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THE FATIGUE RESISTANCE ANALYSIS OF STEEL DOUBLE HELICAL GEAR WHEELS

Abstract: *The computer experiment to determine the stress and strain state and fatigue of the pinion and gear wheel material after 250,000 loading cycles was performed on the example of the double helical gear train.*
Key words: *the double helical gear wheel, material fatigue, the stress and strain state, engagement.*
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Introduction

The double helical gear train is the type of the helical gear train [1-9]. The pinion and the gear wheel in this gear train consist of equal-length sections with right-hand and left-hand teeth. The incision between the teeth sections is provided for the cutting tool outlet in the manufacture of the gear train parts. The double helical gear train is mainly used in heavy-duty machines assemblies to ensure the reliable operation due to the lack of axial load on the bearing due to the complexity of manufacturing the pinion and the gear wheel [10].

Features of loading the teeth of the gear train parts allow us to identify the trend of material fatigue for the certain number of loading cycles. Material of the pinion and gear wheel teeth is destructed over time from accumulated internal stresses. The material quality of the parts plays an important role in the operation of the double helical gear train. The dimensions inaccuracy of the parts, the unbalanced chemical composition and violations of the technological process of heat treatment of material lead to uneven stress of the teeth of the pinion or the gear wheel. The calculation of fatigue resistance of material that has ideal physical, mechanical, operational, and other properties will determine the life for the uniformly loaded double helical gear train. The research results will be the basis for predicting the destruction of the double helical gear wheels in real production conditions.

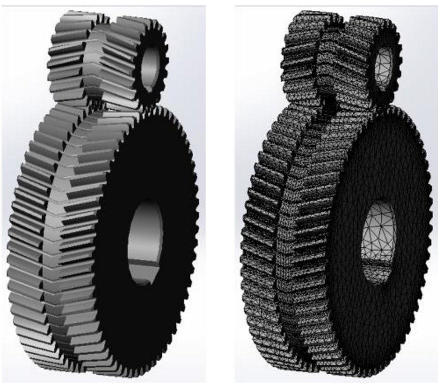
Materials and methods

Finite element modeling, which includes the calculations of the stress and strain state and fatigue of the parts material of the double helical gear train, was implemented in the "SolidWorks" program. The geometry of the pinion and the gear wheel was calculated in the "Gear" module of the "Kompas-3D" program. The geometry parameters of the driving and driven members of the double helical gear train are presented in the table 1.

Table 1. The geometric parameters of the pinion and the gear wheel.

Parameter	***Pinion***	***Gear wheel***
Module	3	
Number of teeth	20	60
Helix angle of teeth	16°15'37"	
Helix hand of tooth	double helical from left to right	double helical from right to left
Basic rack tooth profile	according to GOST 13755-2015	
Addendum modification coefficient	0	
Accuracy grade according to GOST 1643-81	8-B	
Base tangent length	$23.085^{-0.1}_{-0.2}$	$69.255^{-0.14}_{-0.28}$
Tolerance of base tangent length variation	0.028	0.05
Variation tolerance of measuring center distance per wheel revolution	0.063	0.09
Variation tolerance of measuring center distance on one tooth	0.028	0.032
Gear ring run-out tolerance	0.045	0.063
Tolerance for error of tooth profile	0.014	0.018
Error of base pitch	±0.02	±0.022
Reference diameter	62.5	187.5
Longitudinal form tolerance	0.025	
Axial run-out tolerance of locating face	0.013	0.038

The pinion and gear wheel models were built with the incision in the middle. They were given the properties of heat-treated alloy steel. The shafts and keys models were not built to reduce the calculation time. Fixing the gear wheels and setting the torque of 200 N×m were carried out by the mounting holes of the models. The friction coefficient on the contact surfaces was accepted 0.1. The general view of the three-dimensional solid-state models of the pinion and the gear wheel in engagement is presented in the Fig. 1, *A*. Dividing the double helical gear train model into the finite elements is presented in the Fig. 1, *B*.



A *B*

Figure 1 – The three-dimensional solid-state model of the double helical gear train (*A*) and its dividing into the finite elements (*B*).

The models were divided into 430140 elements with the specified maximum and minimum elements sizes of 8.58843 mm and 1.71769 mm, respectively.

The first part of the experiment was to simulate the contact process along the entire length of the tooth flank of the pinion and the gear wheel to determine the stress and strain state of material. The static calculation was performed using the FFEPlus solver. The resulting reaction force of 4724.17 N (*X*-axis – -3121.09 N, *Y*-axis – 2091.99 N and *Z*-axis – -2863.59 N) occurs on the contact surfaces of the pinion and the gear wheel under the specified operating conditions of the double helical gear train.

The second part of the experiment was to simulate the fatigue process of the pinion and gear wheel material after 250,000 loading cycles with the constant amplitude. The *S-N* curve of material must be taken to calculate the fatigue damage. It is the diagram that defines the values of alternating stress relative to the cycles number required to cause fracture at the given stress coefficient. The *S-N* curve of material of the pinion and the gear wheel is presented in the Fig.2.

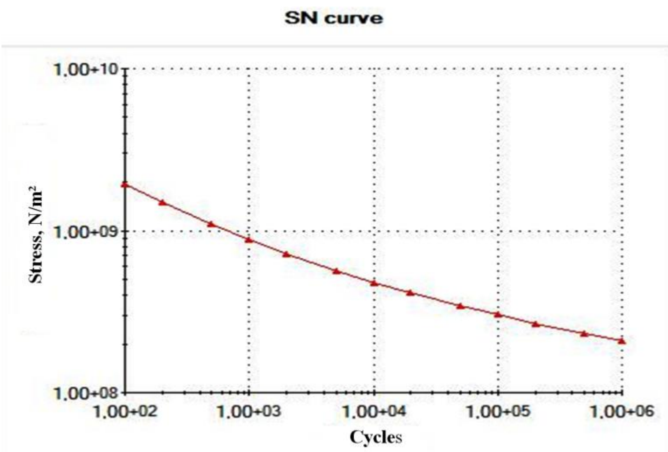
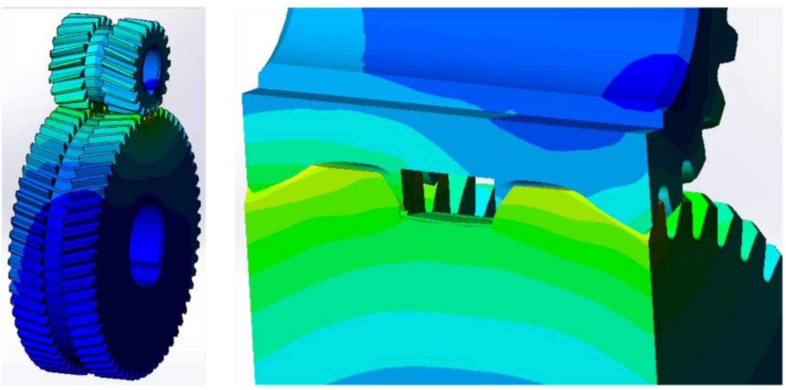


Figure 2 – The *S-N* curve of material of the double helical gear train parts.

The local stress concentration coefficient of material was accepted 1. The strength criterion for alloy steel was accepted maximum von Mises stress. The load on the pinion and gear wheel teeth was counted from zero. The calculated average stress was corrected according to the Gerber method.

Results and discussion

The calculation results were presented in the form of contours and vectors plotted over the entire volume of material of the pinion and gear wheel models. The contours and the vectors had the color scheme (red is the maximum value, blue is the minimum value) to estimate the value of each calculated parameter. The analysis of the distribution of stresses, deformations and fatigue of material was performed after the cross-section of the double helical gear train parts at the engagement point. The contours of the material displacement (deformation) of the double helical gear train parts are presented in the Fig. 3. The contact pressure vectors on the teeth flanks of the pinion and the gear wheel are presented in the Fig. 4. The fatigue contours of material of the double helical gear train parts are presented in the Fig. 5.



A *B*

Figure 3 – The contours of the material displacement (deformation) of the pinion and the gear wheel: *A* – the general view of the gear train; *B* – the cross-section at the engagement point.

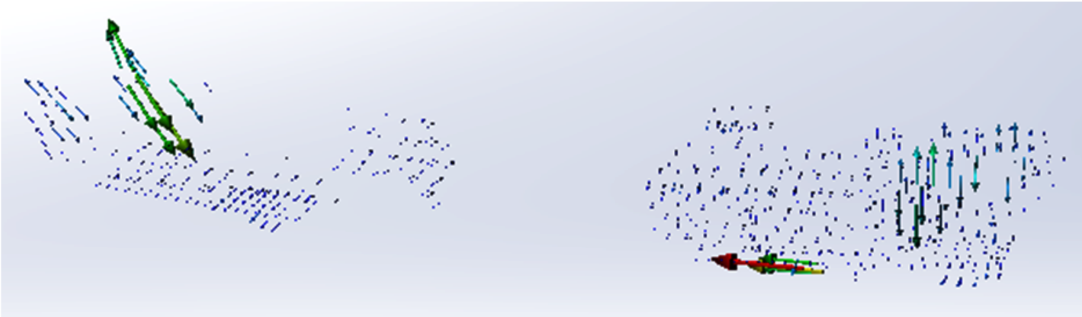
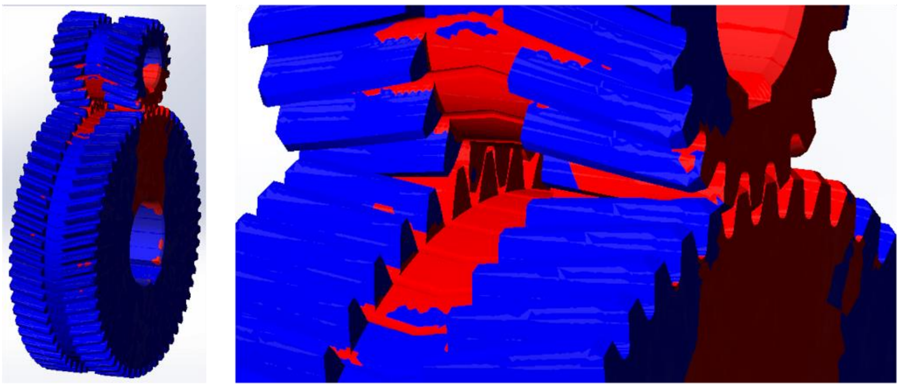
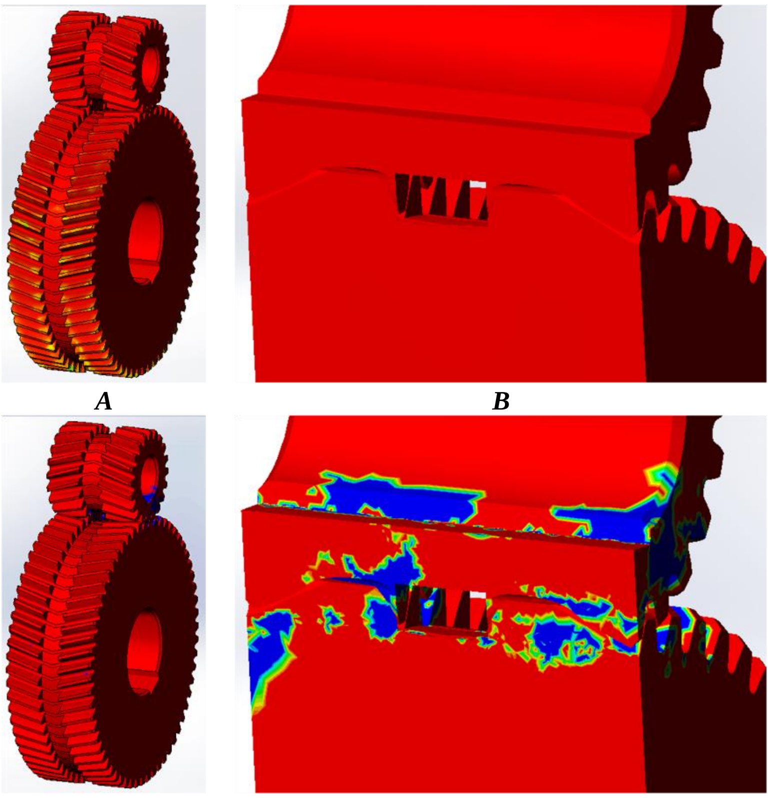


Figure 4 – The contact pressure vectors on the teeth flanks of the pinion and the gear wheel.



A ***B***

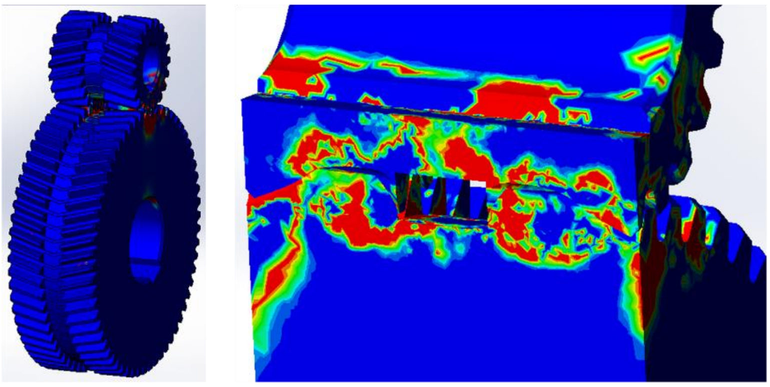
Figure 5 – The fatigue contours of the pinion and gear wheel material: *A* – the general view of the gear train; *B* – the magnification of the engagement point.



A ***B***

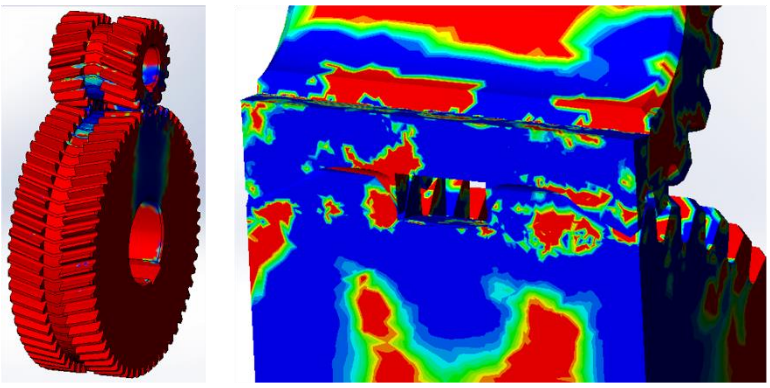
C ***D***

Figure 6 – The contours of the safety factor of the pinion and gear wheel material: *A* and *C* – the general view of the gear train after the preliminary and final calculations, respectively; *B* and *D* – the cross-section at the engagement point after the preliminary and final calculations, respectively.



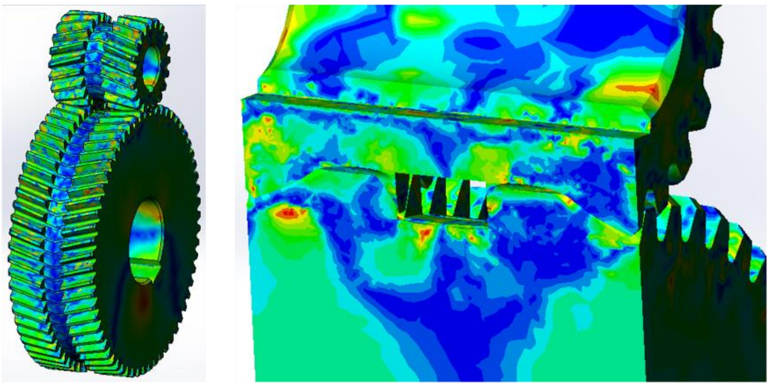
A ***B***

Figure 7 – The damage contours of the pinion and gear wheel material: *A* – the general view of the gear train; *B* – the cross-section at the engagement point.



A ***B***

Figure 8 – The life contours of the pinion and the gear wheel: *A* – the general view of the gear train; *B* – the cross-section at the engagement point.



A ***B***

Figure 9 – The biaxiality contours of the pinion and gear wheel material: *A* – the general view of the gear train; *B* – the cross-section at the engagement point.

The contours of the safety factor of the pinion and gear wheel material after the preliminary and final calculations are presented in the Fig. 6. The damage contours of material of the double helical gear train parts are presented in the Fig. 7. The life contours of the pinion and the gear wheel after 250,000 loading cycles are presented in the Fig. 8. The biaxiality contours of the pinion and gear wheel material are presented in the Fig. 9.

The teeth of the pinion and the gear wheel deform (the displacement contours) equally on the left and right sections during contact. This indicates the correct engagement of the pinion and gear wheel models. Maximum deformation of the wheel tooth occurs in the addendum, minimum deformation occurs in the dedendum.

The contact pressure vectors form the tooth contact pattern of the pinion and the gear wheel on the two sections. The maximum contact forces occur in the middle of each of the sections.

The cracks formation in material of the wheels rims (the parts surfaces were accepted sanded) is predicted after 250,000 loading cycles. Also, material of the incisions of the double helical gear train parts is subjected to variable residual stresses.

The safety factor gives an idea of the loaded state of the parts material of the double helical gear train in the selected operating modes. The preliminary and final calculations of the safety factors were performed for the pinion and the gear wheel. The safety factor is 1.5-2.2 in the engagement zone of the teeth. The preliminary calculation does not give the complete estimate of the distribution of the safety factor of material in the inner layers. The final calculation gives the best result, allowing for the complete analysis of material loading.

The accumulation sequence of internal stresses of the pinion and gear wheel material can be determined by the damage and life contours. The expected destruction of material, first of all, occurs in the parts volumes indicated in blue (corresponds to 100 loading cycles based on the life contours). The destruction of the material volumes indicated in red can occur after 1,000,000 loading cycles.

The biaxiality indicator determines the local stress concentration coefficient of material, which is equal to the ratio of minimum stress to maximum stress. The blue color of the biaxiality contours, equal to -1, indicates the simple shear of the parts material. The red color of the biaxiality contours, which is almost 1, indicates the simple biaxial state of the parts material.

Conclusion

Variable deformation of the teeth is observed during symmetric loading the sanded pinion and gear wheel. The nonlinear calculation of material fatigue of the parts showed that not only the teeth can be subjected to the destruction, but also the volume of the pinion and the gear wheel located in the engagement zone. The damage contours on the pinion and gear wheel models indicate the gradual chipping the teeth, but after the considered 250,000 loading cycles, the probability of the material destruction is no more than 1%. This indicates the sufficient safety factor of the parts material of the double helical gear train.

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