A Modular System for Gear Calculations: A Comprehensive Computational Approach

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Abstract: - An automated system for calculating gear transmissions has been developed with the goal of enhancing the accuracy of engineering calculations and minimizing the likelihood of errors in mechanical engineering. The problems of traditional calculation methods, which are characterized by high labor intensity and significant human influence, have been investigated. A modular system has been proposed that integrates a mathematical apparatus for calculating the geometric, kinematic, and energy parameters of transmissions. The system's algorithms provide automatic validation of input data. The software implementation is performed using Windows Forms (.NET), which provides an intuitive user interface. An experimental verification of the accuracy of the calculations was conducted, which demonstrated a maximum error of less than 0,44 % compared to manual calculations. Key advantages of the system: reduction of calculation time, integration of all design stages in a single environment, and adaptability to different load ranges. The results of the study confirm the effectiveness of the proposed approach and its competitiveness compared to existing commercial solutions.

Key-Words: - Gear transmissions, mechanical design, transmission parameters, engineering calculations, software.

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1 Introduction
1.1 Relevance and Purpose of work
Nowadays, automation and computerization cover almost all areas of human activity – from everyday solutions to managing complex technological processes in industry [1], [2], [3]. This issue is especially relevant for mechanical engineering, where design errors can result in millions of dollars in losses. According to research [4], approximately 23 % of gear failures in industry are caused by errors in manual calculations.

Modern mechanical engineering requires high-precision methods for designing mechanical transmissions, especially gear mechanisms, which are the main components of most industrial equipment. According to [5], [6], the CAD market for mechanical transmissions is showing steady growth during 2018-2025, confirming the relevance of innovative solutions today. Traditional methods for calculating gear parameters are based on manual calculations using reference data, which leads to [7]:

– significant time spent on calculations;
– risk of errors;
– limited ability to optimize the design.

The efficiency of gear design directly affects key indicators of industrial equipment: energy efficiency, service life, and operating costs.

The development of computer technologies has opened up new opportunities for the creation of specialized software systems for the automation of engineering calculations. However, an analysis of existing solutions [8], [9], [10] has revealed critical gaps:

– lack of full integration of calculation modules;
– limited validation of input data;
– insufficient automation of interrelationships between calculation stages.

The purpose of this study is to develop a modular system for automated calculation of gear parameters that:

1. Ensures accuracy.
2. Reduces calculation time.
3. Minimizes the influence of the human factor.

Main tasks:

1. Analysis of modern methods for calculating the characteristics of gear mechanisms.

2. Development of mathematical apparatus taking into account dynamic loads.
3. Implementation of automatic data validation algorithms.
4. Creation of an intuitive interface for engineers.

1.2 Work-related Analysis

Traditional methods of calculating gear transmissions, based on manual calculations, are still used in design practice. However, their main drawback – significant labor intensity and the need to perform a large number of routine operations – has become one of the factors in the development of modern digital tools.

The automation software market offers a range of engineering software products (e.g., KISSsoft [11], [12], Romax Designer [13], [14], SolidWorks Toolbox [15], [16]) that partially automate the process of calculating and designing transmissions. At the same time, analysis of the literature and user reviews shows that there are certain limitations to their application:

– fragmentation of functionality. A significant part of the tools specialises in calculating individual parameters (e.g., modulus, gear ratio, or efficiency, etc.) without comprehensive integration of geometric, kinematic, and energy calculations [17], [18];

– input data verification. Not all solutions have advanced tools for validating the entered parameters (e.g., automatic verification of the admissibility of the center distance for a given torque, etc.) [19];

– complexity of the workflow. In some cases, engineers have to use several separate modules or even different programs for the complete design cycle, which increases the overall project execution time [20].

Thus, despite the availability of powerful commercial software packages, there is still a need for integrated solutions capable of combining geometric, kinematic, force, and energy analysis with the current regulatory framework and a user-friendly interface.

2 Mathematical Apparatus for Calculating the Characteristics of Gear Mechanisms

The design of gear transmissions is based on a set of interrelated mathematical dependencies that describe the geometric, kinematic, and force characteristics of mechanisms [21]. The analysis of these dependencies is the basis for the creation of effective computational algorithms and software tools for automated design.

The mathematical apparatus for calculating gear transmissions includes several main groups of parameters, each of which is characterized by specific calculation dependencies.

The initial stage of the energy analysis of a gear mechanism is to determine the torque on the input shaft T_{in}, which establishes the relationship between the kinematic and power characteristics of the transmission [7], [22].

$$T_{in} = \frac{T_{out}}{i_{tot} \cdot \eta_{tot}}\ , \tag{1}$$

where T_{out} – output torque;
i_{tot} – total gear ratio;
η_{tot} – total efficiency of the mechanism.

The key parameter in formula (1) is the total efficiency coefficient η_{tot}, which takes into account the total energy losses in the mechanism. Its determination is based on the product of the partial efficiency coefficients of individual transmission elements:

$$\eta_{tot} = \eta_{wp} \cdot \eta^2{}_{bp} \cdot \eta_{op}, \tag{2}$$

where η_{wp} – efficiency coefficient (EC) of worm gear pair;
η_{bp} – EC of intermediate bearing pair;
η_{op} – EC of the output pair of bearings.

The kinematic characteristics of the mechanism are described by the total gear ratio i_{tot}, which for a two-stage transmission consists of sequentially connected stages U_{12} and U_{23} and is determined by the ratio of the motor rotation speed (n_{rot}) to the output shaft speed (n_{ot}):

$$i_{tot} = U_{12} \cdot U_{23} = \frac{n_{rot}}{n_{ot}}\ . \tag{3}$$

Calculating the gear module m is a transition from kinematic to geometric transmission design. This parameter is determined from the condition of tooth bending strength according to formula (4), which takes into account the torque, geometric, and strength characteristics of the system:

$$m \geq K_{F\beta} \cdot \sqrt[3]{\frac{T \cdot K_v \cdot K_{F\alpha} \cdot Y_F}{z_2^2 \cdot \psi_{bd} \cdot [\sigma_F]}}\,. \tag{4}$$

where $K_{F\beta}$ – coefficient of uneven load distribution across the tooth width;
T – torque on the worm gear;
K_v – dynamic coefficient;
$K_{F\alpha}$ – load distribution coefficient between teeth;

Y_F – tooth shape coefficient;
z_2 – number of teeth on a worm gear;
ψ_{bd} – ratio of the width of the gear rim to the diameter;
$[\sigma_F]$ – allowable bending stress of tooth material.

The torque on a worm gear can be defined as:

$$T = \frac{T_{out}}{i_{gear} \cdot \eta_{gear}}, \quad (5)$$

where i_{gear} – gear ratio from worm gear to output shaft;
η_{gear} – efficiency coefficient of the section from the worm gear to the output shaft.

Having determined the module as the main geometric parameter, we proceed to calculate the overall dimensions of the transmission elements. The main diameters of the worm d_1, the diameter of the worm thread peaks d_{a1}, and the diameter of the worm troughs d_{f1} are calculated using the gear module in the axial section of the worm m, and the worm diameter coefficient q, taking into account the standard tooth height ratios, and can be represented as:

$$\begin{cases} d_1 = m \cdot q, \\ d_{a1} = d_1 + 2m = m(q+2), \\ d_{f1} = d_1 - 2(h_a + c). \end{cases} \quad (6)$$

where h_a – tooth head height coefficient;
c – radial clearance coefficient.

The pitch diameter of the worm is the main dimension that determines the overall dimensions of the worm.

After determining the main geometric parameters of the worm by the gear module m and the diameter coefficient q, we proceed to calculate the overall dimensions of the worm wheel.

The calculation is performed by analogy, based on the gear module m and the number of teeth z_2, using standard ratios for calculating diametrical dimensions:

$$\begin{cases} d_2 = m \cdot z_2, \\ d_{a2} = d_2 + 2 \cdot h_a = m(z_2 + 2), \\ d_{f2} = \mathrm{m} \cdot \left(z_2 - 2 - \frac{c}{m}\right), \\ d_h \le d_a^2 + k_h. \end{cases} \quad (7)$$

where d_2 – wheel pitch diameter;
d_{a2} – diameter of tooth tips;
d_{f2} – diameter of depressions;
$h_a = \mathrm{m} \cdot \mathrm{h_a}$ – tooth head height;
$c = 0{,}4 \cdot \mathrm{m}$ – radial clearance coefficient;
k_h – additional clearance.

The pitch angle of the screw line determines the angle at which the worm thread runs along its body and affects the efficiency and self-locking of the transmission, so it can be determined from the expression:

$$\mathrm{tg}\,\gamma = \frac{\pi \cdot m \cdot z_1}{\pi \cdot d_1} = \frac{z_1}{q}, \quad (8)$$

at the same time

$$q = \frac{d_1}{m}. \quad (9)$$

The next step is to calculate the center distance, which is an important design parameter of the gear. It determines the distance between the axes of the worm and the wheel and depends on the gear module, the number of teeth on the wheel, and the worm diameter ratio.

The center distance for a gear (namely, worm) transmission without offset is determined by the formula:

$$a_w = 0{,}5 \cdot m\,(z_2 + q). \quad (10)$$

Number of teeth on the second wheel:

$$z_2 = z_1 \cdot U_{23}. \quad (11)$$

where z_2 – number of teeth on the second (driven) wheel;
z_1 – number of worm turns or drive wheel teeth;
U_{23} – the gear ratio between the worm and the wheel (i.e., how many times slower the wheel rotates than the worm).

The center distance determines the relative position of the shafts, which affects the correctness of the engagement, the tension in the transmission, and the overall dimensions of the structure. The center distance is represented as:

$$a_w = 0{,}5 \cdot (d_{w1} + d_{w2}), \quad (12)$$

where d_{w1} – worm pitch diameter, where $d_{w1} = \mathrm{m} \cdot \mathrm{q}$;
d_{w2} – the pitch diameter of the worm wheel, with it $d_{w2} = \mathrm{m} \cdot \mathrm{z_2}$.

The calculation of the geometric, kinematic, and force parameters of the gear transmission ensures its operability in terms of strength, accuracy, and dimensional compliance.

However, to ensure stable and reliable operation of the mechanism under real operating conditions, it is also necessary to take into account the influence of manufacturing, installation, and operating errors, which can negatively affect the accuracy and smoothness of operation.

The next step is to figure out the total error of the mechanism, which takes into account the main sources of inaccuracies in transmission: backlash error in the gearing, shaft deformation, gaps in the bearings, coupling error, temperature changes, and drive element error.

These errors lead to reduced accuracy and smoothness of rotation, increased noise, reduced efficiency, and uneven load distribution between the teeth.

The total angular rotation error is determined by the formula:

$$\delta_c = \delta_{be} + \delta_{te} + \delta_{ce} + \delta_{cpe} + \delta_{tee} + \delta_{edg}, \quad (13)$$

where δ_{be} – backlash error;
δ_{te} – shaft torsion error;
δ_{ce} – bearing clearance error;
δ_{cpe} – coupling error;
δ_{tee} – thermal expansion error;
δ_{edg} – error in the driving gear.

Thus, the mathematical apparatus described above allows for a comprehensive analytical calculation of the geometric, kinematic, and force characteristics of a gear transmission, taking into account design features, strength criteria, and accuracy.

The constructed formulas cover key design parameters – from the engagement module to the center distance and total angular error. These relationships serve as the basis for the algorithmization of engineering calculations and lay the foundation for the further development of software tools for automated transmission modeling.

The following section will present the software implementation of these calculations, including the structure of the computing module, the implementation of calculation algorithms, and examples of practical applications of the developed system.

3 Algorithm for Calculating and Checking Gear Parameters

Effective implementation of the mathematical apparatus for calculating gear transmissions requires a structured algorithmic approach that ensures the sequence of calculations and takes into account the interrelationships between parameters. In this section, Fig. 1 presents a detailed description of the main algorithm for calculating and verifying the parameters of a gear (worm) transmission.

Let us describe the algorithm shown in Fig. 1 in more detail.

Stage 1. Entering initial data. At the initial stage of calculation, it is necessary to set the input parameters that determine the initial requirements for the gear transmission and form the basis for all further calculations. Such data include: torque on the output shaft of the transmission (T_{out}); rotation frequency of the output shaft (n_{ot}); rotation frequency of the input shaft (n_{rot}); worm and worm wheel materials (mat_{wg}, mat_{ww}); preliminary or specified center distance (a_w) (optional) because in some cases the center distance may be specified by design constraints. If not, it is determined at the calculation stage.

Stage 2. Calculation of kinematic parameters. At this stage, the main transmission parameters of the gear transmission are determined, in particular the gear ratio (i_{tot}) and the number of teeth of the worm and worm wheel (z_2). The gear ratio is set by the requirements for changing the rotation speed or torque. Taking this into account, the appropriate number of worm threads and the number of wheel teeth are selected to provide the required gear ratio. After that, the additional gear ratios of individual links (U_{23}) are refined, and compliance with the kinematic diagram is ensured.

Stage 3. Determining the efficiency of the system. At this stage, the overall efficiency of the gear transmission (η_{tot}) is determined, taking into account all losses in the mechanism. The overall efficiency is calculated as the product of the efficiency of the worm gear pair itself and the efficiency of the intermediate and output bearing supports. This allows you to estimate the actual energy losses in the system and ensure the accuracy of further torque calculations.

Stage 4. Determination of the input torque (T_{in}). At this stage, the torque that must be applied to the input of the gear transmission to ensure the specified output torque is determined. The calculation takes into account the overall efficiency of the system, which allows you to establish the actual load on the drive motor or other element connected to the worm gear.

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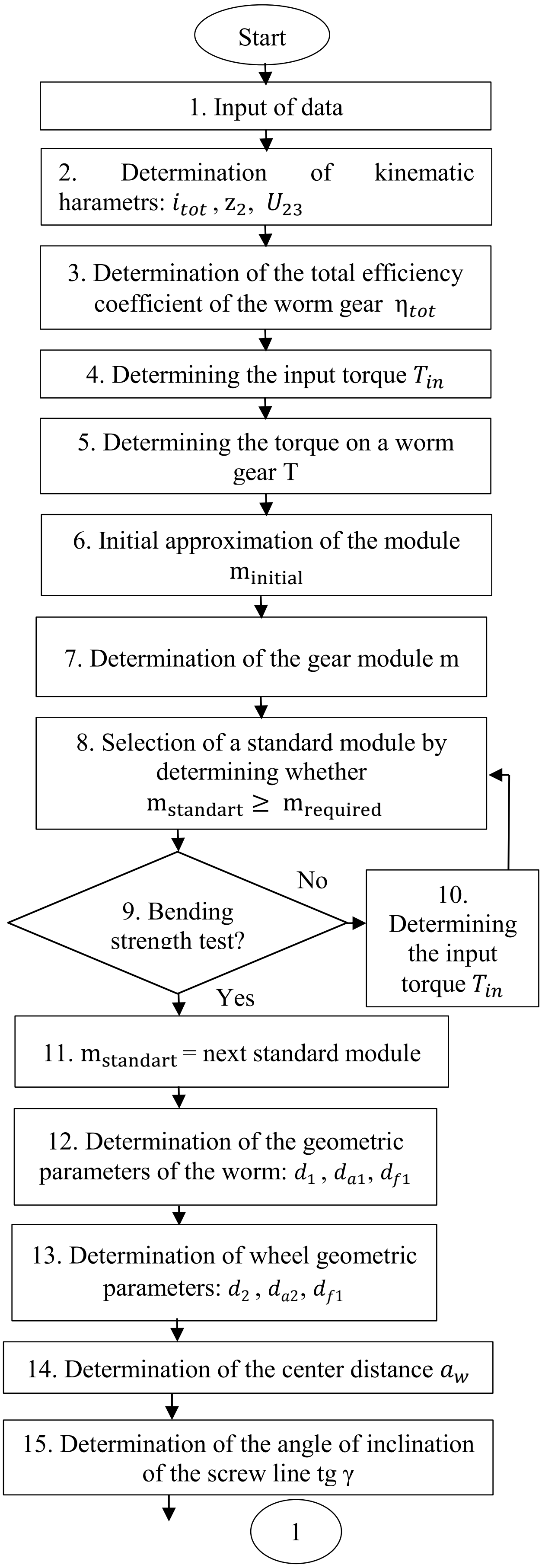

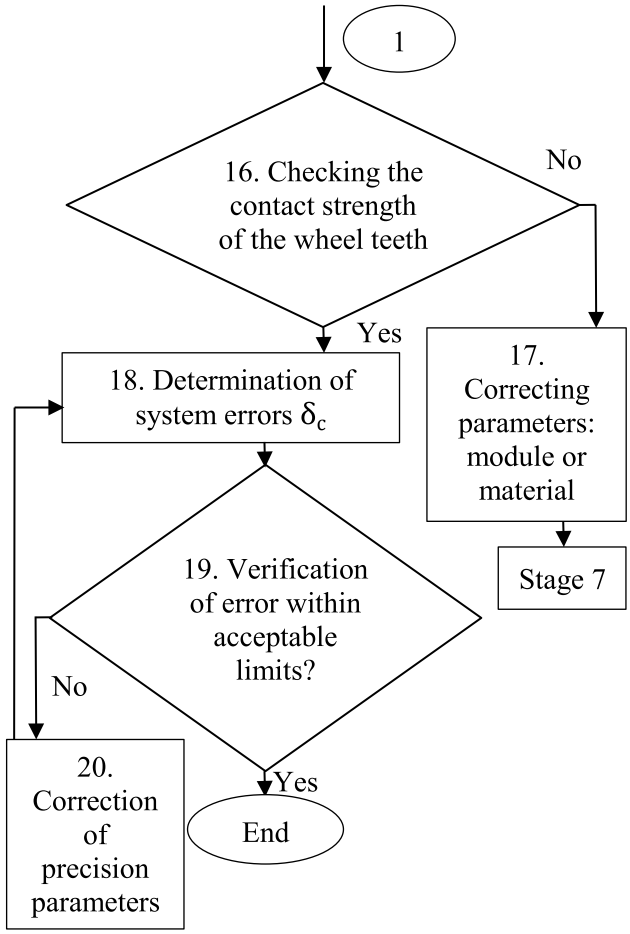

Fig. 1: Algorithm for calculating and checking gear (worm) transmission parameters

Stage 5. Determining the torque on the worm wheel (T). At this stage, the torque transmitted directly by the worm wheel is calculated. It is determined based on the output torque, taking into account the gear ratio and losses in the system. This torque is used for further calculations of the strength and geometric parameters of the meshing.

Stage 6. Initial approximation of the module ($m_{initial}$). This stage is performed after calculating the moment on the worm wheel T, and is critical for further calculations of the system's strength.

$$m_{initial} = K \cdot \sqrt[3]{T}, \tag{14}$$

where K – empirical coefficient (depends on the type of transmission).

Stage 7. Determination of the gear module m. The gear module is the main parameter that determines the dimensions of the wheel teeth. It is calculated based on the bending strength of the teeth and contact stresses.

Stage 8. A standard module is selected by determining whether $m_{standart} \geq m_{required}$. At this stage, the closest larger standard value $m_{standart}$ is selected from the calculated value of the module $m_{required}$ in accordance with the normative series. The calculated module has an arbitrary numerical value, so it must be rounded to a standard size that will provide the necessary strength and meet the requirements for production standardization.

The standard module must be no less than the calculated module to ensure the strength of the gear transmission. If the difference between the standard and calculated modules is too large, other transmission parameters may need to be adjusted.

Step 9. Checking bending strength. At this stage, it is checked whether the wheel teeth can withstand the bending stresses that occur during transmission operation. If the test shows that the bending stresses exceed the permissible values, it is necessary to move on to the next larger standard module (Stage 11). This process is repeated until sufficient tooth strength is achieved. If the strength test is successful, the selected standard module is approved for further calculations.

Stage 10. Determining the input torque T_{in}. This stage is performed when the preliminary bending strength check has shown an unsatisfactory result. The system automatically moves on to the next higher value of the standard module from the normalized series.

The next standard module, which is larger than the previous one, is selected to ensure higher tooth strength. After selecting a new module, the process returns to the bending strength check to confirm its suitability. This iterative process continues until a standard module is found that satisfies all the strength conditions of the gear transmission.

Stage 11. Transition to the next larger standard module from the normalized series. This is necessary when the previous standard module did not provide sufficient bending strength of the teeth. The system automatically selects the next larger standard module to recheck the strength characteristics of the transmission.

Stage 12. At this stage, the main diametric dimensions of the worm are determined based on the accepted standard module: d_1, d_{a1}, d_{f1}. The pitch diameter of the worm, the diameter of the thread peaks, and the diameter of the worm valleys are calculated. The calculations are performed using the gear module, the worm diameter coefficient, and the standard tooth head height and radial clearance coefficients. These parameters determine the overall dimensions of the worm and ensure the correct formation of the thread profile for reliable engagement with the worm wheel.

Stage 13. At this stage, the main diametrical dimensions of the wheel are determined based on the accepted standard module: d_2, d_{a2}, d_{f2}.

Stage 14. Determination of the center distance a_w. The distance between the axes of the worm and the worm wheel is calculated. The center distance is determined based on the pitch diameters of the worm and the wheel and affects the overall dimensions of the gear. This parameter is critical for proper meshing and ensuring the necessary kinematic characteristics of the gear transmission.

Stage 15. At this stage, the angle of inclination of the worm screw line $\mathrm{tg}\,\gamma$ is calculated, which characterizes the inclination of the turns relative to the perpendicular to the worm axis. It is an important geometric parameter that affects the gear ratio, efficiency, and strength characteristics of the gear transmission.

Stage 16. Checking the contact strength of the wheel teeth. The ability of the worm wheel tooth surfaces to withstand contact stresses arising in the area of engagement with the worm is checked. The actual contact stresses are calculated and compared with the permissible values for the wheel material.

If the contact stresses exceed the permissible values, it is necessary to increase the gear module or change the material to a more wear-resistant one. If the check is satisfactory, the transmission parameters remain unchanged, and the calculation continues.

Stage 17. This stage is performed if the contact strength of the wheel teeth is unsatisfactory. Correction is made by increasing the gear module to the next standard value or replacing the worm wheel material with a stronger one with higher permissible contact stresses.

After making changes, the calculation returns to the contact strength verification stage to confirm the effectiveness of the correction.

Stage 18. Determination of system errors δ_c. At this stage, the total angular error of the gear transmission rotation is calculated, which consists of all possible sources of inaccuracy in the system. The obtained value of the total error is compared with the permissible requirements for transmission accuracy according to the technical specifications. This allows you to evaluate the kinematic accuracy of the developed gear transmission.

Stage 19. Checking whether the error is within the permissible δ_c? The actual error value is compared with the permissible limit value δ_c. If the error exceeds the permissible limits, the transmission parameters must be corrected. If the error is satisfactory, the calculation is considered complete with acceptable accuracy.

Stage 20. Correction of accuracy parameters. At this stage, the transmission parameters are refined

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and corrected to ensure the required manufacturing and operating accuracy. Tolerances for the main geometric dimensions, center distance deviations, and other accuracy characteristics are determined.

Correction may include changing the offset coefficients, refining the center distance, or other parameters to achieve optimal meshing and ensure the specified transmission accuracy class.

This paper presents the basic algorithm for calculating and verifying gear parameters. A detailed description of additional algorithms of the modular system, including algorithms for optimizing geometric parameters and calculating dynamic characteristics, will be presented in subsequent publications.

4 Structure of the Developed System for Calculating Gear Parameters

The structure of the developed gear parameter calculation system is shown in Fig. 2 and represents a modular system consisting of interconnected forms, each of which performs specific gear parameter calculation functions. The system is built on the principle of a user interface with multiple forms, where each form is responsible for a separate type of calculation.

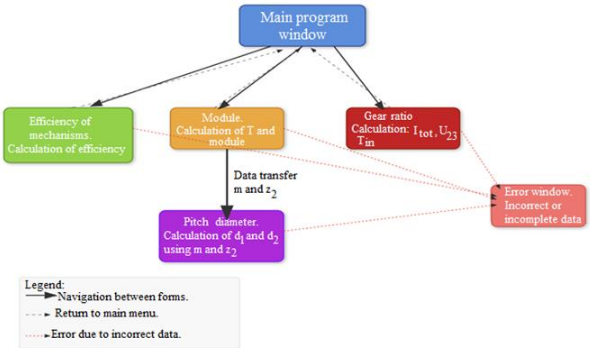

Fig. 2: Structure of the developed system for calculating gear parameters

The structure of the developed system consists of a main window and four main modules organized in the form of interconnected forms with centralized navigation control.

The main window of the system is the central component of the system, which provides navigation to four calculation forms. When you click on any form, a new window opens where the user can perform calculations according to the task at hand.

The «Efficiency of the Mechanisms» form is designed to calculate the efficiency of the mechanism using the appropriate formula. The user can enter the necessary data in the active text fields, clear all text fields, return to the main menu, and perform calculations.

The «Module» form provides calculations of the T and module parameters using the formulas described. The T text field is not editable, as the system calculates it automatically based on the data entered and the formula presented in this form.

The «Pitch diameter» form opens automatically when you click the «Calculate module» button in the «Module» form. The data m and z_2 obtained during the calculation are automatically transferred from the previous form. The user can calculate the parameters d_1 and d_2, while for the calculation of d_2 it is additionally necessary to enter the parameter q.

The «Gear Ratio» form allows you to calculate three formulas: i_{tot}, $U_{2\ 3}$, and T_{in}. Calculation of the $U_{2\ 3}$ and T_{in} formulas is not available without first calculating the i_{tot} formula.

Error handling system – a single exception handling system for all forms, which is triggered when incorrect or incomplete data is entered. When an error occurs, the system displays a special window with a message for the user.

Error handling system – a unified exception handling system for all forms, which is triggered when incorrect or incomplete data is entered. When an error occurs, the system displays a special window with a message for the user.

Sequence of operation of the gear parameter calculation system. The software package is operated according to a clearly defined sequence of operations, which ensures a logical order of calculations and effective user interaction with the system.

Initialization takes place from the main form of the system, which acts as a central navigation dispatcher. The main window allows the user to familiarize themselves with the available calculation modules and make a selection in accordance with the engineering tasks at hand.

The type of calculation is selected by activating the corresponding form via the main window interface. The user can choose one of four available calculation modules: calculation of the mechanism's efficiency, determination of the module, calculation of the pitch diameter, or calculation of the gear ratio of the elements.

The input parameters stage involves the user filling in the active text fields with the necessary numerical values according to the specifics of the selected calculation. The system provides a convenient interface for data entry with the ability to clear fields and return to the main menu.

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The system automatically validates the input data before starting calculations. It checks the correctness of the entered values, their completeness, and compliance with the requirements of the calculation algorithms. If incorrect or incomplete data is detected, the system generates a corresponding error message.

Calculations are performed automatically after successful validation of the entered data. The system applies the appropriate mathematical formulas and algorithms to obtain results according to the selected calculation type.

The transfer of results between forms is implemented to ensure the continuity of calculations. In particular, when calculating the modulus, the obtained values m and z_2 are automatically transferred to the calculation form for the dividing diameter, which allows the user to continue working without re-entering data and ensures the integrity of the calculation process.

The developed system structure has a number of distinctive features that distinguish it from standard software solutions:

1. Automatic opening of dependent forms. When you click the «Calculate module» button, in addition to getting the result, the «Pitch diameter» form automatically opens with the transferred values m and z_2, which ensures the continuity of the calculation process.

2. Restricting access to calculations. In the «Gear ratio of elements» form, the calculation of formulas $U_{2\ 3}$ and T_{in} is not available without first calculating the i_{tot} formula, which ensures the correct sequence of calculations.

3. Control of dependencies between forms. If the user attempts to calculate diameters without the obtained modulus value, the system displays a corresponding error, preventing incorrect calculations.

4. Uneditable calculation fields. The text field T in the «Module» form cannot be edited by the user, as the system must calculate it automatically based on a formula.

5. Unified error handling system. Exception handling is performed almost identically for all forms in the system, ensuring interface consistency and user convenience.

5 Software Aspect of Implementing a System for Calculating Gear Parameters

5.1 Technologies for Creating a Payment System Interface

The created system includes the most important function – calculating the necessary parameters for solving specific problems. The system should provide the user with a simple and intuitive interface for convenient calculations. All functionality is divided into four windows, each responsible for a specific task. The logic of the gear parameter calculation system is shown in Fig. 3.

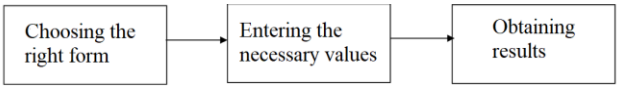

Fig. 3: The logic behind the gear parameter calculation system

Fig. 3 shows the following design elements: selection of the required form depending on the task at hand, calculation interface on each form, entry of required values, and clearing all forms of values. The user can select one of the listed forms and, after selection, has quick access to parameter calculations.

To create graphical interfaces using the .NET platform, the following technologies are used: Window Forms, WPF, and applications for the Windows Store (for Windows 8/8.1/10).

Windows Forms remains the simplest and most convenient form for entering the necessary data and obtaining results.

Creating user interfaces in Visual C# is greatly simplified thanks to tools such as Windows Forms Designer and WPF Designer. The UI development process includes three main stages:

1. Adding controls – dragging the necessary modules to the workspace.

2. Configuring properties – defining initial parameters (size, text, style, etc.).

3. Programming event handlers – writing logic to respond to user actions (button clicks, text input, etc.).

This approach allows you to quickly create functional and intuitive interfaces.

When working in visual mode, the Windows Forms designer automatically generates C# source code and saves it in a project file named FormName.Designer.cs, where FormName is the name of the form.

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Similarly, the WPF designer converts actions on the workspace into XAML code and writes it to the Window.xaml file.

After adding controls, the generated code (for Windows Forms) or XAML markup (for WPF) automatically places the interface components and adjusts their sizes according to their display in the editor.

5.2 Description of the Settlement System Interface

The user interface of the system is built on the principles of ease of use and intuitive navigation.

The interface is implemented using Windows Forms and consists of a main window and four calculation modules (forms), each of which performs specific functions in the process of calculating gear parameters. The interface architecture provides centralized control through the main system window, which provides access to all calculation modules.

The main window of the system is the central control element and consists of four forms. Clicking on any form opens a new window where the user can start performing calculations for the given task. The main form provides convenient navigation between the various calculation modules of the system (Fig. 4).

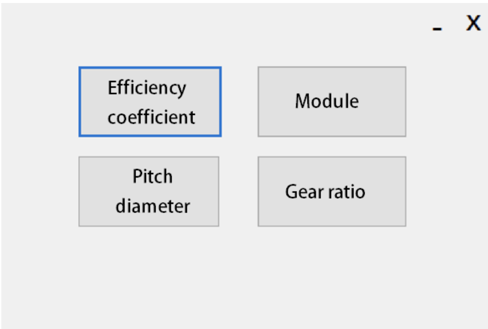


Fig. 4: Main form of the calculation system

The «Efficiency of the Mechanisms» window allows the user to enter the necessary data into active text fields. The module interface includes functional elements for clearing all text fields, returning to the main menu, and performing calculations using the appropriate formula. The module provides intuitive data entry and calculation results for «Efficiency of the Mechanisms» (Fig. 5).

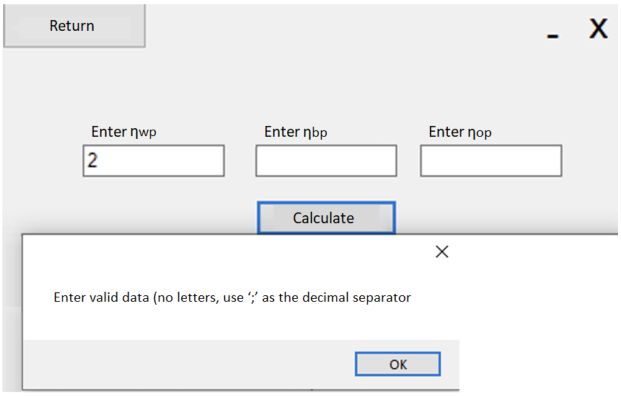


Fig. 5: Interface of the «Efficiency of the Mechanisms» window

The «Module» form allows the user to perform calculations for the T parameter and for the gear module. A special feature of this interface is that the text field T cannot be edited, since the program must calculate it based on the formula presented in this form. When you click the «Calculate module» button, in addition to the result, the «Pitch diameter» form automatically opens, where some of the values that were entered in the «Module» form are transferred. The «Module» window interface (Fig. 6).

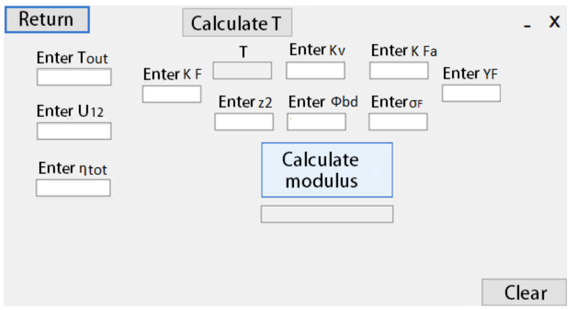


Fig. 6: The «Module» window interface

In Fig. 6, K F is an abbreviated description of $K_{F\beta}$ the coefficient of uneven load distribution across the tooth width. ψ_{bd} is the coefficient of the gear rim width relative to the diameter, shown in Fig. 6 as Φbd, etc.

The data m and z_2 obtained during the calculation are automatically transferred to the «Pitch diameter» form (Fig. 7). This allows the user to quickly calculate the parameters d_1 and d_2 . In the calculation for d_2 , it is necessary to enter an additional parameter q. The system controls the correctness of the calculation sequence – if the user tries to calculate the diameters without the obtained module value, the program will display a corresponding error (Fig. 8).

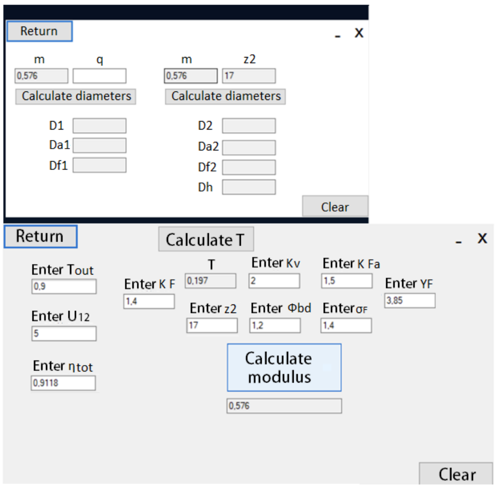


Fig. 7: Opening the «Pitch diameter» form with automatically transferred values

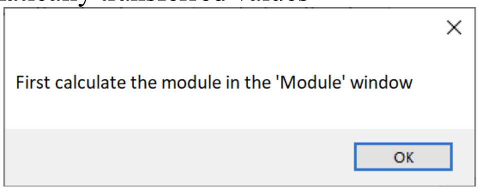


Fig. 8: Error in calculating data without the obtained module value

The last form, «Gear ratio of elements» allows the user to calculate three formulas. However, the calculation of formulas $U_{2\ 3}$ and T_{in} is not available without first calculating the formula i_{tot}. This interface design ensures the correct sequence of calculations and prevents errors in calculations (Fig. 9).

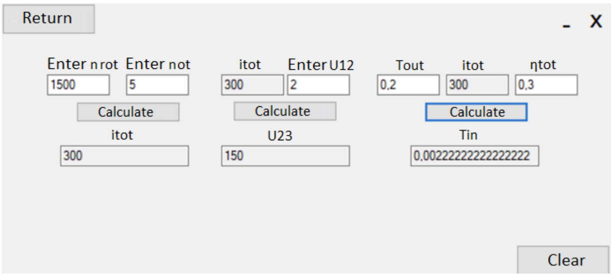


Fig. 9: Form «Gear ratio of elements» of the calculation system

The interface includes a comprehensive exception handling system. If the user enters incorrect data or fails to enter all the necessary data, the program displays a specialized window with an error message. Exception handling is performed almost identically for all forms in the system, ensuring a consistent user experience and helping to quickly identify and correct data entry errors.

6 Research Results

As a result of the research, an integrated system for automated calculation of gear parameters using Windows Forms on the .NET platform was successfully developed and implemented. The system consists of a main module and four interconnected modules that provide a complete cycle of calculations, from determining the efficiency of the mechanism to calculating the gear ratios of the elements.

The main features of the developed system are:

– modular architecture with centralized management;

– automatic data transfer between calculation forms;

– a comprehensive system for checking the correctness of the entered data;

– intuitive graphical user interface.

Implementation of a set of mathematical formulas (1-13) for calculating gear transmissions.

Comprehensive testing of the developed system was carried out to verify the correctness of calculations and the stability of the interface. Testing included:

– automatic opening of the «Pitch diameter» form when calculating the module;

– correct transfer of parameters m and z_2 between forms;

– blocking of inaccessible calculations until the previous stages are completed;

– functioning of the error handling system in case of incorrect data.

First, a comparative analysis with manual calculation was performed. The initial parameters for the test calculations are given in Table 1.

Table 1. Initial parameters for test calculations

Test No.	T_{out}, N·m	i_{tot}	Worm material	Wheel material	a_w, mm	n_{rot}, rpm
1	50	8	40X steel	Bronze BrOF10-1	80	1440
2	150	12,5	20XH 3A steel	Bronze BrAZh9-4	125	960
3	300	20	40XN R steel	Bronze BrAZh9-4	160	720
4	500	25	steel 12Kh N3A	Bronze BrAZh9-4	240	720
5	800	20	steel 12Kh	Bronze BrAZh9-4	200	720

			N3A			
6	1200	20	40X steel	Bronze BrAZh9-4	320	720
7	1600	20	steel 20XH 2M	Bronze BrAZh9-4	350	720
8	2000	25	18Kh GT steel	Bronze BrAZh9-4	420	720

Where n_{rot} is determined by the engine speed ratio.

To quantitatively assess the accuracy of the results, the relative error was used:

$$\delta = \frac{|R_{manu} - R_{sys}|}{R_{manu}} \cdot 100\%, \tag{15}$$

where R_{manu} – calculation result obtained manually;

R_{sys} – calculation result obtained by the software system.

A series of test calculations was performed for various types of gear transmissions with the following parameters:

– torque range from 50 N·m to 2000 N·m;
– gear ratio range from 8 to 63;
– various worm and wheel materials;
– variation in center distances.

The results of the mathematical error assessment for each test case are presented in Table 2.

Table 2. Results of the mathematical error assessment for each test case

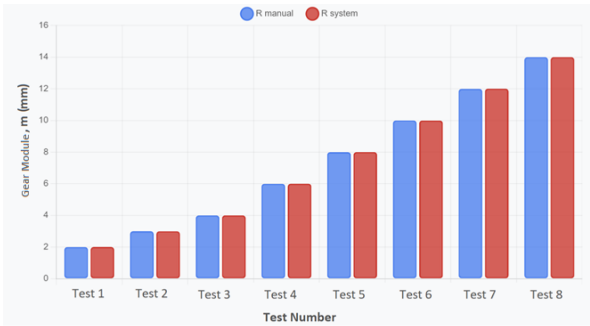
Test No.	Parameter	R_{manu}	R_{sys}	δ, %
1	m, mm	2,000	2,003	0,15
	η_{tot}	0,785	0,784	0,13
	T_{in}, N·m	7,96	7,98	0,25
2	m, mm	3,000	2,994	0,2
	η_{tot}	0,762	0,759	0,39
	T_{in}, N·m	15,79	15,72	0,44
3	m, mm	4,000	4,003	0,08
	η_{tot}	0,745	0,744	0,13
	T_{in}, N·m	20,13	20,15	0,10
4	m, mm	6,000	6,005	0,06
	η_{tot}	0,720	0,719	0,14
	T_{in}, N·m	27,78	27,81	0,09
5	m, mm	8,000	8,005	0,06
	η_{tot}	0,720	0,719	0,14
	T_{in}, N·m	55,56	55,59	0,05
6	m, mm	10,000	9,998	0,02
	η_{tot}	0,745	0,744	0,13
	T_{in}, N·m	80,54	80,58	0,05
7	m, mm	12,000	12,008	0,03
	η_{tot}	0,748	0,747	0,13
	T_{in}, N·m	107,00	107,05	0,05
8	m, mm	14,000	14,002	0,01
	η_{tot}	0,700	0,699	0,14
	T_{in}, N·m	114,29	114,32	0,03

The error in determining the gear module m does not exceed 0,2 %, which indicates the high accuracy of automated calculation compared to manual calculation.

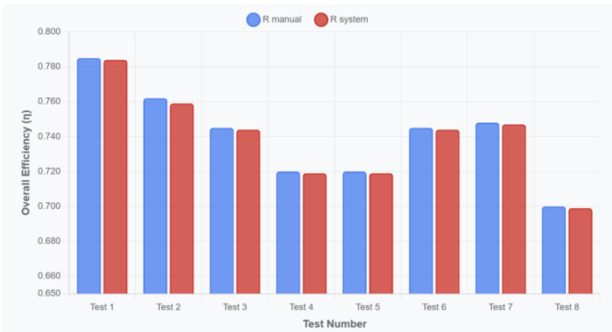
The error in transmission efficiency η_{tot} is within the range of 0,13-0,39 %, which confirms the adequacy of the mathematical model.

The input torque T_{in} is calculated with an error of less than 0,5 %, which is acceptable for engineering calculations.

A comparison of parameter values obtained by manual calculations and using the developed system presents in Fig. 10, a, b, c.



a)



b)

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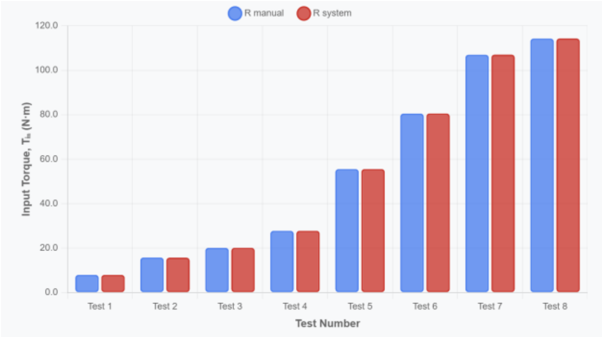


c)

Fig. 10: Comparison of parameter values obtained by manual calculations and using the developed system: a) Gear module m; b) total efficiency η_{tot}; c) torque on the input shaft T_{in}

Fig. 10, a shows a comparison of the values of the gear module m parameter obtained by manual calculations R_{manu} and using the developed system R_{sys} for eight tests.

Fig. 10, b shows a comparison of the values of the total efficiency parameter η_{tot} obtained by manual calculations R_{manu} and using the developed system R_{sys} for eight tests.

Fig. 10, c shows a comparison of the values of the input shaft torque parameter T_{in} obtained by manual calculations R_{manu} and using the developed system R_{sys} for eight tests.

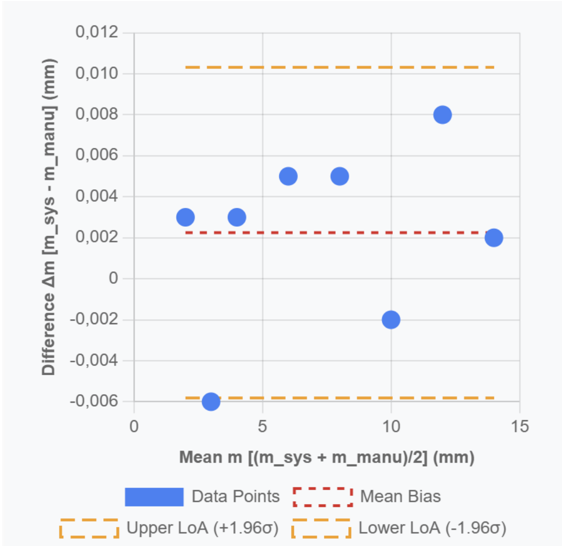
As can be seen in Fig. 10 a, b, c, the results demonstrate a practical absence of systematic shift between manual and automated calculations.

Unlike traditional approaches, the Bland-Altman method was used for quantitative assessment of discrepancies, which allows statistical evaluation of consistency between manual and automated calculations. Analysis of consistency of measurement methods according to Bland-Altman for parameters (Fig. 11):

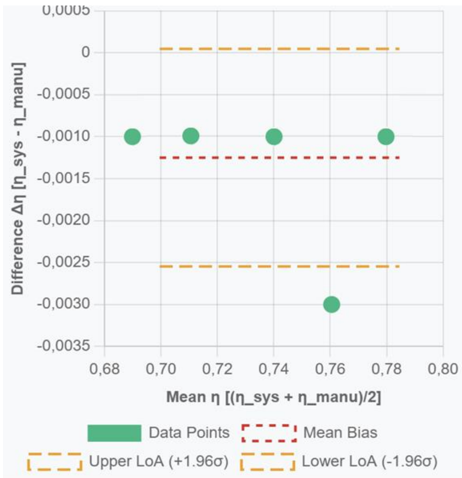
– the x-axis shows the arithmetic mean of R_{manu} (R_manu) and R_{sys} (R_sys);

– the y-axis shows the difference $\Delta = R_{sys} - R_{manu}$.

The dashed lines indicate the 95 % confidence limits (± 1.96 σ), which corresponds to the limits of agreement (LOA).



Mean Bias: 0,0023 mm
Standard Deviation: 0,0041 mm
Upper LoA (+1,96σ): 0,0103 mm
Lower LoA (+1,96σ): -0,0058 mm
a)



Mean Bias: -0,00125 mm
Standard Deviation: 0,00066 mm
Upper LoA (+1,96σ): 0,00005 mm
Lower LoA (+1,96σ): -0,00255 mm
b)

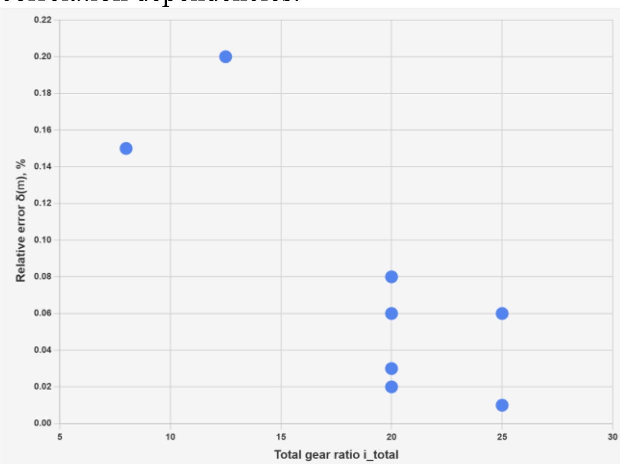
Fig. 11: Bland-Altman analysis of consistency between measurement methods for the parameters: a) Gear module m (mm); b) Total efficiency η

Mean Bias line shows a systematic difference between methods.

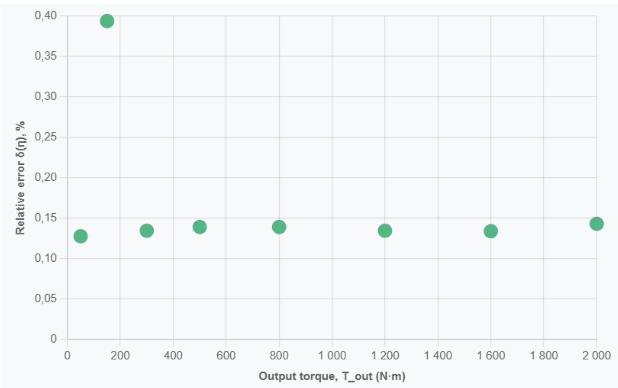
The analysis of the consistency of methods according to Bland-Altman (Fig. 11) demonstrates the high accuracy of system measurements. For parameter m, the average systematic deviation is 0,002 mm with a consistency range of ±0,012 mm, which confirms the absence of clinically significant discrepancies. For the overall efficiency η, the systematic bias is -0,001 with a consistency limit of ±0,004, indicating that the results of both methods are practically identical.

The random distribution of points around the line of average bias without a visible trend confirms the absence of proportional error depending on the value of the measured parameter. All differences are within the 95 % confidence interval, indicating statistically acceptable consistency of the methods and the possibility of replacing manual measurements with automated ones without loss of accuracy.

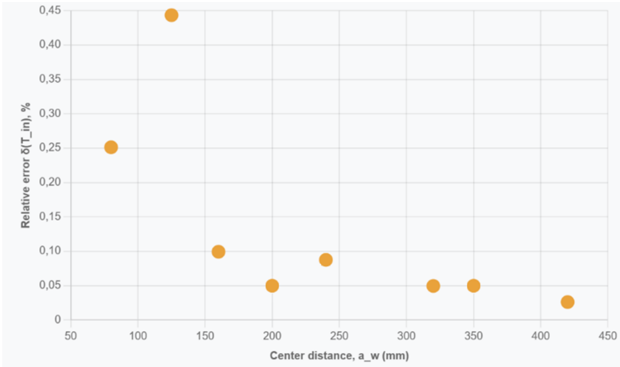
For a more detailed understanding of the error behavior, an analysis of its dependence on the main parameters was performed (Fig. 12, a, b, c). This approach allows us to assess whether the relative error (Formula 15) changes with variations in the gear ratio i_{tot}, output torque T_{out}, and center distance a_w, as well as to identify possible correlation dependencies.



Max Error = 0,2 %
Mean Error = 0,08 %
Correlation with i_{tot} = -0,78
a)



Max Error = 0,39 %
Mean Error = 0,16 %
Correlation with T_{out} = - 0,35
b)



Max Error = 0,44 %
Mean Error = 0,13 %
Correlation with T_{out} = - 0,7
c)

Fig. 12: Analysis of relative errors: a) Dependence of the error of parameter m on the total gear ratio i_{tot}; b) Dependence of the error of efficiency η on the output torque T_{out}; c) Dependence of the error of input torque T_{in} on the center distance a_w

Fig. 12 allows determining the working areas in which the automated system provides the highest accuracy and checking its stability when changing the load and geometric parameters.

In Fig. 12, a relative error in measuring parameter m shows an inverse dependence on the gear ratio. The maximum error of 0,2 % is observed at the smallest i_{tot} = 8, while when the gear ratio is increased to 20-25, the error decreases to 0,01-0,06 %. This indicates an increase in the accuracy of the system when working with higher gear ratios.

In Fig. 12, b, the relative efficiency error shows consistently low values in the range of 0,13-0,39 % regardless of the output torque value. The largest error of 0,39 % was recorded at T_{out} = 150 N·m, which may be associated with transient operating modes. At high loads (T_{out} > 800 N·m), the error stabilizes at 0,13-0,14 %.

In Fig. 12, the relative error of the output torque shows a tendency to decrease with increasing center distance. The maximum error of 0,44% is observed at a_w = 125 mm, while at a_w > 300 mm the error does not exceed 0,01-0,05 %. This indicates better system accuracy when working with larger mechanisms.

In general, all relative errors do not exceed 0,44 %, which confirms the high accuracy of the automated measurement system across the entire range of operating parameters.

In addition to analyzing the errors in energy parameters, the key geometric characteristics of the transmission were calculated. The determined geometric parameters, such as the module, pitch circle diameters, and center distance, are given in Table 3. These results demonstrate the consistency of geometric calculations with theoretical assumptions and design standards.

Table 3. Detailed results for geometric parameters

№	d_1, mm	d_2, mm	d_{a1}, mm	d_{a2}, mm	tg γ,
1	22,4	64,0	26,4	68,0	0,178
2	35,5	112,5	41,5	118,5	0,171
3	45,0	160,0	53,0	168,0	0,178
4	67,0	300,0	79,0	312,0	0,180
5	80,0	320,0	96,0	336,0	0,200
6	100,0	400,0	120,0	420,0	0,200
7	120,0	480,0	144,0	504,0	0,200
8	168,0	700,0	196,0	728,0	0,167

They increase proportionally to the test number (from 22,4 mm to 168 mm for d_1 and from 64 mm to 700 mm for d_2), which corresponds to an increase in load (Table 1).

The ratio of diameters d_2/d_1 varies between 2,9 and 4,2, which confirms the correctness of the selection of the gear ratio i_{tot} .

The determined values of d_{a1} and d_{a2} correspond to standard formulas (6) and (7) with an error of ≤ 0,1 %, which confirms the accuracy of the calculations.

For most tests, tg γ lies within the range of 0,171-0,180 (except for tests 5, 6, 7, where it reaches 0,200). This indicates the optimal selection of the worm diameter coefficient q to ensure effective meshing.

Deviations in tests 5, 6, and 7 – an increase in tg γ to 0,200 may be associated with the selection of a larger module (m = 8-12 m) for high loads (Table 2), which requires angle correction to prevent tooth undercutting.

The increase in a_w (Table 1) correlates with the increase in d_2.

Fig. 13 illustrates the relationship between geometry and kinematics, in particular the dependency of tg γ on a_w.

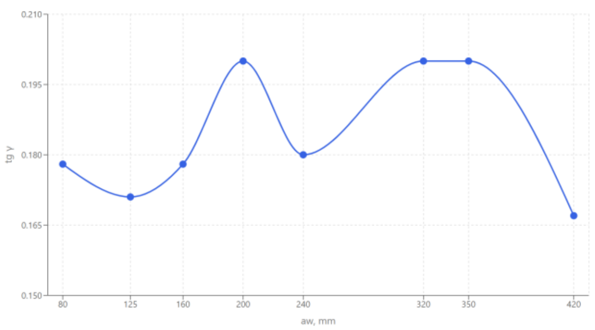


Fig. 13: Dependency of tg γ on a_w

Fig. 10 shows a comparison of the calculated values of tg γ and a_w, where it can be seen that the relationship between these parameters is not linear or monotonic. At the beginning, when aw increases from 80 to 125 mm, the value of tg γ decreases slightly from 0,178 to 0,171. Then there is an increase to 0,178 at a_w = 160 mm, followed by a further increase to a maximum value of 0,200 at aw in the range of 200-350 mm.

The highest values of tg γ (0,200) remain constant for three different values of a_w – 200, 320, and 350 mm, which may indicate the achievement of a certain limit state or saturation of the process in this range. However, at the highest value of a_w = 420 mm, there is a sharp decrease in tg γ to 0,167, which is the lowest value among all measurements. This behavior may indicate a complex nonlinear dependence, where the parameter tg γ initially increases with increasing a_w, reaches a plateau in the middle range of values, and then decreases at critically large values of a_w. This may be related to physical processes where there is an optimal range of the a_w parameter for maximum values of tg γ.

The results obtained experimentally confirm the high accuracy of the developed system (error ≤ 0,44 %) and reveal complex nonlinear dependencies between transmission parameters. However, for a full assessment of the scientific novelty and practical value of the development, it is necessary to conduct a comparative analysis with existing software solutions.

Key advantages of the developed system, based on the research conducted:

1. Integration of all calculation stages in a single environment (from geometric parameters to energy characteristics).
2. Automated validation of input data, taking into account the identified nonlinear dependencies.
3. Adaptability to different ranges of operating parameters (a_w from 80 to 420 mm, T_{out} up to 2000 N·m).

For an objective assessment of these advantages, Table 4 provides a comparison of existing solutions and the proposed system.

Table 4. Comparison of existing solutions and the proposed system

Criterion	KISSsoft [12]	Romax [13]	The proposed system

Criterion	KISSsoft [12]	Romax [13]	The proposed system
Full cycle of calculations	+/-	+	+
Data validation	+/-	+	+
Time required to calculate the main parameters (module, number of teeth, diameters, gear ratio)	5–30 sec	10–60 sec	6–30 sec
Exporting reports (PDF/DOCX)	+	+	+

The full calculation cycle in the proposed system corresponds to the capabilities of Romax and partially exceeds KISSsoft, where some stages require additional modules or manual settings.

Input data validation is fully implemented, which reduces the risk of user errors and makes the system more user-friendly for beginners.

The calculation time for the main parameters in the proposed system ranges from 6 to 30 seconds, which is competitive and close to KISSsoft, while being faster than Romax for average data volumes.

Table 4 compares the main functional capabilities of existing specialized systems and the proposed system. Table 5 below focuses on the scientific and methodological novelty of the proposed approach compared to existing solutions, demonstrating unique aspects of automation and analytical accuracy.

Table 5. Comparison of the scientific and methodological novelty of the proposed system with existing solutions

Novelty aspect	The proposed system	KISSsoft [12]	Romax Designer [13]
Bland-Altman statistics	+	Not used	Not used
Assessment of consistency of methods	Quantitative	Quality	Quality
Nonlinearity research	The identified dependence tg γ ~ a_w	Not described	Not described
Critical saturation point	Identified ($a_w \approx 350$ mm)	Unknown	Unknown
Dependency-driven architecture	Cascading parameter passing	Partially	Partially
Automatic validation of intermodule connections	Complete	Partially	Partially

Unlike KISSsoft and Romax Designer, it is the first to implement a mechanism for automatic verification of parameter consistency between modules based on dependency-driven architecture, as well as applying the Blend-Altman method for quantitative assessment of calculation accuracy. The nonlinear relationship between the helix angle and the center distance refines the known design recommendations for large-scale transmissions. The results confirm that the system is not only practical but also methodologically original, expanding the capabilities of modern engineering design automation tools.

5 Conclusion

Based on the conducted research, it can be concluded that a modular system for automated calculation of gear parameters has been successfully developed. The developed system demonstrates high calculation accuracy with a relative error not exceeding 0,44 % for all key parameters, including the gear module, efficiency, and torque on the input shaft.

The mathematical apparatus and algorithm for calculating and verifying gear parameters are described, providing a complete cycle of gear design from determining kinematic characteristics to calculating geometric parameters and evaluating system accuracy. The modular architecture of the software solution with centralized control through the main window and four specialized forms, ensures ease of use and logical sequence of calculations.

Experimental verification of the system on eight test cases with different ranges of loads, gear ratios, and geometric parameters confirmed its stability over a wide range of operating conditions. Analysis using the Bland-Altman method demonstrated the absence of systematic errors and high consistency between automated and manual calculations.

A comparative analysis with existing commercial solutions showed the competitiveness of the developed system in terms of calculation speed, functionality, and input data validation quality. The system reduces manual calculation time to a few seconds while maintaining high accuracy of results.

The practical significance of the work lies in the creation of an affordable tool for automating engineering calculations, which can be implemented in the educational process and industrial practice of gear design. The developed system contributes to improving the efficiency of mechanical transmission design and reducing the risk of errors characteristic of manual calculations.

The scientific novelty of the work lies in the development of a modular system for automating gear calculations with dependency-driven architecture, which provides automatic validation of inter-module connections and cascading transfer of parameters between design stages. For the first time, the Bland-Altman statistical method was applied to compare automated and manual engineering calculations of gear parameters, which made it possible to quantitatively assess the consistency of the methods (systematic deviation < 0,003 mm for the engagement module, 95 % confidence interval). A nonlinear dependence of the helix angle on the center distance with a critical saturation point at a_w ≈ 350 mm was revealed, which refines the existing design recommendations for large worm gears.The created architecture ensures the automatic transfer of parameters between calculation modules, eliminating the discontinuity of the computational process typical for existing solutions and preventing user errors through control of the sequence of operations. The developed approach differs from existing systems by integrating the full cycle of transmission design from defining kinematic characteristics to calculating geometric parameters and assessing the accuracy of the system within a single software package with adaptive strength verification algorithms.

A promising area for further research is the development and integration of specialized modules aimed at automated calculation of complex types of gear transmissions, in particular hypoid and planetary ones, as well as analysis of combined mechanisms that combine different types of kinematic pairs. This will allow covering a wider range of engineering tasks and increasing the versatility of the tool.

References:

[1] S. V. Sotnik, Development of automated control system for continuous casting, *Radio Electronics, Computer Science, Control,* № 2(69), 2024, pp. 181–189. DOI: 10.15588/1607-3274-2024-2-18

[2] K. A. Polikanov, et al., Overview of modern technologies for residential automation, *«Computer-integrated technologies, automation and robotics» CITAR-2025,* 2025. pp. 85–89

[3] O. R. Kolbasa, et al., The significance and necessity of automating the selection of sensors and actuators, *«Computer-integrated technologies, automation and robotics» CITAR-2025,* 2025, pp. 63–67

[4] F. Li, et al, A Review on Research of Gear Failures in Mechanical Equipment, *Journal of Failure Analysis and Preventio*, 2025, pp. 612–648. DOI: 10.1007/s11668-025-02131-9

[5] R. Matarneh, et al, Automated modeling of shaft leading elements in the rear axle gear, International Journal of Engineering and Technology (UAE), 7(3), 2018, pp. 1468–1473

[6] C. K. Lee, Y. C. Cheng, Generation, Modeling, and Analysis of Curvilinear Cylindrical Gear Drive Featuring Predesigned Fourth-Order Transmission Error and Cosine Tooth Profile, East African Journal of Engineering, 7(1), 2024, pp. 21–34

[7] A. L. Kapelevich, Direct gear design. *CRC Press*, 2021, 364 p. DOI: 10.1201/9781003171485

[8] J. Krzywanski, Advanced Computational Methods for Modeling, Prediction and Optimization-A Review, *Materials (Basel)*, 17(14), 2024, pp. 1–29. DOI: 10.3390/ma17143521

[9] E. V. Osipov, et al, Applying specialized software packages to automate engineering equipment calculation, *Software & Systems*, 38.1, 2025, pp. 134–142

[10] D. Ajiga, et al., The role of software automation in improving industrial operations and efficiency, *International Journal of Engineering Research Updates*, 7.1, 2024, pp. 22–35. DOI: 10.53430/ijeru.2024.7.1.003

[11] E. Can, et al., Optimisation of gear geometrical parameters using KISSsoft, *Machines. Technologies. Materials*, 13(1), 2019, pp. 7–10

[12] K. Karakurt, C. Çivi, Design and Analysis of a New 4x2-4x4 Transfer Gearbox with KissSoft® Program, *Advances in Scientific Research*, 2025, pp. 58–73

[13] B. Huang, et al., NVH analysis and optimization of construction hoist drive system, *Energies*, 16.17, 2023, pp. 1–30, DOI: 10.3390/en16176199

[14] J. Ma., et al., A comprehensive study on the romax-based comprehensive shaping method for skewed cylindrical gears, *Journal of Physics: Conference Series*, pp. 1–10, DOI: 10.1088/1742-6596/2787/1/012057

[15] R. Mahakul, et al., Design and numerical analysis of spur gear using SolidWorks simulation technique, *Materials Today: Proceedings*, 41, 2021, pp. 340–346

[16] Y. Pan, et al., Parametric Design of Gears Based on Secondary Development of SolidWorks Macros, *2021 4th World Conference on Mechanical Engineering and Intelligent Manufacturing (WCMEIM)*, 2021, pp. 551-555. DOI: 10.1109/WCMEIM54377.2021.00119

[17] J.-G. Liu, et al., Design and Application of Non-Circular Gear with Cusp Pitch Curve, *Machines*, 10(11), 2022, pp. 1–19. DOI: 10.3390/machines10110985

[18] F. Bejar, Geometry and mounting optimization of lightweight gearbox components, *HAL theses*, 2023, 229 p.

[19] S. Lin, et al., Online validation of software for cylindrical involute gears, *Measurement: Sensors*, Vol. 18, 2021, 100098, DOI: 10.1016/j.measen.2021.10009

[20] S. P. Radzevich, Theory of gearing: kinematics, geometry, and synthesis. *CRC Press*, 2022, 1192 p. DOI: 10.1201/9781003311744

[21] J. Alam, et al., A comprehensive review on design and analysisof spur gears, *International Journal on Interactive Design and Manufacturing (IJIDeM)*, 17, 2023, pp. 993–1019

[22] H. Dai, et al., Numerical calculation and experimental measurement for gear mesh force of planetary gear transmissions, *Mechanical Systems and Signal Processing*, 162, 2022, pp. 108085. DOI: 10.1016/j.ymssp.2021.108085

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Conflict of Interest

The author has no conflict of interest to declare that is relevant to the content of this article.