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Measurement and numerical method for determining the contact position of gear rims in a spiroid gearbox

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ABSTRACT

As the literature indicates, spiroid gears are characterized by a compact design and small space required for their installation, so they are used in modern drive systems of many means of transport. In practice, they constitute an alternative solution to worm gears. It is emphasized that in the case of this type of gear, the basic factors that have a direct impact on proper operation are the geometric parameters of the teeth and meshing cooperating with the worm disc wheel. The aim of this article was to evaluate selected geometry parameters that have a decisive impact on the amount of wear in the contact area of cooperating parts and the operating temperature, and thus on the durability as well as reliability of the gear. This work presents a method for determining and measuring the position of the cooperation trace of the worm coil and the teeth of the disc wheel using a numerical method based on CAD software. Model analyses have shown that one of the key factors affecting the correct operation of the gear transmission is obtaining the correct shape and position of the trace of cooperation of parts in the meshing area during gear operation. In practice, the proposed method may be helpful in the process of designing this type of gear in terms of determining the correct geometric tolerances for the tooth profile and line, as well as the position of the longitudinal axis of the worm relative to the center of the ring wheel.

Keywords: drive system, spiroid gear, design and construction, CAD modeling. measurement methods, contact position of the spiroid gear rims.

INTRODUCTION

The transmissions that use mechanical linkages to achieve power transmission and change motion parameters are called mechanical gears. Such devices can be divided into three main types: linkage gears, friction gears and pinion gears [1]. In modern machine and equipment construction, the most widespread type of gearbox is the pinion gear. The possibility of transferring virtually unlimited power, great operational reliability, ensuring the constancy of the gear ratio and a number of other advantages have ensured the more frequent use of the toothed gear than other gears. The toothed gear itself is most often used to transmit rotary motion, but it can also be used as a mechanism for converting rotary motion into progressive motion (a toothed wheel with a toothed bar, known as a pinion).

Depending on the criteria adopted, the following types of gears are distinguished:

1. According to the position and relative movement of the axes of the elements:
   - fixed axes:
     - with axes in one plane: parallel axes, with intersecting axes,

- with worm axes: worm gears, helical gearboxes, spiroid gearboxes,
- with non-constant axes: helical planetary gearboxes, bevel planetary gearbox.

2. According to the relative positions of the surfaces of the vertices and bases of the wheels forming the gear:
- outer toothed gears (briefly: external gears), in which both gears are externally toothed;
- internal gears (briefly: internal gears), in which one gear wheel is internally toothed.
- an intermediate solution between external and internal gears is the rack-and-pinion gear consisting of a gear wheel and a pinion.

3. According to the value of the kinematic ratio:
- reduction gears, in which the angular velocity of the driven (reactive) element is less than the angular velocity of the driving element;
- multiplying gears, in which the angular velocity of the driven (reactive) element is greater than the angular velocity of the driving element.

Different types of gears are used in these transmissions.

4. According to the shape of the pitch surface: spur gears, bevel gears.
5. According to the shape of the tooth outline: wheels with an involute tooth outline (involute wheels), wheels with a cycloid tooth pattern (cycloid wheels), wheels with a Novikov toothing; the teeth of one component have a convex outline and the teeth of the other component have a concave outline, the outlines being arcs of circles or close to them.

Other shapes of the outlines of the cooperating teeth are also possible.

6. According to the nature of the tooth line:
- wheels with straight teeth; in these wheels, the tooth line is straight and lies on an axial plane passing through the wheel axis,
- helical-tooth wheels; in these wheels, the tooth line is a helical line of any kind; among helical-tooth wheels a distinction is made between:
- helical tooth wheels - the tooth line on the coaxial cylindrical surface is a helical line of constant pitch, i.e. on the development of this coaxial surface it is a straight line;
- wheels with cup-shaped teeth - a cup-shaped tooth consists of sections of right- and left-hand inclined teeth;
- wheels with tangential teeth - the tooth line on the development of the conical pitch surface is a straight line tangent to a concentric circle;
- wheels with curvilinear teeth - the tooth line on the development of the pitch surface is an arc of a circle, an involute, a cycloid or any other curve.

7. According to the mutual position of the surfaces of the apexes and the bottoms of the notches:
- externally toothed wheels; in these wheels, the surface of the apexes is outside the surface of the bases,
- internally toothed wheels (ring gears); in these wheels, the apex surfaces are inside the faces of the bases.

In toothed gears, the outlines of the mating gear rims move over each other in a rolling and sliding motion during operation, creating a trace at the point of contact. The parameters associated with this motion affect wear, including tribological wear, and the mechanical efficiency of the gear mesh. The relative motion and forces occurring in the gear mesh, including the frictional force occurring at the surface of the mesh track, can be the cause of accelerated wear or destruction of the gear.

The damage that can occur during gearbox operation can be classified as follows:

- pitting – this is a fatigue-like phenomenon caused by varying surface pressures in the area of the mating track. In addition, tangential stresses in the surface layer of the material have an adverse effect. The effect of this phenomenon is the occurrence of cracks in the initial stage and further on of surface spalling.
- adhesion and fatigue fracture of the tooth – ad hoc and fatigue tooth fracture, which is the result of exceeding the permissible bending stresses in the dangerous section.
- tooth seizure, which results from the occurrence of large, constant values of normal and tangential stresses in the contact area. This is accompanied by high temperatures in the contact area. The result is, among other things, surface furrowing.
- wall wear – this is a type of wear that builds up over time and manifests itself as a loss of the layer of mating surfaces.

- deformation – this phenomenon may be accompanied by vibration, the deformations are then elastic in nature and plastic deformations occur when the limits are exceeded.

As the available literature on the subject indicates, gears are used in drive systems due to their operating characteristics defined by long operational life, high peripheral speeds and their full load [2]. Examples of their use are the structures of drive systems for road and air transport, off-road vehicles and machines, as well as the arms industry [2–6]. However, ensuring a failure-free operation process requires meeting detailed assumptions during the design stage [7, 8]. In the prototyping and production phase [9], meeting the requirements regarding the reliability and quality of gear operation involves carrying out a thorough geometric as well as metallographic inspection of the gear components and checking the quality of gear meshing [10–12]. Although this process applies to all components of drive systems, spirolidal gears play a special role in this process. In principle, this gear is a mechanical toothed gear with twisted axes and small overall dimensions [13–19] (Figure 1). As one of the researchers emphasized, this type of gear is an alternative to worm gears [11], assuming the same position in relation to worm gears - a spiroid gear has the following advantages:

- greater quiet operation and technical efficiency,
- possibility of obtaining higher torque values,
- more favorable bearing lubrication parameters,
- a larger number of cooperating teeth of the disc wheel with the worm turns,

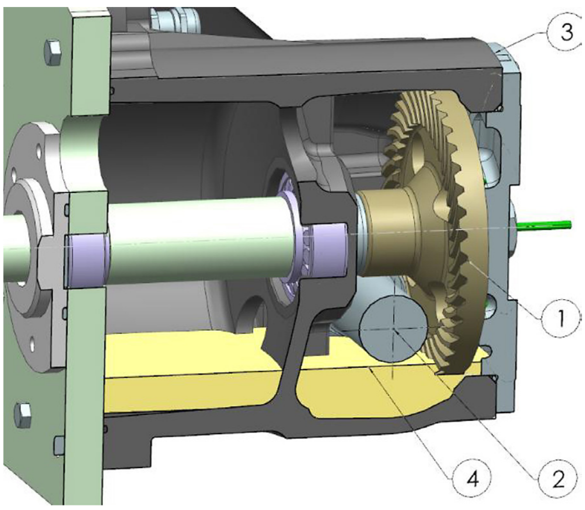

Figure 1. Spiroid gear: 1 – disc wheel, 2 – worm, 3 – gear housing, 4 – oil

- distribution of pressure over a larger contact surface,
- possibility of placing bearings close to the meshing.

The result of this process is greater stiffness of the gear structure [11].

In practice, these gears are used in drive systems with a significant reduction in rotational speed, because they can transmit significant torque values. Therefore, they are used in many industries, including:

- aviation, including flight control mechanisms and radar antenna positioning.
- reinforcement: gun control mechanisms, opening and closing of hatches, doors, devices replacing hydraulic systems.
- related to the construction of various types of means of transport - in the drive systems of electric vehicles, elevators, escalators, mechanisms supporting the operation of actuators [19, 20, 22].

Therefore, the research in the field of numerical methods in the process of measuring and determining the position of the contact pattern of spiroid gear rims in modern drive systems is becoming an imperative of great importance in today's realities. On this basis, the authors set themselves the goal of developing a method for model analyses of key factors affecting the correct operation of the gear transmission in the area of the correct shape and location of the trace of cooperation of parts in the meshing circle.

This work presents a method for determining and measuring the position of the cooperation trace of the worm coil and the teeth of the disc wheel using a numerical method based on CAD software. According to authors' knowledge, the presented results may be useful for designers designing not only spiral gears, but also other types of gears. The presented model allowed the authors to determine the correct position of the axis of the cooperating parts of the gear, and therefore the correct geometry as well as position of the track of its cooperating parts.

Therefore, this article could have many important practical and theoretical implications. To the best of authors' knowledge, this is the first research approach to the mentioned topic. The presented considerations bridge the research gap in the literature on the subject. At the same time, it is a new perspective on the described problem in relation to the described means of transport. The article is organized as follows: Section 1 concerns the description of important research issues and the purposefulness of undertaking research. Section 2 provides a detailed description of the conceptual framework, the research method used to answer the research questions, and the research instrument. Section 3 describes the experimental results and their interpretation. In turn, Section 4 discusses the results achieved by the authors and presents conclusions - pointing to their limitations in the perspective of research conducted so far, and future research directions are identified in relation to this type of gears used in modern drive systems.

MATERIALS AND METHODS

The available literature emphasizes that the spiroid gear consists of two main parts: a worm and a disc wheel. In this type of gears (reducers), the driving part is a shaft with a worm cut on it. As it was mentioned in the chapters above, this type of gearbox is used in drive systems, e.g. in various means of transport, in which it is necessary to transmit large torques with a simultaneous reduction of rotational speed.

While worm gears have been and are the subject of many studies [23–25], the results of which are generally available, spiroid gears are not yet fully known. Previous research conducted in this area regarding post-use parts has shown that the disc wheel cooperating with the worm often undergoes significant wear. Wear occurred in the area of direct contact (Figure 2), on the side surfaces of the teeth on the outside and inside. This phenomenon was accompanied by significant increases in temperature in the engagement of the mating parts [26]. Moreover, the analysis of phenomena accompanying wear showed a significant impact of the mutual location of the axes of the cooperating parts - the worm and the disc wheel - on increasing the durability and reliability of the transmission. Their mutual location determines the location and shape of the cooperation trace on work surfaces under real conditions. In order to determine the trace of cooperation at this stage of research, the authors developed an innovative method in which real parts (worm and disc wheel) made as nominal ones were used. The mutual location of the worm axis and the disc wheel is shown in Figure 3.

Conceptual assumptions – geometry of the toothing of the disc wheel and worm

Determining the location of the cooperation trace on the working surfaces of spiroid parts under real conditions or on specialized research stations is troublesome and cost-intensive. With this in mind, it was decided to simulate these conditions using the reverse engineering process and appropriately dedicated CAD software. The method developed in this way makes it possible to simulate operating conditions taking into account the geometric tolerances of

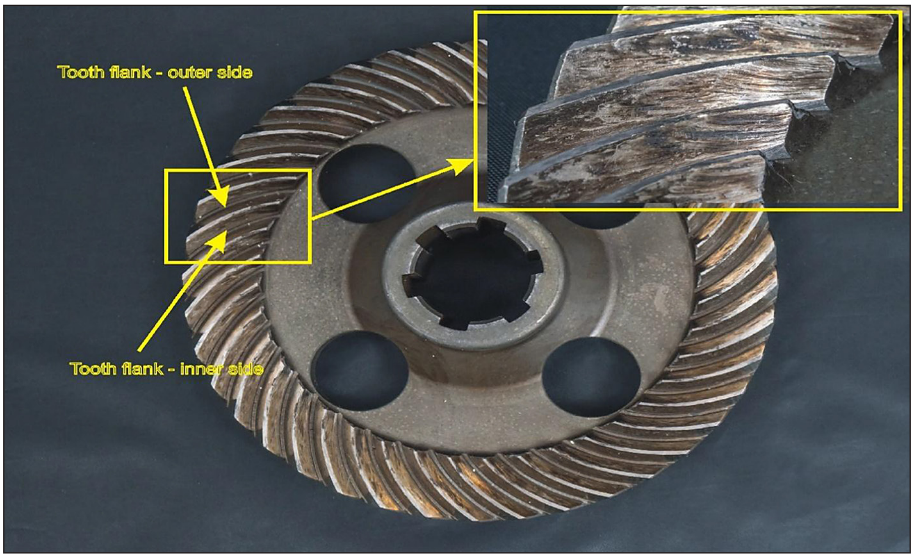

Figure 2. Traces of abrasive wear of the spiroid gear ring wheel

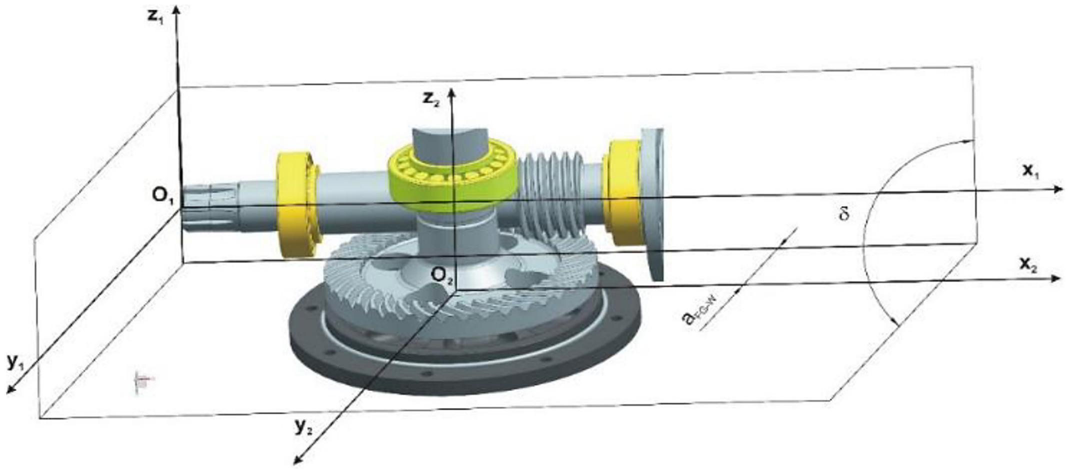

Figure 3. Mutual location of the worm axis and the disc wheel – a model obtained using CAD software

individual parts and their mutual location during gear operation.

Tool description

Measurement of the nominal parts of the gear: crown wheel and worm was carried out on a Roland MDX-40 coordinate measuring machine armed with a ZSC-1 scanning head. The measurements were carried out using the contact method and included both scanning of entire physical models of gears, as well as concerned precise linear measurements in key sections. The contact scanning process was chosen because of the high accuracy of the method, and the need to measure the wheel models that have both large dimensions and at the same time the areas requiring much more detailed digitization. Particularly important for the subsequent evaluation were the areas of gear rims, and tooth profiles in key areas of cooperation. Contact scanning is carried out by direct contact between the tip of the scanning module and the material to be measured, so it does not require any additional preparation of the models. The dulling of measuring surfaces by applying a special coating, required in optical contactless methods, could affect the obtained results, especially in the areas where there are traces of tooth cooperation. An additional factor influencing the choice of a Roland MDX-40A for measuring gear models is the very small diameter of the measuring tip of the scanning module, several times smaller than those installed in large measuring machines used in industry. As indicated by observations of market realities, this tool is used

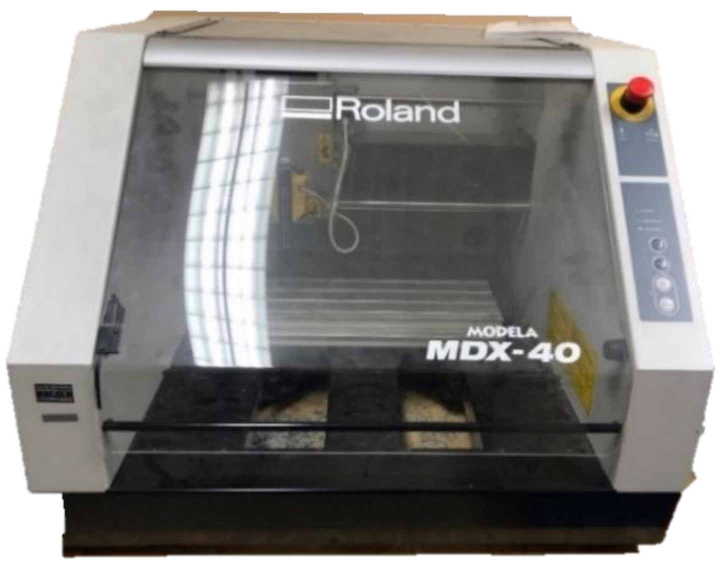

Figure 4. Roland MDX-40 coordinate measuring machine

in economic practice to evaluate phenomena studied by many reputable research institutes, including the Art Center College of Design in California related to the transportation sector (Figure 4).

The process of scanning spatial models involves taking measurements in the X,Y,Z coordinate system of the CNC machine at the moment of contact between the head tip and the model surface. The operation of the scanning process is carried out using the Dr.Picza3 program, which is supplied by the manufacturer together with the Roland MDX-40 CMM. When defining the scanning process, it is necessary to specify the working area and the resolution in the direction of the horizontal X and Y axes. The scanning range can be selected by indicating it on the panel in the settings window, or more precisely by entering the coordinates for the corners of the working rectangle. A maximum and minimum measurement level in the Z-axis direction must also be set. The scan result is stored as a point cloud and can also be transformed into a triangle mesh. This measurement result can be saved as an STL file and forms a spatial image of the measured object. The digital model of the scanned gear can be exported to any CAD program for further geometry correction and parameter editing. The Roland MDX-40 machine can scan models with a resolution of $\Delta x = \Delta y = \Delta z = 0.04$ mm and the measurement accuracy at the measurement points was 0.01 mm. When digitizing the gears, it was this high accuracy that was adopted for the key areas, reducing the scanning resolution in the urban important fragments of the models. As a result of processing the measurement results, 3D models were obtained reflecting the actual dimensions of both the screw and the disc wheel. The 3D models were obtained using NX CAD SIMEMNS software and are presented in Figure 5.

RESULTS

Analysis of 3D models using specialized software allowed for the determination of the basic geometric dimensions of the disc wheel and worm. These values are included in the Tables 1 and 2.

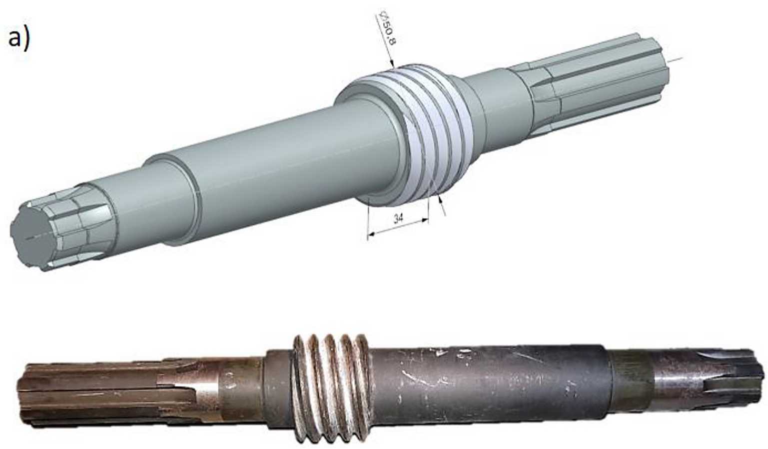

Figure 5. Actual structure and 3-D models obtained based on measurements of: (a) worm, (b) disc wheel

Table 1. Measurement results obtained on the basis of the 3D models of the worm

The geometry of the screw turns		
Parameter	Symbol	Value
Number of turns	z_1	2
Module	m_n	3 [mm]
Angle of rise of the turn line	g	5° 50'
Worm type	-	Left, straight teeth
Coil height	h_1	4 mm
The angle of the cochlea coil	α_1	30°
Internal diameter of the screw	d_{f1}	42.8 mm
Outer diameter of the screw	d_{a1}	50.8 mm

Table 2. Measurement results obtained on the basis of 3D models of the disc wheel

Geometry of the disc wheel		
Parameter	Symbol	Value
Number of teeth	$_{z}2$	40
Module	m_n	3 [mm]
Tooth type		Straight teeth
Tooth height	$_{h}2$	4.4 mm
Tooth line	Spline	
Tooth contour angle	$_{\alpha}2$	30°
Inner diameter of the disc wheel	d_{w1}	117.76 mm
Outer diameter of the disc wheel	d_{z1}	152.40 mm

Determining the trace of the cooperation of the disc wheel and the worm

One of the geometric parameters that determine the correct operation of the assembly is the distance between the planes in which the longitudinal axes of the disk wheel and the ayFG-W (distance of the center of the disc wheel from the longitudinal axis of the worm) worm lie (Figure 6). In order to obtain the dimension above, in the first stage, the tooth line of the ring gear was determined for the 3D model of the ring wheel using a spline function of order 3. Further, for the assumed distance of the longitudinal axis of the worm from the center of the ring wheel (aFG-W) and the lateral circumferential clearance jt = 0 mm between the worm and the disc wheel, a position was sought for which there is no interference of the cooperating profiles of the worm coil and the disc wheel teeth. The angle between the planes in which the axes of the disk wheel and the worm lie is assumed to be equal (δ – angle between the axes of the screw and the disc wheel) δ=90°. The result of the search is the distance of the planes in which the axes of the disk wheel and the worm lie and at which there is no interference of contours. This distance for the case under consideration is aFG-W = 43.18 mm.

Cooperation of the outlines of the disc wheel and the worm with the shift of the worm axis relative to the disc wheel

The reason for the interference of the cooperating profiles of the worm coil and the gear rim may be a change in the nominal position of the disk wheel axis relative to the longitudinal axis of the worm, which ensures correct operation. These axes are inclined in their nominal position. However, as a result of the manufacturing process, this

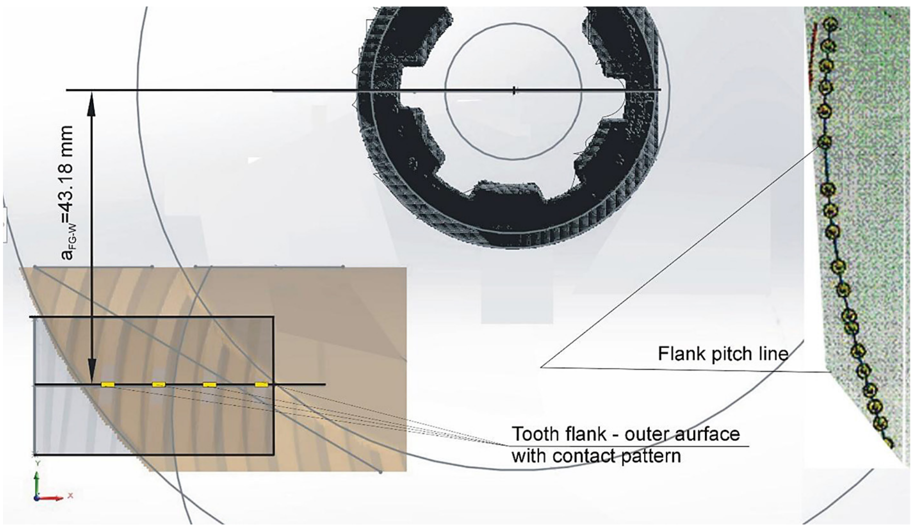

Figure 6. Model of the disk wheel and worm in a position without interference of the outlines of the cooperating parts

position may be subject to manufacturing errors. The axis position error may result from the shift of the worm axis relative to the disk wheel (Δy), angular displacement of the planes (δ≠0) in which the axes of the disk wheel and worm are located. This error may also be a complex error resulting from the shift and change of angles between the considered axes. To illustrate the problem, the axis was moved by Δy = 0.1 mm and the interference of contours near the inner diameter of the disc wheel, visible in Figure 7, was obtained. The position of the overlapping contours is consistent with the observed wear of the ring wheel in Figure 2.

The authors emphasize that, at a later stage of the research, they also attempted to determine the depth of wear traces for the post-use wheel (Figure 2). This task was accomplished by comparing 3D models of the topography of the nominal (non-exploited) and post-exploitation wheel surfaces. The observed depths of wear traces ranged from 0.0 to 0.21 mm (Figure 8).

Algorithm of the process

The process of designing, manufacturing and controlling the performance of a spiroid gear is a complex engineering task. A significant challenge encountered during the design process pertains to the paucity of available data concerning the geometry of the mating gear rims and the parameters necessary for ensuring the proper assembly of the gear components. The research undertaken

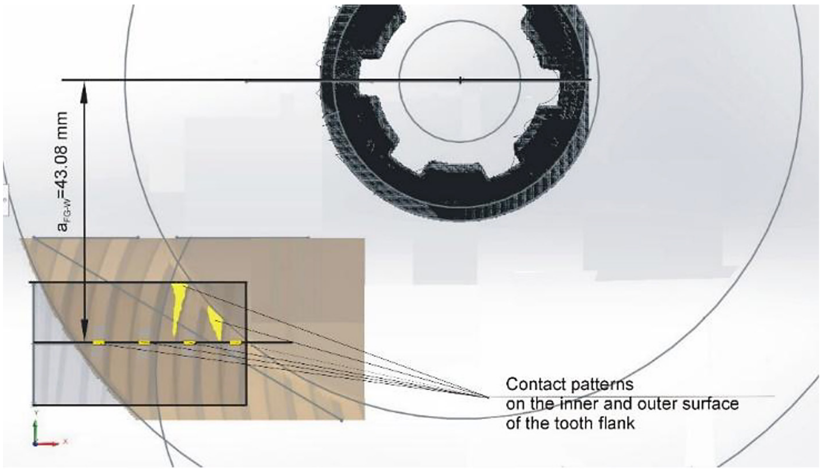

Figure 7. Models of the disc wheel and worm in a position with interference of the outlines of mating spare parts

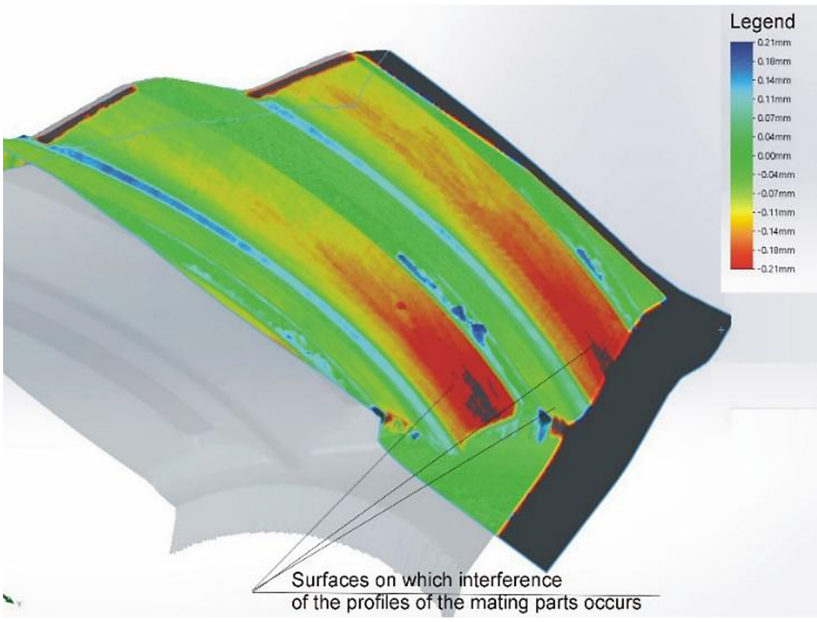

Figure 8. 3D model of a disk wheel with interference surfaces of the outlines of cooperating parts

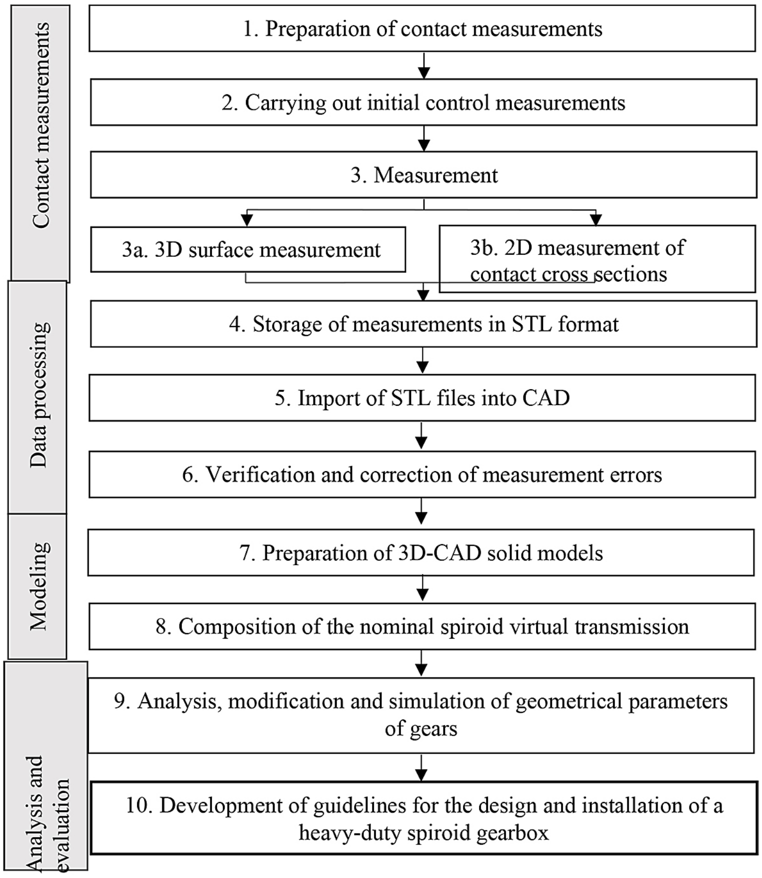

Figure 9. Algorithm of the process

has enabled the development of a methodology for the design of this particular gearbox. The methodology under discussion involves the delineation of design stages, thus facilitating the execution of diverse analyses pertaining to gearbox operating parameters. The algorithm of the method is presented in Figure 9. The main stages of the developed algorithm include:

- preparing to measure the disc wheel and the worm, determining the measuring field and position the parts to be measured so that their axes are aligned with the coordinate system of the Roland MDX-40 measuring machine. The parts to be tested are new and have not been in service.
- carrying out preliminary control measurements.
- 3D measurement of the external surface of the part with high measurement resolution;
- 2D measurement of the parts in key cross-sections with high accuracy.
- evaluation of the correctness of the digitization process and saving the measurement results in STL format.
- import files with measurement results into CAD software.
- verification and correction of measurement errors and geometry anomalies.
- fusion of partial surface models describing the digitized part into a unified solid model.
- adjusting the models of the measured parts to take into account their nominal position.
- modification of the assembly parameters of spiroid gear parts (disc wheel and worm) to influence their correct operation, such as the distance between the axes, the angle between them and the axial offset;
- development of conclusions concerning the influence of changes in selected geometric parameters on the interaction of the gear rims of the disc wheel and gear worm.

CONCLUSIONS

Correct operation of spiroid gear rims occurs when the tooth outline of the disc wheel and the worm gear are adjacent to each other and do not overlap. The result of overlapping is the phenomenon of interference. This is very inappropriate and undesirable. Therefore, during the design process, it should be checked that there is no interference of the outlines. The gear unit must be dimensionally designed in such a way that overlapping is absolutely avoided.

As a result of the measurements, the rectilinear tooth outline of the disc wheel and the worm coil was determined, the outline angle being α = 30°. The radius of the wheel tooth side line outline was determined using the spline function. The measured spline angle was (γ – helix angle of the turn line) γ = 5° 50'. The results of the measurements are included in Table 1. The advantage for this type of gearbox is the association of the tooth of the disc wheel and the scroll of the worm that allows sliding friction to be replaced by rolling friction. Thus, when the gearbox is heavily loaded, it is possible to reduce the resistance to motion. It should also be noted here that the association of gear rims with the occurrence of contour interference will lead to additional forces and deformations in the contact zone, which may consequently result in accelerated abrasive wear and material extrusion in the interference area. Such phenomena can be observed in the examined gearbox by analyzing wear marks, see Figure 2.

On the basis of the presented research, the authors confirmed the thesis promoted in the literature on the subject that one of the causes of damage to the cooperating surfaces of the worm coil and the toothed ring of the spiroid gear ring may be the interference of their contours. The interference of the contours is influenced by the geometry of the cooperating gear rings and, as research has shown, the position of the ring wheel axis in relation to the longitudinal axis of the worm. An important element of the research is the fact that the dimensions of the tested pair: the screw and the disc wheel were obtained based on measurements on a coordinate measuring machine with appropriate software. The key result of the research was the development of a method for determining and measuring the position of the contact trace of the disk wheel and the worm. For the measured values of the geometric parameters of the gear ring and the screw coil, the location of the cooperation trace was determined for which there is no interference of contours. They were described by the distance of the center of the disc wheel from the longitudinal axis of the screw (aFG-W = 43.18 mm). Moreover, the influence of shifting the longitudinal axis of the screw relative to the center of the disk wheel on the formation of contour interference was examined. The conclusions from the presented research are as follows: a displacement of Δay = 0.1 mm causes interference of the contours and damage to the ring gear. The resulting wear traces appear on the inner side of the tooth side in the same part of the gear ring as was observed on the post-wear wheel.

This article focused on the research in the area of worm gears manufactured from materials commonly used in selected means of transport. There will certainly be a need for interdisciplinary analyses in the near future, in particular those covering technological changes related to the introduction of newly implemented materials based on the idea of Industry 4.0. The authors mention that the method can be used by designers of this type of gears to determine the correct geometric tolerances for the tooth contour and line, as well as the position of the longitudinal axis of the worm relative to the center of the ring gear. In the event of contour interference, it can also be used to measure the amount of wear of the ring wheel rim and worm turns in relation to structures with nominal dimensions [27–29].

Summarizing the presented research on the essence of the use of numerical methods in the process of measuring and determining the position of the contact pattern of spiroid gear rims in modern drive systems they do not fully exhaust the essence of the issue, but constitute an original approach to the presented research problem. This topic certainly requires further analysis and research. Therefore, such analyses will be the subject of future work to determine the selected parameter for the operation process of both the gears themselves and the drive systems.

REFERENCES

1. Lewicki W. Technical and economic aspects of starting a selected power unit at low ambient temperatures. Open Engineering. 2021; 11(1): 606–616. https://doi.org/10.1515/eng-2021-0059.
2. Mork B., Porter T., Quist A., Evertz F., Gangireddy M. Hightorque Skew Axis Gearing. 2019; Available: 28.02.2024), https://spiroidgearing.com/faq/design/
3. Goldfarb V.I. Proceedings of the International Conference on Mechanical Transmissions, Science Press, China. 2008; 19–26.
4. Goldfarb V.I., Trubachev E.S., Glavatskikh D.V. Spiroid gears with small gear ratios. Some problems of design and production. In Proceedings of the International Conference on Gears, Munich, Germany, 4–6 October. 2010; 429–442.

5. Abadjiev V., Abadjieva E. Hyperboloid gear transmissions: Innovations, experimental and manufacture realization. MATEC Web Conf., 287, 04003. 2019; https://doi.org/10.1051/matecconf/201928704003.
6. Goldfarb V.I., Trubachev, E.S. Mechanisms and Machine Science. In Proceedings of the 11th World Congress in Mechanisms and Machine Science, Tianjin, China, 1–4 April. 2004; 2: 901–905.
7. Goldfarb V.I, Trubache E.S. Proceedings of the International Conference on Gears. SciencePress, China, 1. 2005; 1755–1759.
8. Paul D. Spiroid® and Helicon® Gearing. In Encyclopedia of Tribology; Wang Q.J., Chung Y.W., Eds.; Springer: Boston, MA, USA. 2013; https://doi.org/10.1007/978-0-387-92897-5_592
9. Chodoła Ł. Control of the technical condition of the gearbox on the basis of the physico-chemical properties of the working oil (in Polish). Materiały, Technologie, Konstrukcje, Eksploatacja, 7, OW-PRz, Rzeszów. 2022; 15-30.
10. Gessner A., Staniek R. Modeling and machining of the gearing of a spiroidal double stroke flat gearbox (in Polish). Modelowanie Inżynierskie, 39, Gliwice. 2010; 61–68.
11. Żabicki D. Diagnostics of gears (in Polish), Główny Mechanik. 2020; 46–47.
12. Total Polska Sp. z o.o., Industrial Lubricants - Guide, Warszawa. 2003; (Available: 28.02.2024), https://totalenergies.pl/system/files/atoms/files/rozdzial_01_spis_tresci.pdf
13. Chodoła Ł., Mazurkow A., Surowaniec M., Markowski T., Homik W. Measurement method of temperature of the face gear rim of a spiroid gear. Sensors. 2020; 22: 8860. https://doi.org/10.3390/s22228860
14. Boloş V. Achievements of Study Concerning Worm Gear, Scientific Bulletin of the “Petru Maior” University of Tîrgu Mureş: Tîrgu Mureş, Romania; 7 (XXIV). 2010; 2.
15. Abadjiev V., Abadjievaof E. One approach to the the synthesis, design and manufacture of hyperboloid gear sets with face mating gears. Part 1: Bascic Theoretical and CAD experience. J. Theor. Appl. Mech. Sofia. 2016; 46: 3–26.
16. Barmina N., Goldfar V.I., Trubachev E. Innovations in design and production of spiroid gears in the XXI century. MATEC Web Conf. 2019; 287.
17. Trubachev E.S., Kuznetsov A.S., Sannikov A.M. Advanced Gear Engineering; MMS 51; Springer: Cham, Switzerland. 2018; 45–72.
18. Litwin F.L. Development of Gear Technology and Theory of Gearing; NASA RP-1406; National Aeronautics and Space Administration, Lewis Research Center: Cleveland, OH, USA. 1997.
19. Spiradrive™ Brochure, (Available: 28.02.2024) online: http://www.davall.co.uk/davall-gears/spiradrive-and-spiradrive-ec.
20. Spiroid High Torque Gearing, (Available: 28.02.2024), https://www.spiroidgearing.com/application-industries.
21. Lockheed Martin F-35 Lightning II, (Available 28.02.2024), https://en.wikipedia.org/wiki/Lockheed_Martin_F-35_Lightning_II#/media/File:F-35A_flight_(cropped).jpg.
22. Liew, Y.W.; Matthews, O.; Dao, D.V.; Li, H. Power Transmission Mechanism and Tribological Performance of Modern Bicycle Drivetrains—A Review. Machines 2025; 13, 66. https://doi.org/10.3390/machines13010066
23. Karabacak Y. E., Özmen N. G., GümüşelL. Intelligent worm gearbox fault diagnosis under various working conditions using vibration, sound and thermal features. Applied Acoustics. 2022; 186: 108463.
24. Karabacak Y. E., Gürsel Özmen N., Gümüşel L. Worm gear condition monitoring and fault detection from thermal images via deep learning method. Eksploatacja i Niezawodność. 2020; 22(3): 544–556.
25. Hızarcı B., Ümütlü R. C., Kıral Z., Öztür H. Fault severity detection of a worm gearbox based on several feature extraction methods through a developed condition monitoring system. SN Applied Sciences. 2021; 3: 1–12.
26. Chodoła Ł., Mazurkow A., Surowaniec M., Markowski T., Homik W. Measurement method of temperature of the face gear rim of a spiroid Gear. Sensors. 2022; 22: 8860. https://doi.org/10.3390/s22228860
27. Skawinski P: An Application of Neural Network in Recognizing of the Tooth Contact of Spiral and Hypoid Bevel Gears, New World Situation: New Directions in Concurrent Engineering Proceedings of the 17th ISPE International Conference on Concurrent Engineering 123, https://doi.org/10.1007/978-0-85729-024-3, Springer London Dordrecht Heidelberg New York, Library of Congress Control Number: 2010933505, Springer-Verlag London Limited 2010. https://www.ijame-poland.com/Influence-of-the-Mesh-Geometry-Evolution-on-Gearbox-Dynamics-during-Its-Maintenance,167028,0,2.html
28. Dąbrowski Z, Dziurdź J and Klekot G, Influence of the mesh geometry evolution on gearbox dynamics during its maintenance, int. J. Of applied mechanics and engineering, 2017; 22(4), 1097–1105 https://doi.org/10.1515/ijame-2017-0071 https://www.tandfonline.com/doi/full/10.1080/20464177.2017.13648383
29. Dąbrowski Z, Deuszkiewicz P, Dziurdź J, Proposition of the vibroacoustic diagnostic methodology of testing toothed gears of marine drives, Journal of Marine Engineering & Technology, ISSN: 2046-4177 (Print) 2056-8487 (Online) Journal homepage