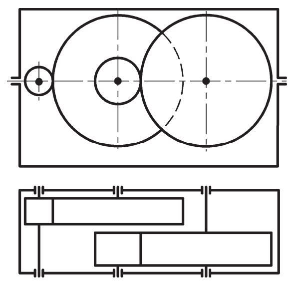


Fig.5. Gearbox volume

Optimal gearbox conceptions according to all four criteria are shown in Table 5.

Table 5. Gearbox optimal conception diagrams

Objective function	Optimal conception diagram
OPT - L	
OPT - B	
OPT - H	
OPT - V	

5. CONCLUSION

In this paper benefits of optimization over analytical methods has been shown. Four different types of analytical calculations have been done for a gearboxes with the same input/output conditions, as well calculations done using optimization with four different objective functions. A quantitative analysis of the results has been conducted.

Comparing the analytical calculations and optimization results has been done according to four separate criteria: length, width, height, and volume of the gearbox. Optimization gives better results in the following measure:

- Length is around 14% less than the smallest analytically calculated length according to A. I. Petrusevic, and even 26% smaller than the largest calculated length;
- Width is around 28% less than the smallest analytically calculated width according to GOST standards, and even 32% smaller than the largest calculated width;
- Height is around 3% less than the smallest analytically calculated height according to A. I. Petrusevic, and even 29% smaller than the largest calculated height;
- Volume is around 17% less than the smallest analytically calculated volume according to A. I. Petrusevic, and even 47% smaller than the largest calculated volume according to Kudrijavcev.

As opposed to analytical calculation, the numerical method with optimization as an automated process directly determines parameters of the gearbox with simultaneously fulfilling all set conditions.

Implementing optimization in the gearbox design process is important. Using this approach improved gearbox characteristics can be achieved. These methods give better results than analytical calculations, and the results are practically usable.

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