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AUTOMATED SELECTION OF ANALYTICALLY CALCULATED GEARBOX CONCEPTS ACCORDING TO DIMENSIONAL CRITERIA

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RESEARCH ARTICLE

ABSTRACT: This research allows for a selection of gearbox according to minimal dimensional criteria from automated analytical calculations. An automation of the calculation process for four different analytical approaches from literature. The results achieved in the software are compared according to various criteria, minimal length, height, width, and volume. The automation of the process allows for a selection of gearbox concept depending on the chosen criteria. For specific input values, a verification of the automated software operation was conducted, and the resulting values are compared and discussed. Differences in calculated volumes of gearboxes, depending on choice of calculation, reach over 50%. This approach allows for adequate choice of gearbox for specific cases and speeds up the calculation process.

KEY WORDS: gearbox volume, comparative analysis, automated selection, analytical calculation

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AUTOMATISKI IZBOR ANALITIČKI ODREĐENIH KONCEPTA MENJAČA NA BAZI DIMENZIONALNOG KRITERIJUMA

REZIME: Ovo istraživanje omogućava izbor menjača na osnovu kriterijuma minimalnih dimenzija na bazi automatskih analitičkih proračuna. Automatizacija procesa proračuna obrađuje se za četiri različita analizička pristupa iz literature. Rezultati dobijeni softverom upoređuju se prema različitim kriterijumima, minimalnoj dužini, visini, širini i zapremini. Automatizacija procesa omogućava izbor koncepta menjača u zavisnosti od izabranih kriterijuma. Za specifične ulazne vrednosti izvšena je verifikacija rada automatizovanog softvera i dobijene vrednosti su upoređene i diskutovane. Razlike u izračunatim zapreminama menjača, koje zavise od izbora proračuna, dostižu i preko 50%. Ovaj pristup omogućava adekvatan izbor menjača za specifične slučajeve i ubrzava proces proračuna.

KLJUČNE REČI: zapremina menjača, komparativna analiza, automatska selekcija, analitički proračun

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1. INTRODUCTION

Recent research in the field of development and application of gearboxes is oriented on achieving better working characteristics, decreasing mass, volume, used material, as well as decreasing the number of different elements used in the construction. This allows transmissions to be more cost-effective from a production and maintenance standpoint. Also, these transmissions have useful exploitation characteristics in terms of performance. Improving gearboxes boils down to an engineer's vast knowledge and experience in this field and the use of alternate approaches, in order to allow for progress.

A lot of research is directed towards the development of reducers and their improvement. Marjanovic et al. [1] developed a practical approach to optimizing gear trains with spur gears based on a selection matrix of optimal materials, gear ratios and shaft axes positions. Researchers in [2] compared optimization results to analytical calculations comparing the performance of these processes. Kostic et al. [3] presented a new approach for solving gearbox optimization using the mimicking of natural processes to achieve layout solutions comparable to optimization results without using computerized optimization methods. Clearances between cycloid gearbox elements were optimized in [4] in order to provide a realistic picture of contact and machining tolerances. Golabi et. al [5] presented gear train volume/weight minimization optimizing single and multistage gear trains' gear ratios. Mendi et al. [6] aimed to optimize gear train component dimensions to achieve minimal volume comparing GA results to analytic method parameter volume. Savsani et al. [7] described gear train weight optimization comparing various optimization methods to genetic algorithm (GA) result values. Gologlu and Zeyveli [8] performed preliminary design automation through optimization of gear parameters and properties using a GA based approach.

The motivation behind this research is based in the desire to determine the real influential parameters of different methods and standards for calculating geared speed reducers. The calculation process has been automated, in order to allow for application on a larger number of reducers. By giving a comparative analysis, based on dimensional criteria, the best calculation for a specific case can be determined. Choosing the adequate calculation method a smaller length, width, height or volume of a gearbox can be achieved, resulting in the best possible gearbox applicable in practice.

2. PROBLEM DEFINITION

Designing a gearbox presents a complex task due to the large number of parameters which influence its operation. Design solutions can be achieved analytically or numerically. For the purposes of this research analytical processes based on ISO standard [9], Petruševič, GOST standard [10] and Kudrijavcec [11] have been automated. Testing criteria is based on dimensions of a gearbox. Length, width, height, and volume are used for a comparative analysis of calculation results.

2.1 Conditions and constraints of calculations

Input/output values for calculating gearboxes are singular, in order to be comparable. Values for input/output are given in Table 1.

Table 1. Input parameters and working conditions

Denotation	Value
Input power, P_i (kW)	25
Material	34CrAlNi7
Input speed n_i (rpm)	2800
Total gear ratio u_r	12.5
Usage	Electricity motor
Available modules (mm)	1, 1.125, 1.25, 1.375, 1.5, 1.75, 2, 2.25, 2.5, 2.75, 3, 3.5, 4, 4.5, 5, 5.5, 6, 6.5, 7, 8, 9, 10, 11, 12, 14, 18, 20, 22, 25, 28, 30, 32, 36, 40

In order for the gearbox to properly function and to ensure adequate lubrication, certain clearances must be created. There must be clearances between gears and bearings, between the largest gear diameters and the housing, as well as between the gears themselves. These values also go into the calculation of the total length, width, height, and volume of the gearbox. Technical clearances are adopted according to suggestions, and are used for the purposes of this research as is shown in Table 2.

Table 2. Technical clearances

Denotation	Label	Value
Distance between gear face and bearing	c_1	15 mm
Distance between outside gear diameter and gearbox housing	c_2	15 mm
Distance between outside diameter of the biggest gear and gearbox housing bottom	c_3	50 mm
Distance between gears	c_5	15 mm

Values and positions of technical clearances are illustrated in Figure 1. The figure also shows the length (L), width (B), and height (H) which are the output values for comparing calculation results. These values are the basic criteria for comparing gearboxes.

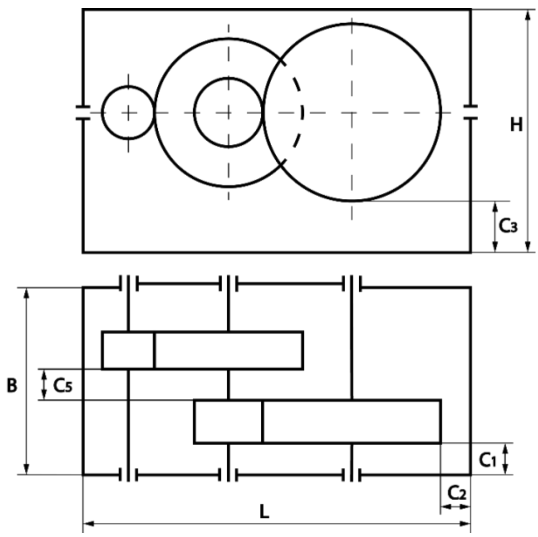

Figure 1. *Gearbox dimensions*

For the minimal safety factor against pitting and brakeage SHmin = SFmin = 1.2. Testing for the safety factors against pitting and brakeage was done in Autodesk Inventor, in order to verify the analytically calculated results.

3. AUTOMATED ANALYTICAL CALCULATION

The conducted research requires a large number of extensive calculations which is why it has been automated. Aside from this, in order to allow for application on a larger number of problems it is necessary to automate the process so that the invested time and effort of calculating would not be too large in comparison to the resulting effects. Automating the previous calculation is conducted in Microsoft Excel and covers the following segments:

- Input of values (material characteristics, input/output of the gearbox, clearances between elements)
- Database of standard modules and constraints of specific values (i.e. integers for number of gear teeth)
- Calculations according to the used suggestions (ISO, Petrusevic, GOST, Kudrijavcev)
- Visualization and result processing (comparative tables, calculation of length, width, height, and volume).

Values from table 1 are plugged in as input values for calculation in the Excel file and all calculation types are done based on identical input values. The calculation is automated in such a way as to require manual input of technical clearance values between the gearbox elements, and is thereby taken into account in the final dimension results of the gearbox. Technical clearances for this specific case have the same values as are given in table 2. Once these values are entered, the final results which are used for the analysis are obtained. As output values length, width, height, and volume are set as the basis for comparing the resulting gearboxes.

Based on defined input values the analytical calculation was automatically done, according to different suggestions. Stiffness was tested in AD Inventor, and the calculated values were also automatically compared to each other based on length, width, height and volume criteria. Based on these results an adequate design concept can be adopted which would be suitable for practical application on real-world problems.

4. RESULTS

According to calculations based on the various suggestions, parameter values are obtained for the gearboxes. In values shown in Table 3 these gearboxes are completely defined and can be used. These values show various dimensions, which mean various length, width, height, and volume, therefore it is possible to analyse which calculation should be used, and when it shouldn't.

Table 3. Gearbox comparison for all design solutions

Denotation	ISO	Petrusevic	GOST	Kudrijavcev
1st Stage				
Normal module, m_{n1st} (mm)	1.75	1.75	1.75	2
Gear ratio, u_{12}	4.309	4.488	3.15	2.5
Number of teeth on pinion, z_1	24	24	24	24
Number of teeth on wheel, z_2	103	108	76	60
Face width, b_{12} (mm)	38	38	38	43
2nd Stage				
Normal module, m_{n2st} (mm)	3.75	3.75	3.25	3
Gear ratio, u_{34}	2.901	2.785	4	5
Number of teeth on pinion, z_3	18	18	18	19
Number of teeth on wheel, z_4	52	50	72	95
Face width, b_{34} (mm)	61	61	53	51

Based on values from Table 3 the length, width, height, and volume of each gearbox is derived. This approach is important, as it is not always explicitly required that volume is minimized, but a specific dimension depending on available space. Therefore it is often more important to adopt a design with a specific value minimized, rather than the volume. This approach leads to designs of various dimensions and volumes based on the previous calculations. Calculated lengths are shown in Figure 2 for all calculation cases. The range of values for all the different designs is from 387.75 (Petrusevic) to 451.5 mm (Kudrijavcev). According to this criteria the best concept is the design according to Petrusevic's calculations.

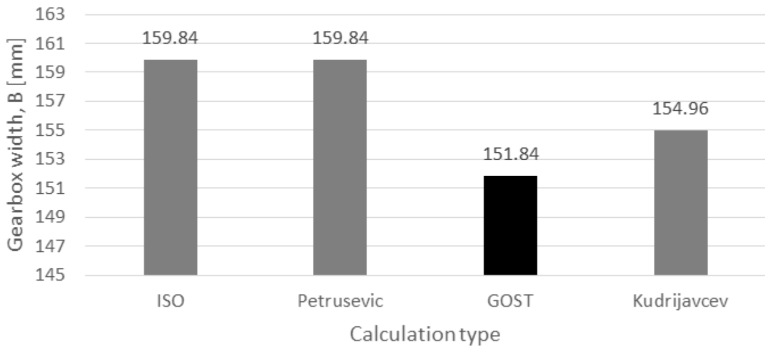

Figure 3. Gearbox widths

According to height criteria values corresponding to each design solution are given in Figure 4. The range of values is from 252.6 (Petrusevic) to 350 mm (Kudrijavcev). According to this criteria the most favourable solution is according to Petrusevic.

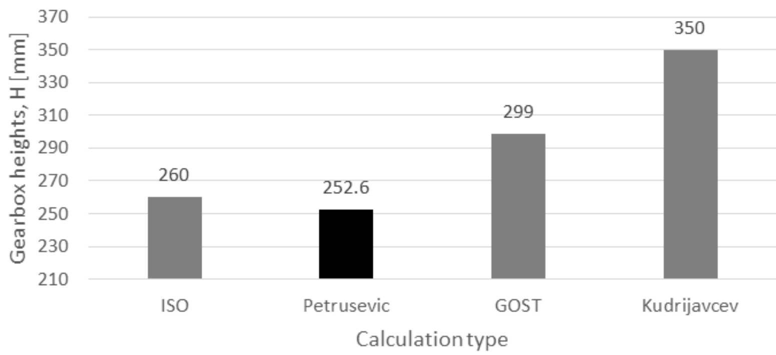

Figure 4. Gearbox heights

According to the criteria of overall volume of the gearbox each design solution value is given in Figure 5. The range of values is from 15.65 (Petrusevic) to 24.49 mm3 (Kudrijavcev). According to this criteria the most favourable solution is according to Petrusevic.

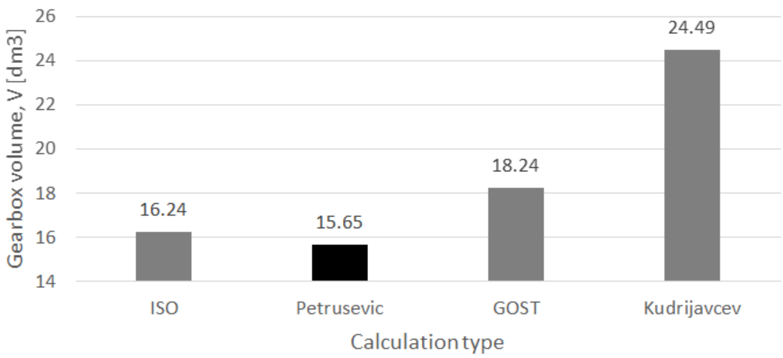

Figure 5. Gearbox volumes

All calculated values take into account technical clearances. For practical application of gearboxes it is possible to determine the type of calculation which gives desired results, while all calculated design concepts are practically applicable.

5. CONCLUSIONS

For this research an approach to the choice of concept of gearbox was developed based on criteria of length, width, height, and volume. Gearboxes were designed based on different suggestions for calculation. An automated process of calculating was developed, which based on input parameters achieves final dimension values. The calculations take into account clearances between elements of the gearbox, standard modules, as well as other realistic constraints. A validation of gear stiffness was conducted in AD Inventor. This approach gives practical results and based on specific situations, an engineer can choose the most suitable calculation for their application.

The calculated values vary greatly, which indicates the large influence of the calculation type on final gearbox design dimensions. The most suitable value according to length criteria is achieved using Petrusevic's suggested calculation (387.75 mm). Compared to the ISO standard the length is greater by 1% which is negligible. The difference for the GOST standard is around 3.6%, while the difference from Kudrijavcev's calculation is 16.5%.

According to width criteria, the best value is achieved according to GOST standard (151.84 mm). For ISO and Petrusevica calculations give larger widths than the GOST for around 5.3%, while Kudrijavcec's calculations give around 2% larger width.

According to the criteria of height, the best values are achieved using Petrusevica's calculation (252.5 mm). For ISO calculation the height is around 3% larger, the GOST standard around 18.4% larger, while the values according to Kudrijavcec are larger by abour 38.6%.

In terms of volume criteria the best solution is using Petrusevic's calculations (15.65 dm3), followed by ISO standard (16.24 dm3), then GOST standard (18.24 dm3), and lastly using Kudrijavcev's calculations achieving (24.49 dm3). Compared to the lowest value, ISO standard volume is 3.8% greater, 16.6% greater using GOST standard and using Kudrijavcev's calculations is around 56.5%.

The smallest difference is achieved in terms of volume criteria, then by length, while the greatest difference can be made in the height of the gearbox. The most common criteria for choice of gearbox concept is volume, however it is not compulsory. Using the here proposed approach, an alternative is created for engineers to choose adequate designs depending on the type of chosen calculation. Further research in this field should include a comparative analysis of achieved values to those achieved through optimization according to defined criteria.

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