International Journal of Engineering & Technology, 7 (3) (2018) 1468-1473

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET
doi: 10.14419/ijet.v7i3.12258
Research paper

Automated modeling of shaft leading elements in the rear axle gear

Rami Matarneh [1] *, Svitlana Sotnik [2], Nataliya Belova [3], Vyacheslav Lyashenko [3]

[1] Department of Computer Science, Prince Sattam Bin Abdulaziz University, Al-Kharj, Saudi Arabia
[2] Department of Computer-Integrated Technologies, Automation and Mechatronics, Kharkiv National University of RadioElectronics, Kharkiv, Ukraine
[3] Department of Informatics, Kharkiv National University of RadioElectronics, Kharkiv, Ukraine
**Corresponding author E-mail: ramimatarneh@gmail.com*

Abstract

The aim of this work is to automate the design process of the "shaft leading" of the rear axle gear in order to reduce the time and effort. All the technical requirements for the design process are given and SolidWorks development medium is selected. A 3D model was developed and steel material 40X was added and its parameters were specified. A finite element analysis of the created design performed under the action of the torque transmission force.

Keywords: *Model; Shaft Leading Detail; Deformation; Solidworks.*

1. Introduction

Nowadays, the equipment for heavy duty work with the "shaft leading" of the rear axle gear is being actively developed and introduced [1-3].
There are vehicles with a power unit located in front with a front drive axle. Also vehicles with a rear drive axle and a power unit located at the rear. Front-wheel-drive vehicles suffer from poor traffic on slippery roads more than rear-wheel-drive vehicles, besides the design of the bridge with the leading and steering wheels is more complex and expensive [4], [5].
Vehicles with a rear drive axle and a power unit located at the rear also do not have a longitudinal propeller drive, which allows to lower the floor of the body as much as possible, and thereby improve the car stability [6-9].
In addition, when the power unit is placed at the rear, the exhaust gases, heat and noise stay away and also there is an opportunity to give the body a shape that creates more comfort for the passengers and better streamlining [1], [9-11].
When considering the above details, a more robust bridge design is used, for example KrAZ Kuga vehicles [1].
Regarding the shaft leading of KrAZ, both the middle and rear shafts are leading (Fig. 1). Shafts are identical in design and differ only in the displacement of the main gears relative to the car's axis. The main transmission of the rear (middle) shaft is a central double shaft, consisting of a bevel gears pair with spiral teeth and a pair of cylindrical gears with straight teeth. The inter-wheel differential is conical, with four satellites. Transmission ratio of central double final drive 8.21 [12].
The semi-axles of the rear and middle shafts are unloaded. The casing of the semi-axes is pressed into the crankcase of bridges. The wheel hub is mounted on two tapered bearings. Bearings are supported on the half-axle housing and tightened with a nut, the pin of which enters the hole of the lock washer, and the projection of the washer – into the groove of the half-axle housing; the nut and the washer are locked by a lock nut [13-16].
The inner rings of bearings have a sliding fit; the outer rings are pressed into the hub nests. Lubrication in the hub is ensured from the inside by the oil seal and by the flange of the axle shaft on the outside [17], [18].

2. Materials and methods

2.1. Related work

Many authors have studied the design methods of the rear axle gearbox for road conditions, structural analysis and damage assessment. The use of neural networks to predict damage to the rear axle gear is considered in [19]. In this paper, a new method, consisting of data pretreatment (recursive processing) and artificial neural networks, was proposed to accurately predict the damage of the rear axle. Simulated experimental results showed high prediction accuracy. This study provides a new approach for gear remaining useful life prediction.
In [20] design for driving axle with double-gear wheel reductor based on the CATIA is described. This paper designs a new driving axle with double-gear wheel reductor which is used in the Pavement Accelerated Loading Experimental Facility. Three-dimensional assembly model is established based on the CATIA and strength calculation and finite element simulation analysis to the rear axle housing and the axle shaft are carried on based on finite element analysis software. The correlation data and strength analysis of the driving axle for the Pavement Accelerated Loading Experimental Facility are obtained.
Optimal scheduling of the gear shift schedule for automated vehicles: an analytical approach based on hybrid systems was investigated in [21]. In this paper is presented a systematic design framework for a gear shift schedule using hybrid system. The longitudinal

Copyright © 2018 Rami Matarneh et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

motion of the vehicle is regulated by a PI controller. The longitudinal dynamics of the vehicle with a gearbox is a modeled as a hybrid system, and an optimization-based gear. This guarantees that the propulsion requirements are carried while minimizing fuel consumption. The resulting dynamics is proven to be stable in the presence of constraints.

In [22] vibration performance of both powertrains are compared on a test vehicle in experimental and operational conditions. Moreover, the modal coupling between the torsional, longitudinal and vertical motions are analyzed and the slip-ratio dependency assessed. The deterioration in dynamic behavior using IWMs is demonstrated and a precise parametric model identified for vibration suppression control of geared In-Wheel-Motor drivetrains.

In [23] the 3D entity modeling of hypoid gears are established by using UG is described. In this paper, the center distance of driving gear is assembled according to the normal, left and right, the dynamic model of hypoid gear is established by ADAMS, then adding constraints and increase the driving force on it, using the way of virtual prototyping technology combined with the actual vibration testing method to study its effect to micro-vehicle rear axle vibration. Finally, through analysis of the results of dynamic simulation and comparative analysis between actual test results and the results of the dynamic simulation analysis shows that the assembly errors affect the vibration of micro-vehicle main reducer and a theoretical basis is provided.

In [24] experimental investigation of vibration and transmitted power for vehicle rear axle noise research. It is shown in the study that the increase in transmitted energy does not necessarily lead to the radiation of the vehicle rear axle enlarged. Under light load, vibration and noise, along with an increase of transmitted power of rear axle; while continuing to load the gear pair of the final drive. During the whole process of loading, fluctuating of noise is caused by vibration fluctuations.

2.2. Analysis the "shaft leading" detail of the rear axle gear structure

Although the main details of the rear axle column gain significant turnover in production, but still being processed on ordinary machines. An example of the rear axle (rear gear) assembly is shown in Fig. 1 [18].

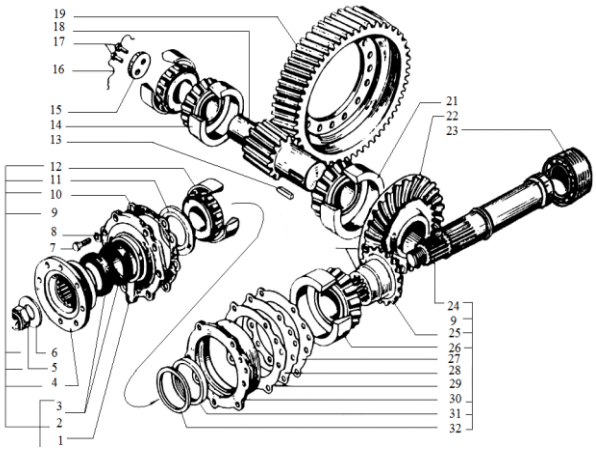


Fig. 1: Assembling the Rear Axle (Rear-Drive Gear).

In Fig. 1 elements: 1 – a cover crankcase bearings, 2 – a cover crankcase bearings in the assembly, 3 – cuff 2.1-75 x 102-4, 4 – flange of the propeller shaft with a display, 5 – special nut, 6 – the disk spring, 7 – bolt M14 x 1.5 x 50, 8 – the washer 14,2, 9 – pinion cone drive in the assembly, 10 – sealing gasket, 11 – support washer, 12 – the roller bearing, 13 – key 2-18 x 11 x 45, 14 – the roller bearing, 15 – support washer, 16 – cotter pin 1.6 x 175, 17 – a bolt M16 x 1,5 x 30, 18 – a pinion leading cylindrical, 19 – a pinion leading cylindrical, 20 – the driving and driven gear (set), 21 – the roller bearing, 22 – the leading conical lead, 23 – the ball bearing, 24 – a shaft of a leading gear wheel, 25 – pinion driving gear, conical, 26 – the roller bearing, 27 – a sealing gasket, 28 – adjusting gasket, 29 – adjusting gasket, 30 – crankcase bearings, 31 – Expansion ring, 32 – washer regulating.

To facilitate the production of the "shaft leading" we need to automate the build process by creating new prototypes of cars and repairing damaged equipment.

Having examined the main constituent elements presented in fig. 1, it is necessary to analyze the surface of the detail, which is determined by the shape and roughness (Table 1, Fig. 2) [2], [18].

Table 1: Surface Analysis

№	Name of the surface	Surface roughness Ra	Finish accuracy	Surface shape	Required machining			
					Previous	The final	Finishing Previous	The final
1, 11	The end	Ra 12,5	12	cylindrical	-	-	-	-
2	Thread	Ra 12,5	12	cylindrical	-	-	-	-
3, 5, 7, 9	Chamfer	Ra 12,5	12	cylindrical	+	+	+	+
4, 6	Key grooves	Ra 0,8	12	cylindrical	+	+	-	-
					+	+	+	-

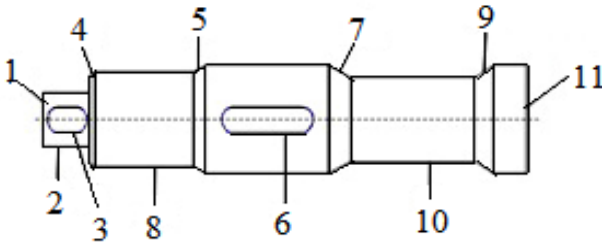


Fig. 2: Surface Analysis.

The detail of the shaft leading: axes, shafts, shaft – gears, plungers, rods, crankshafts and camshafts, rings, spindles, mandrels, slats toothed crowns, bolts, semiaxes, bushings and other details of increased strength, must be made from the alloy steel 40X [14].

The chemical composition of the steel is shown in Table 2.

Table 2: Chemical Composition, %

C		0.36-0.44
Si		0.17-0.37
Mn		0.5-0.8
Cr		0.8-1.1
N		0.30
Ci		0.30
S	not more	0.035
P		0.035

The detail "shaft leading" detail of the rear axle gear is made of constructional carbon steel 40X and the whole area is to be heat treated.

The detail is a stepped shaft and the supply and withdrawal of the cutting tools during machining of the details on both sides does not interfere with anything. This circumstance allows applying cutters through passage when machining which in turn gives the chance to manufacture many instrumental processing on turning the multiple-spindle machines.

The list of technical requirements is indicated in Tab. 3 [18].

Table 3: Technical requirements

Technical requirements	Purpose of the technical requirement	Method of technical requirements
Heat treatment – coils HRC 36…45.5	Ensuring the necessary mechanical properties of the grooves for normal operation	Hardening of grooves

The radial runout of the groove surfaces relative to the bearing surfaces is not more than 0.01 mm	Ensuring high accuracy of groove connection	Finishing
Limit deviations of dimensions are not indicated: holes H12, shafts h12, other IT12 / 2	Reducing the laboriousness of manufacturing details due to low dimensional accuracy, facilitating the drawings reading	Performing the appropriate dimensions with the specified accuracy during the detail machining

The splined clutch surface is located at the beginning of the detail and has two diameters, which are relatively closer to the middle relative to each other. This makes it possible to use the splines cutting on gear-milling machines in the detail production [20].
Analyzing slots characteristics, we come to a conclusion that in this case there is no possibility to use of a high-performance slots shaping method by means of deformation in a cold state.

2.3. Calculation and selection of common interpretational allowances and tolerances for the "shaft leading"

Calculation of general and inter-operational allowances and tolerances is carried out in accordance with the standards that apply to steel stamped castings [25] not exceeding 250 kg and (or) linear dimensions not exceeding 2500 mm, manufactured by hot forging. The standard sets the size tolerance, shape deviation, allowances, forging tolerances, and the smallest curvature radii of the outer corners.
To make the "shaft leading" of the rear axle gear, it is necessary to stamping equipment – a horizontal forging machine. Number of transitions – 6. Heating of blanks – induction.

For external surfaces, intermediate allowances Z_i are defined as [25]:

$$Z_i = a_{i-1} - a_i \quad (1)$$

For internal surfaces

$$Z_i = a_i - a_{i-1} \quad (2)$$

Where a_{i-1} is the size obtained at the previous transition, a_i is the size obtained at the given transition.
The total allowance is determined by the difference in the sizes of the raw (unprocessed) workpiece and the finished detail. For external surfaces [25]:

$$Z_{tot} = a_{bl} - a_{fd} \quad (3)$$

For internal surfaces:

$$Z_{tot} = a_{fd} - a_{bl} \quad (4)$$

Where a_{bl} – blank size, a_{fd} – size of the finished detail.

The total machining allowance is equal to the sum of the operating allowances during machining from the initial blank to the finished detail [25]:

$$Z_{tot} = \sum_{k=1}^{m} Z_{oa.k} = \sum_{i=1}^{n} Z_i \quad (5)$$

Where $Z_{oa.k}$ – operational allowance is removed from the surface during the execution of the technological operation, k is the ordinal number of the operation, m – number of operations for processing a given surface, n – number of transitions.

There are symmetrical and asymmetrical allowances for processing. Symmetrical allowances take place when processing external and internal cylindrical surfaces, as well as parallel processing of the opposite planes. For external surfaces, they are defined as [25]:

$$2Z_i = d_{i-1} - d_i \text{ and } 2Z_i = l_{i-1} - l_i \quad (6)$$

For internal surfaces as

$$2Z_i = d_i - d_{i-1} \text{ and } 2Z_i = l_i - l_{i-1} \quad (7)$$

Where $2Z_i$ – allowance for diameter or allowance on both sides for parallel processing of opposing flat surfaces, d_{i-1} и d_i – diameters of the surfaces, respectively, on the preceding and performed transitions, l_{i-1} и l_i – sizes between flat surfaces accordingly on the previous and executed transitions.
In the case of asymmetric allowances, the operating allowances are determined when processing the external surfaces as [25]:

$$Z_{oa.1} = L_b - L_1 \text{ and } Z_{oa.2} = L_1 - L_{det} \quad (8)$$

Where $Z_{oa.1}$ и $Z_{oa.2}$ – operational allowances for the first and second operations, L_b – blank size, L_1 – operating size, L_{det} – size of the finished part.
The intermediate asymmetric allowances are defined similarly.

3. Results and discussion

3.1. Selecting the modeling medium for the detail

Currently, the world's industry uses so many different types of Computer-Aided Design (CAD) systems, that there is no enterprise, plant or design office that does not use CAD [6], [7], [26].
Such wide distribution became the prerequisite for the creation of software CAD systems, which include the capabilities of several types at once.
Most often in such software complexes there are various systems of volumetric modeling and rapid tests. Many companies that provide the global industry are involved in the development of these software systems, among which Dassault can be distinguished with the SolidWorks software complex.
SolidWorks – a system of computer-aided design, engineering analysis and products production preparation of any complexity and purpose [6], [26].
Traditionally CAD systems are focused on creation of products geometrical models from geometrical primitives, where the most of time working with such systems is spent on selecting the necessary elements and the optimal sequence for their creation. Further express software products are used to implement engineering or technological analysis, the results of which are corrected by the model, and sometimes it is very important [26].
The SolidWorks software package is built on the basis of SolidWorks Intelligent Feature Technology (SWIFT), which is a complex of expert firmware systems that allows to solve problems related to project optimization at early stages of design with a high degree of automation, which includes [26]:

- Technical analysis (durability, aerodynamics, kinematics and dynamics of mechanisms).
- Analysis of manufacturability.
- Comprehensive verification of compliance of an electronic document with selected standards.
- Dimensional chains analysis.

SolidWorks has a quick action when working with complex assemblies where new functionality can be found to analyze the assembly's operational capabilities, as well as ease of use with drawings

and graphics. Based on these features to run the model and the research model, SolidWorks has been selected.

3.2. Development the 3D models for "shaft leading" main detail elements of the rear axle gear

Let's consider using SolidWorks capabilities by creating a detailed shaft.
First you need to select the type of document in which the 3D model will be created. The shaft body is one monolithic part, so choose the type "Three-dimensional representation of one element".
Using the tools of the SolidWorks program, we get a sketch as shoen in Fig. 3.

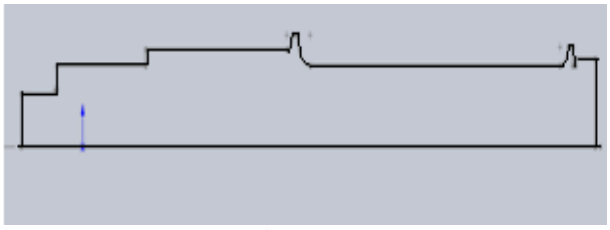


Fig. 3: Sketch for Obtaining 3D Model.

Using the "Returned lag" tool on the "Elements" tab, we get a rotational body (Fig. 4). Note that, we must specify that the object is rotational and its axis of rotation

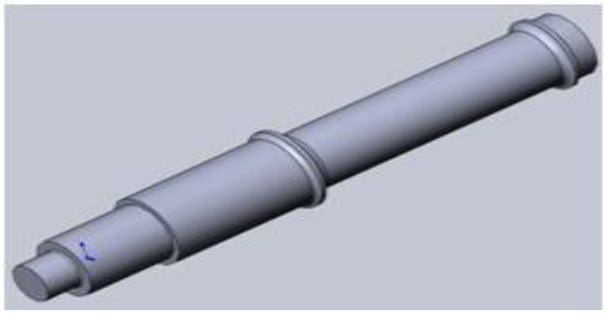
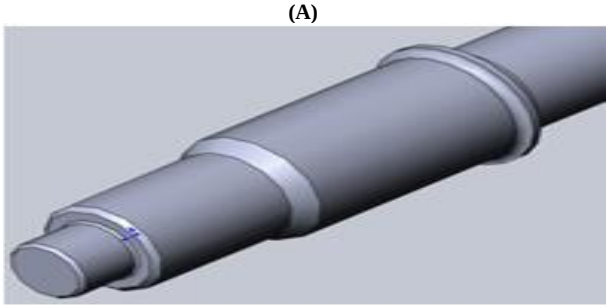


Fig. 4: The Resulting "Rotation Body".

Applying the "Chamfer" tool on some of the surfaces shown in Fig. 5, a, b, we obtain chamfers of the required length.

(A)



(B)

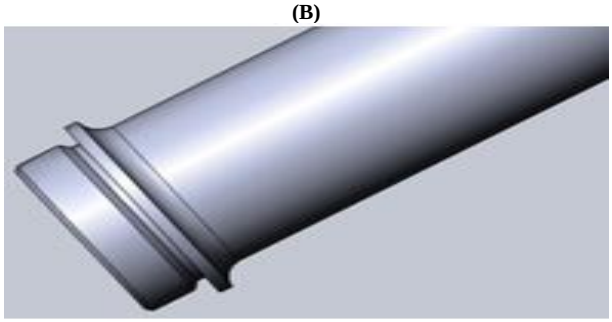


Fig. 5: Creating Chamfers

In the conducted researches it was determined that the optimum number of slots for the shaft is 10 (Fig. 6).

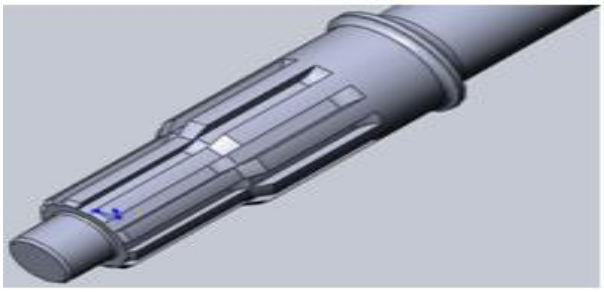


Fig. 6: Circular Array of "Cut-Outs".

To carry out the finite element analysis of the connecting part deformation, it is necessary to select a shaft part on which the force of the transmitted torque will be calculated. The shaft element for analysis is shown in Fig. 7.

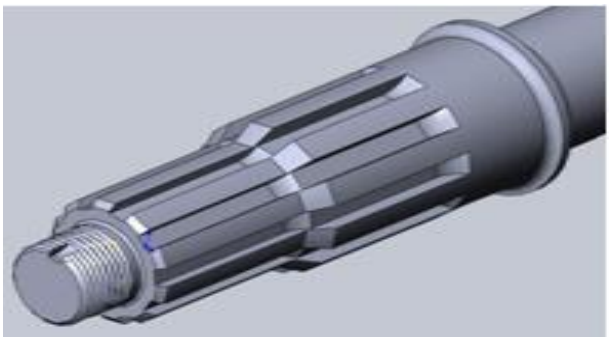


Fig. 7: Shaft Member for Analysis.

3.3. Analysis the "shaft leading" detail slots of the rear axle gear deformation

For model of the slots deformation under the action of torque, the SolidWorks Simulation module is used. This module allows us to: calculate the design for strength, stability, mimic the fall conditions, perform thermal calculations, optimize the model parameters and much more.
To get started, select the "New Research" item in the "Simulation" tab. After that, it is necessary to indicate the specific conditions under which the test will be performed:

- Material of details,
- Ways of fastening,
- Forces and directions of their application,
- Connections types and pattern arrangement.

In the SolidWorks reference material library, there is no information about the 40X steel, so you need to create new material.
Materials in the library cannot be edited immediately, so we must first copy any material, and then replace the required characteristics (Fig. 8).
After choosing the material, the force was 1000 N and the plane on the slots to which it was applied, then for carrying out the analysis by means of a finite element method the grid was created.
The density of the grid affects the accuracy of the calculation, but a high density grid can negatively affect performance, so the grid was created automatically to achieve the optimum size of the elements.

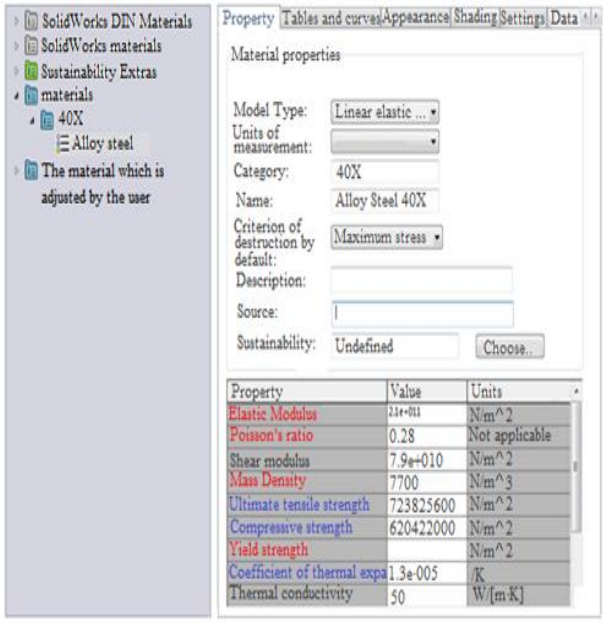


Fig. 8: Setting Parameters of Steel 40X.

A "shaft leading" detail of the rear axle gear with all the specified parameters is shown in Fig. 9.

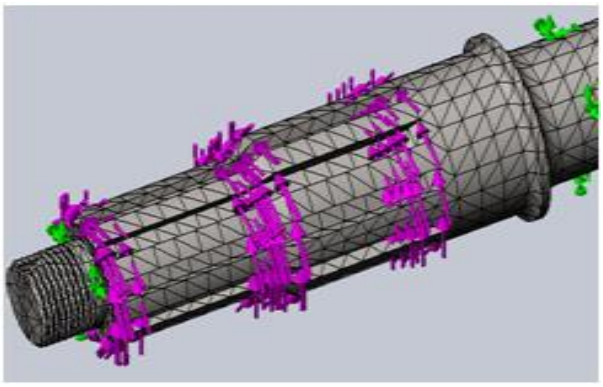


Fig. 9: Modeling Slot Deformations.

After completing all the necessary steps, the "Start" operation is selected.
As a result, in the SolidWorks simulation unit, a separation analysis was performed as a result of the calculated rotational force (Fig. 10).
However, in a real situation, this model can have loaded by other loads, which means that, the slots can be subjected to additional loads and can experience large deformations.

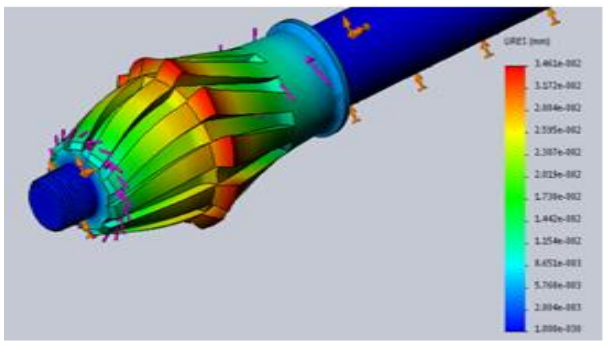


Fig. 10: Diagram of Rotation Force Distribution.

To predict the behavior of the slots under loads other than those calculated, an additional study was conducted in SolidWorks Simulation.
With the help of this module, deformation values were calculated for forces from 0.5 R to 1.5 R.

The results of the analysis are presented in Table 3.

Table 3: The Values of the Slots Deflection with Different Rotation Forces

Cutting force R, H	The deflection amount δ, mm
523	0.0257
704	0.0346
876	0.04305
1000	0.04915
1247	0.06129
1457	0.0716
1648	0.081

Based on the obtained data, the graph shown in Fig. 11 is plotted.

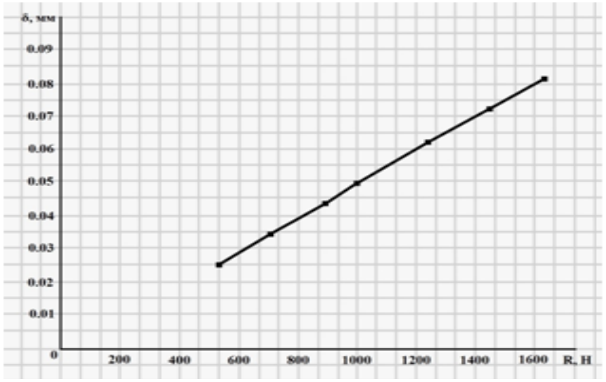


Fig. 11: The Size of A Slots Deflection Depending on Rotation Force.

From the data obtained, it can be seen that the deflection of the slots depends directly on the value of the rotational force R.
With increasing force, the deflection value also increases.
Thus, thanks to the built-in schedule it is determined that a "shaft leading" detail of the rear axle gear can be used economically, without using the maximum speed of rotation only in rare cases.

4. Conclusion

Modeling of the "shaft leading" detail of the rear axle gear was carried out. The developed 3D model can be used to automate the design process of such object type in order to reduce the time and effort.
The analysis of the "shaft leading" detail of the rear axle gear was carried out, as a result of which the basic accuracy requirements for detailed development were determined and carried out.
The computer-aided engineering system (SolidWorks) has been selected as it has a convenient interface and has fast enough procedures with sufficient and quick action.
The final analysis of the developed shaft, which was performed by SolidWorks simulation, clearly shows that the shaft meets requirements of accuracy in the field of its application.

References

[1] X. Zhang, N. Wang, Y. Huang, (Eds.). Mechanism and Machine Science. Springer, 2016.
[2] A. Emadi (Ed.). Handbook of automotive power electronics and motor drives. CRC press, 2017.
[3] R. N. Jazar. Vehicle dynamics: theory and application. Springer, 2017.
[4] N. Guo, W. Shi, G. Wu, W. Liu, C. Hao, (2011). Experimental investigation of vibration and transmitted power for vehicle rear axle noise research. In Electronic and Mechanical Engineering and Information Technology (EMEIT), IEEE, 4, 2106-2108. https://doi.org/10.1109/EMEIT.2011.6023516.
[5] B. Liu, M. Saif, H. Fan, (2016). Adaptive fault tolerant control of a half-car active suspension systems subject to random actuator failures. IEEE/ASME Transactions on Mechatronics, 21(6), 2847-2857. https://doi.org/10.1109/TMECH.2016.2587159.
[6] S. V. Sotnik, (2012). Analiz protsesu stvorennya 3D modeli detali standartnimi Instrumentami Solid Works, Tehnologiya priladobuduvannya, 2, 21-28.

[7] S. V. Sotnik, (2013). Vibir materialu pri proektuvanni littevoyi formi. Visnik NTU «HPI», 56, 31–36.

[8] A. V. Khanapuri, A. Shastri, G. D'souza, S. D'souza, (2015). On road: A car assistant application. In *Technologies for Sustainable Development (ICTSD)*, IEEE. https://doi.org/10.1109/ICTSD.2015.7095903.

[9] M. Okrouhly, J. Novak, (2013). Centralized vehicle diagnostics. In Intelligent Data Acquisition and Advanced Computing Systems (IDAACS), IEEE.

[10] Pospíšil, T. (2013). Validation of centralized diagnostics concept. International Conference on Applied Electronics, 1–4.

[11] Y. Xiao. Structural Design and Modeling Analysis of Carbon-free Car. Atlantis-press, 2015. https://doi.org/10.2991/asei-15.2015.333.

[12] Y. Jie, Z. Jingdong, (2017). A modal analysis for vehicle's crankshaft. 3rd Information Technology and Mechatronics Engineering Conference (ITOEC), 300–303. https://doi.org/10.1109/ITOEC.2017.8122303.

[13] M. A. Razzhivina, B. A. Yakimovich, A. I. Korshunov, (2015). Application of information technologies and principles of lean production for efficiency improvement of machine building enterprises. Pollack Periodica, 10(2), 17-24. https://doi.org/10.1556/606.2015.10.2.2.

[14] M. Kiani, I. Gandikota, M. Rais-Rohani, K. Motoyama, (2014). Design of lightweight magnesium car body structure under crash and vibration constraints. Journal of Magnesium and Alloys, 2(2), 99-108. https://doi.org/10.1016/j.jma.2014.05.005.

[15] A. Nolan, (2010). A dynamic analysis of household car ownership. Transportation research part A: policy and practice, 44(6), 446-455. https://doi.org/10.1016/j.tra.2010.03.018.

[16] B. Peng, R. Zhu, M. Li, Z. Tang, Bending Vibration Suppression of a Flexible Multispan Shaft Using Smart Spring Support. Shock and Vibration, 2017. https://doi.org/10.1155/2017/7859164.

[17] A. Tenconi, S. Vaschetto, A. Vigliani, (2014). Electrical machines for high-speed applications: Design considerations and tradeoffs. IEEE Transactions on Industrial Electronics, 61(6), 3022-3029. https://doi.org/10.1109/TIE.2013.2276769.

[18] R. C. Dorf. Systems, controls, embedded systems, energy, and machines. CRC press, 2017.

[19] Y. Shao, X. Li, C. K. Mechefske, M. J. Zuo, Use of neural networks to predict rear axle gear damage. In Reliability, Maintainability and Safety, 2009. ICRMS 2009, IEEE. https://doi.org/10.1109/ICRMS.2009.5269981.

[20] Q. Jia, Ch. Zhou, H. Li. (2011). Design for Driving Axle with Double-Gear Wheel Reductor Based on the CATIA. 3rd International Workshop on Intelligent Systems and Applications, 347–350. https://doi.org/10.1109/ISA.2011.5873325.

[21] C. R. He, W. B. Qin, N. Ozay, G. Orosz, (2017). Optimal Gear Shift Schedule Design for Automated Vehicles: Hybrid System Based Analytical Approach. IEEE Transactions on Control Systems Technology. https://doi.org/10.1109/TCST.2017.2747506.

[22] T. Beauduin, S. Yamada, H. Fujimoto, T. Kanou, E. Katsuyama, (2017). Control-oriented modelling and experimental modal analysis of electric vehicles with geared In-Wheel motors. In Advanced Intelligent Mechatronics (AIM), IEEE.

[23] S. K. Kusekar, et. al. (2015). Design and Development of Electrical Car. International Journal of Emerging Technology and Advanced Engineering, 5, 4, 239–251.

[24] S. J. Han, X. Li, K. Liu, (2011). Based on ADAMS of the analysis of vibration and noise testing of micro-vehicle rear axle. In Electric Information and Control Engineering (ICEICE), IEEE.

[25] I. O. Sokorov, D. V. Kuis, P. V. Rudak, Technology of mechanical engineering. Moscow, 2013.

[26] G. Verma, M. Weber. SolidWorks Simulation 2017. Black Book, 2017.