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TOOTH CONTACT ANALYSIS OF HELICAL GEARS HAVING MODIFIED STRAIGHT TEETH BY CHANGING OF THE NUMBER OF TEETH ON THE PINION

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Abstract: The helical gears are widely used in different engineering applications especially in case of vehicles on the gear boxes. The aim of this research is the analysis of the effect of number of teeth on the pinion beside of the constancy number of teeth on the driven gear. Five types of helical gears have to be designed for the comparative analysis. Own-designed designing software are necessary for the facilitation of the designing and modelling process. During this research the normal stresses and normal deformations will be analysed into different directions by TCA method. After the analysis the functions of the mechanical properties and the number of teeth will be determined.

KEYWORDS: helical gear, TCA, CAD, number of teeth, normal

1 Introduction

Nowadays, the leader industry is the vehicle industry because many types of cars are needed for the roads. The manufacturers are always developing their products because of the good quality, the profit and the market’s requirements. One of the most important appliance of the vehicles is the gear box with which different gears could be set. These gear boxes are contained tooth gears if we are speaking about a gradual gear box. In this case only discreet gear ratios could be set. The applied gears are often the helical gears (Figure 1).

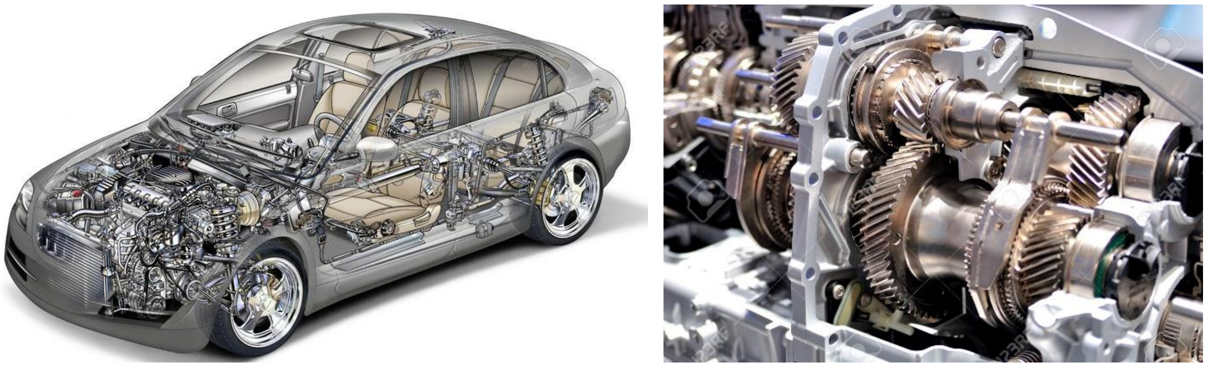

Fig. 1. Cross section of a car gear box [17, 18]

The gear conjunction is continuous. The pressure force affects are worked into three directions (radial, tangential and axial) on the same tooth (Figure 2). Consequently, the helical gear is run more silently. There are many types of helical gears. In this research we design helical gear having modified straight teeth.

The main properties of the helical gear pairs having modified straight teeth are the tooth connection is happened on the standard centre distance (a_0) and the teeth of the gears are designed by profile shift [4 - 8]. However, the gear wheels contact along the pitch circle, the

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addition of the profile shift coefficient is $x_1 + x_2 = 0$, that is $x_1 = -x_2$. It means, if we modify this coefficient on one of the gear wheels then with the same value but with different sign you should correct the other gear wheel too (Figure 3) [4 – 16, 20].

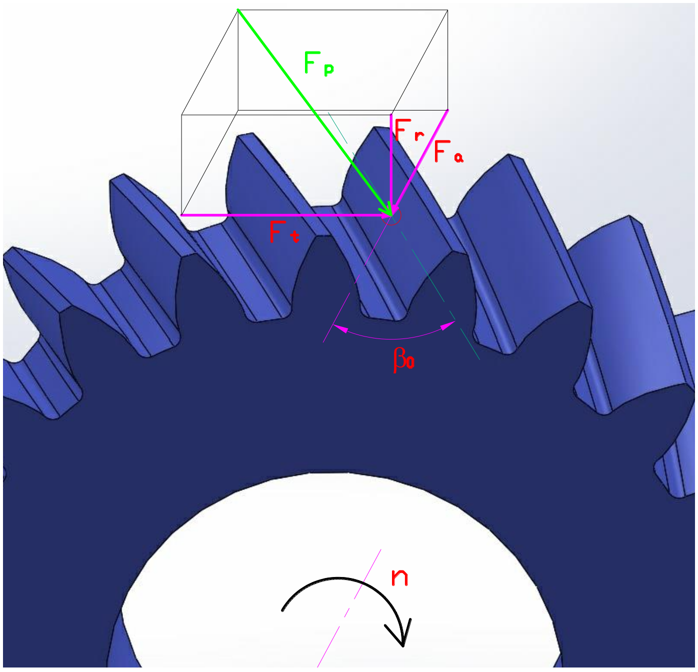


Fig. 2. The arrangement of the pressure force components

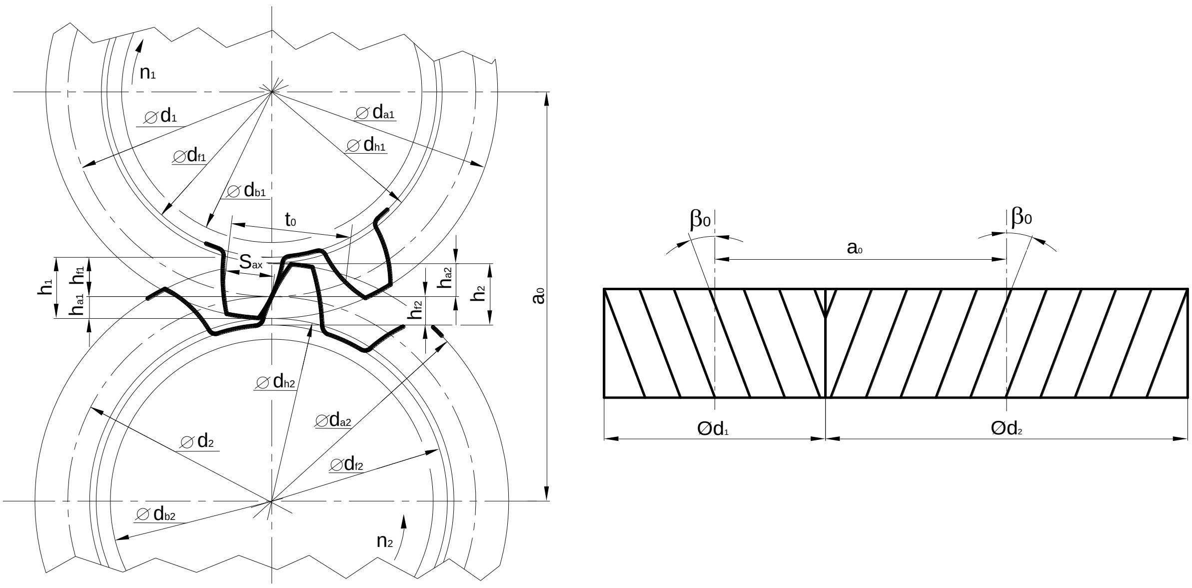


Fig. 3. Parameters of the helical gear pair having modified straight teeth [2, 3]

The addendum values of the gear wheels ($h_{a1,a2}$) based on Figure 2 [4 - 8]:

$$\left.\begin{aligned} h_{a1} &= f_0' \cdot m + x_1 \cdot m \\ h_{a2} &= f_0' \cdot m - x_1 \cdot m \end{aligned}\right\}$$

2 Determination of the main parameters of the helical gear pairs

A MATLAB software has been developed to help the CAD designing process of the helical gears [1, 2, 3].

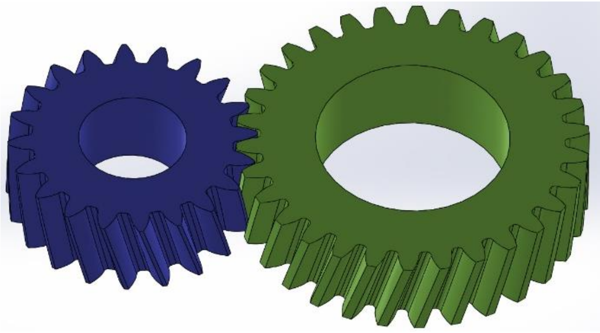
The m module, z_1, z_2 number of teeth, α_0 base profile angle, x_1 addendum modification coefficient and the β_0 tooth trace are the input parameters of the our-designed programme [3].

Table 1. The determined parameters of the helical gear pairs

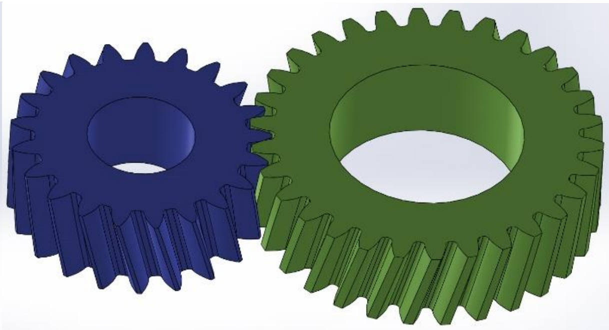
The main parameters of the gear pairs	***Gear drive I.***	***Gear drive II.***	***Gear drive III.***	***Gear drive IV.***	***Gear drive V.***
Axial module (mm)	5				
Number of tooth of the pinion (z_1)	20	21	22	23	24
Number of tooth of the driven gear (z_2)	30				
Standard centre distance (a_0) (mm)	129.409	131.997	134.585	137.174	139.762
Addendum of the pinion (h_{a1}) [mm]	6.035				
Addendum of the driven gear (h_{a2}) [mm]	3.964				
Bottom clearance (c) [mm]	1.25				
Dedendum of the pinion (h_{f1}) [mm]	5.214				
Dedendum of the driven gear (h_{f2}) [mm]	7.285				
Circular pitch (t_0) [mm]	16.262				
Backlash (j_s) [mm]	0.813				
Whole depth (h) [mm]	11.25				
Working depth (h_w) [mm]	10				
Tooth thickness (S_{ax1}) [mm]	7.724				
Pitch circle diameter of the pinion(d_1) [mm]	103.527	108.704	113.88	119.056	124.233
Tip circle diameter of the pinion(d_{a1}) [mm]	115.598	120.774	125.950	131.127	136.303
Root circle diameter of the pinion (d_{f1}) [mm]	93.098	98.274	103.45	108.627	113.803
Basic circle diameter of the pinion (d_{ak1}) [mm]	96.878	101.722	145.317	111.409	116.253
Pitch circle diameter of the driven gear (d_2) [mm]	155.291				
Tip circle diameter of the driven gear (d_{a2}) [mm]	163.220				
Root circle diameter of the driven gear (d_{f2}) [mm]	140.720				
Basic circle diameter of the driven gear (d_{ak2}) [mm]	145.317				
The x_1=-x_2 addendum modification [mm]	0.2				
Transmission ratio (i)	1.5	1.428	1.363	1.304	1.25
Base profile angle (α_0) [°]	20				
Tooth trace (β_0) [°]	15				

Knowing of these starting parameters the gear parameters and the involute profile points could be calculated by this software based on the recommendations of the references [4 -16].

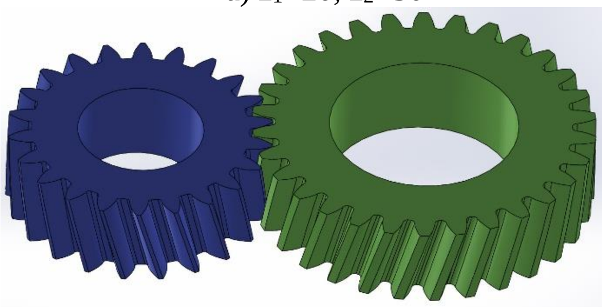
We have designed five types of gear pairs. The difference is the modification of the number of teeth between them. This parameter has been modified from 20 to 24. All of other input parameters have been constant (Table 1). Interpolation B-spline curve has been inserted to all of the gear profiles [1, 2, 3]. Based on the determined parameters and the profile points the CAD models of the helical gear pairs could be generated for all cases (Figure 4). The z_1 is the number of teeth on the pinion which have been changed. The $z_2=30$ number of teeth on the driven gear is constant for all of them (Figure 4).



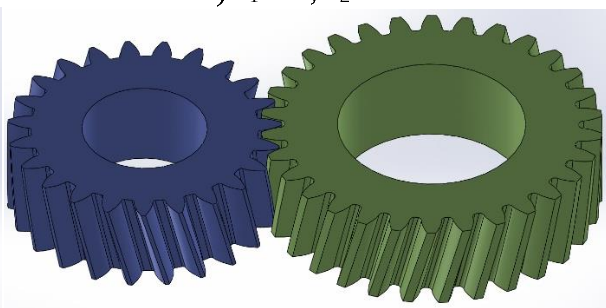
a) $z_1=20$, $z_2=30$



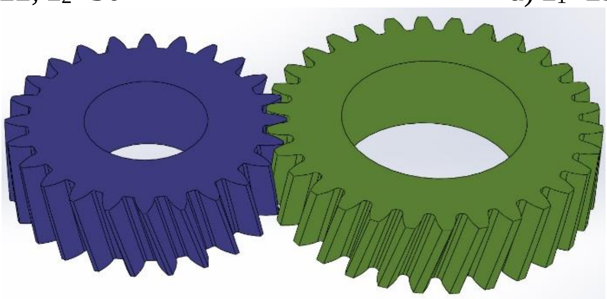
b) $z_1=21$, $z_2=30$



c) $z_1=22$, $z_2=30$



d) $z_1=23$, $z_2=30$



e) $z_1=24$, $z_2=30$

Fig. 4. The CAD models of the designed helical gears

3 TCA analysis of the designed gear pairs

The objective of the TCA is the determination of the mechanical properties of the gear pairs in case of tooth connection by different loads [5, 9 - 16].

Four coordinate systems was needed for the analysis:

- two coordinate systems to the axes of rotations of the elements,
- one coordinate system to the middle of the tooth connection whose *'x'* axes is perpendicular for the connecting surfaces,
- one coordinate system to the middle of the tooth connection whose *'z'* axes is parallel with the axes of rotation.

The friction coefficient was $\mu=0.01$ between the connected elements. The applied mesh type was tetrahedrons having 0.5 mm on the contact zone. The contact zone was limited by a rectangle shape. Automatic meshing was used outside of the contact area (Figure 5).

During the analysis the normal stresses and normal deformations were analysed on the pinion's and the driven gear's sides in case of both pairs. They were analysed into the *'x'* normal direction which is perpendicular for the tooth surfaces and into the *'z'* direction which shows into axial direction.

The driven gear was totally fixed. Only the rotation around the axis of rotation of the pinion was permitted. 800 Nm load torque was loaded on the pinion.

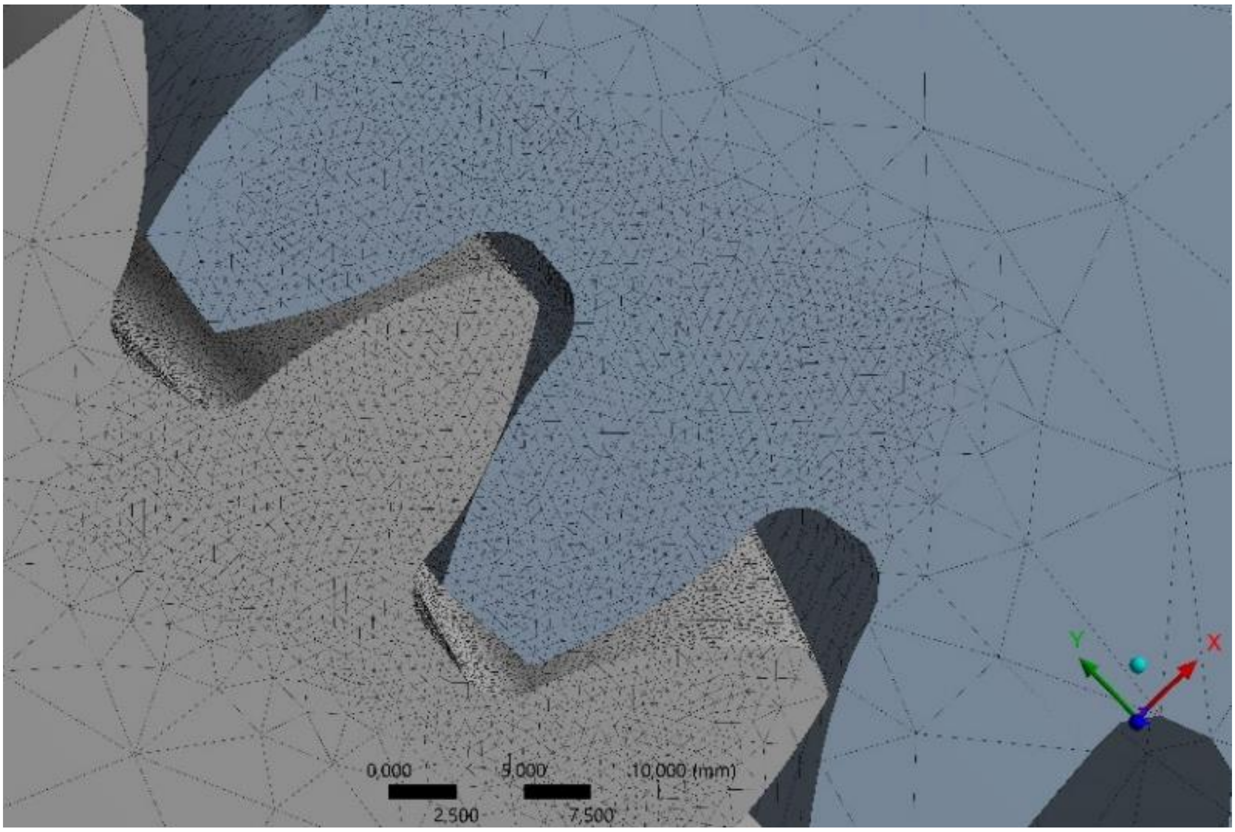
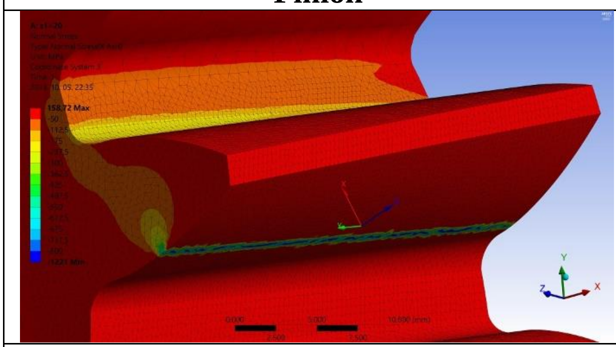
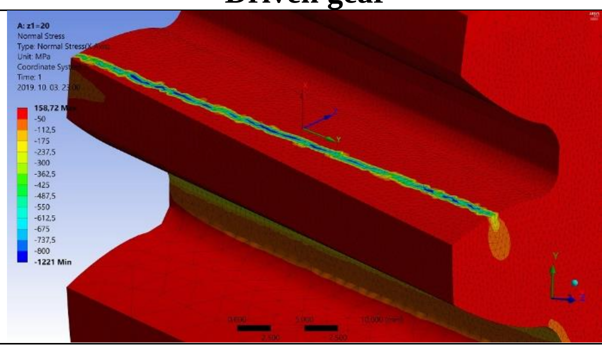


Fig. 5. The meshing on the contact zone

3.1. Analyses of normal stresses

The received *'x'* directional normal stresses [19] could be seen on Figure 6. The received normal stresses on the surfaces were averaged (Figure 7).

Pinion	**Driven gear**
	
$z_1=20$	

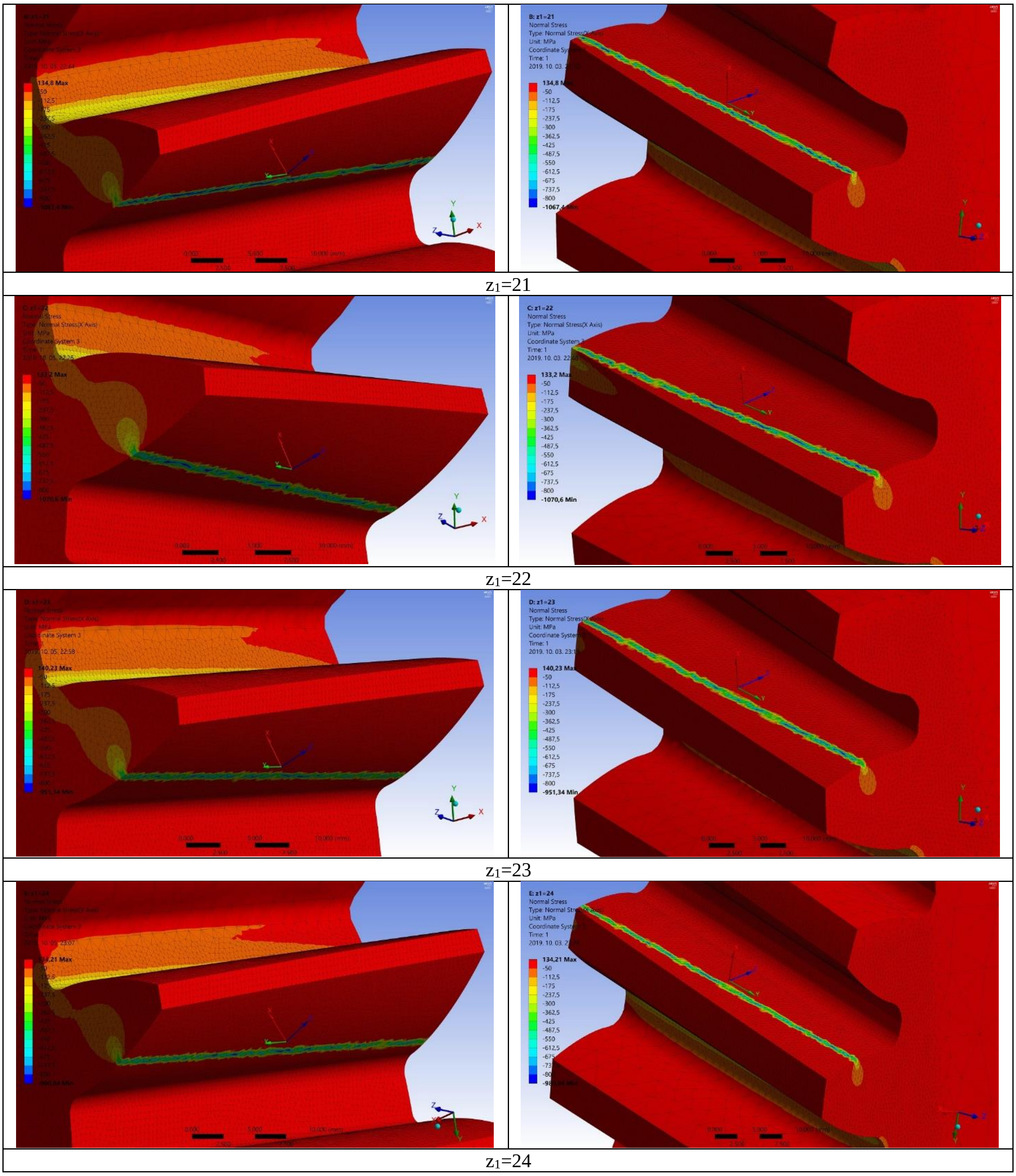
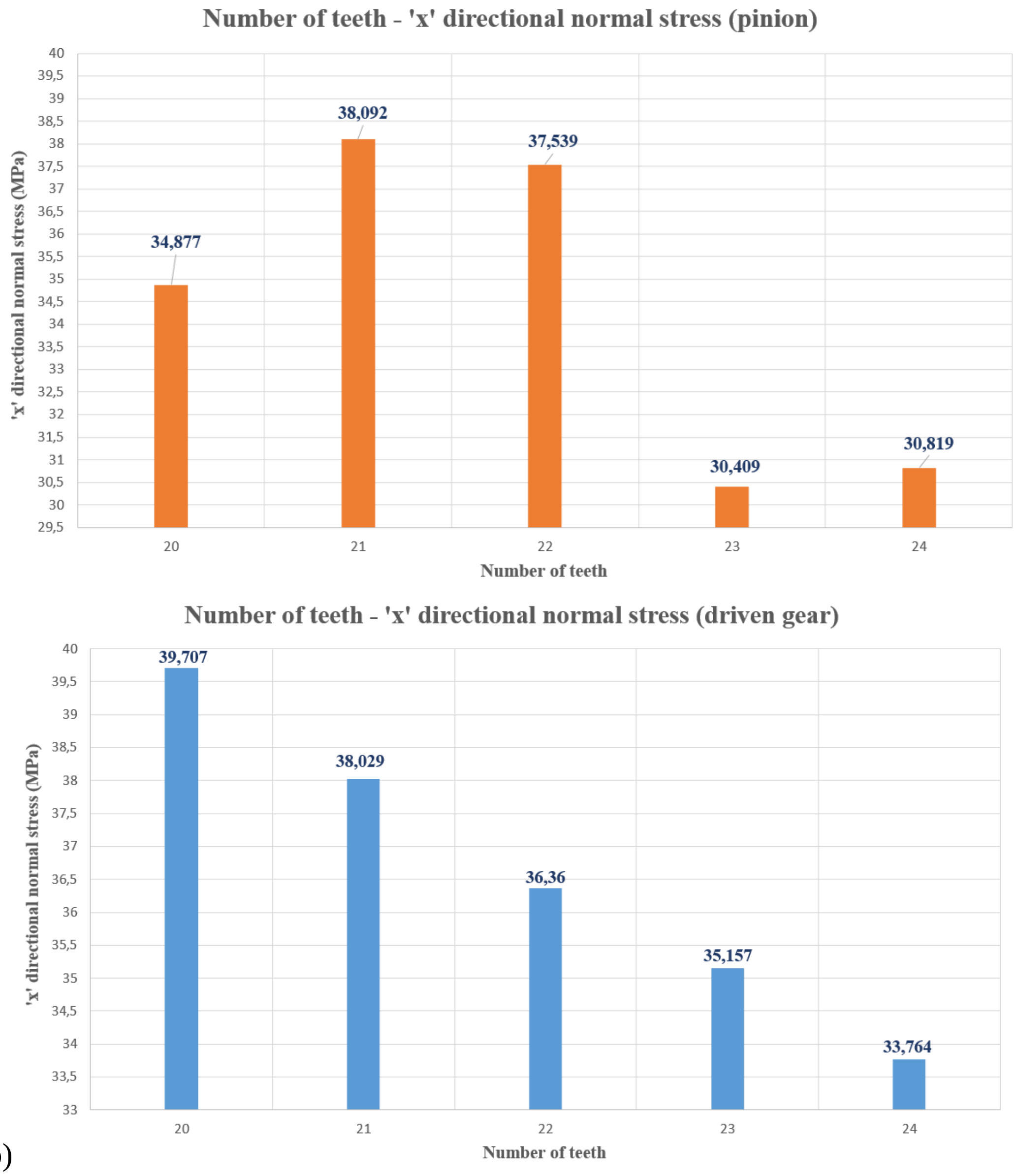


Fig. 6. The *'x'* directional normal stress's distributions



a)

b)

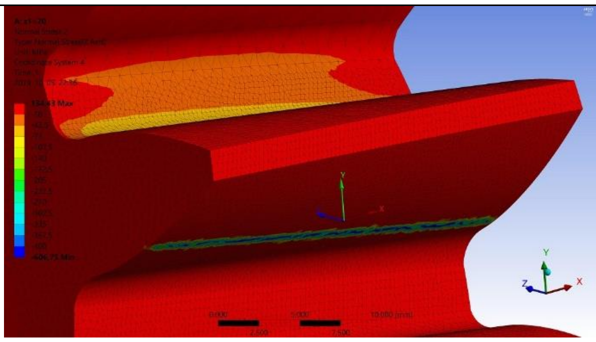
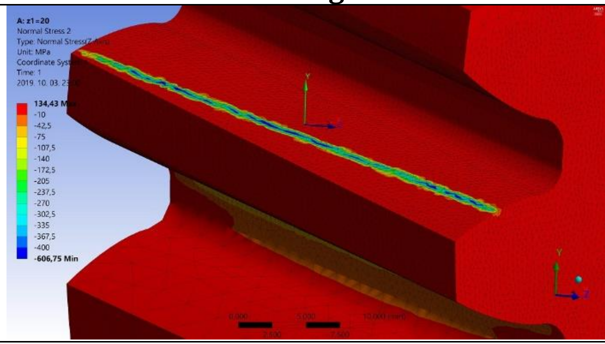
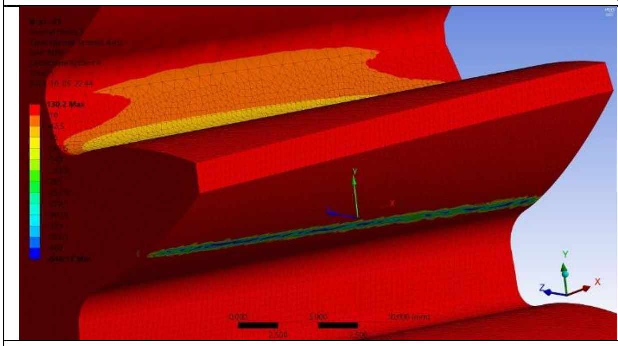
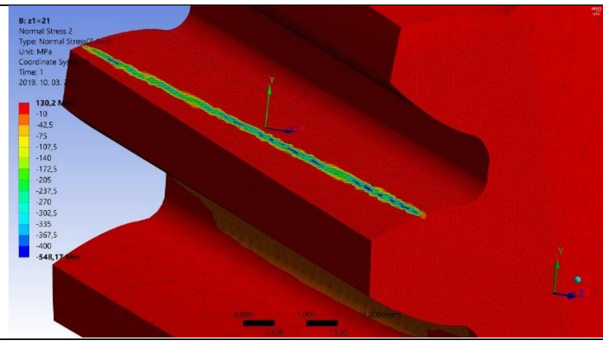
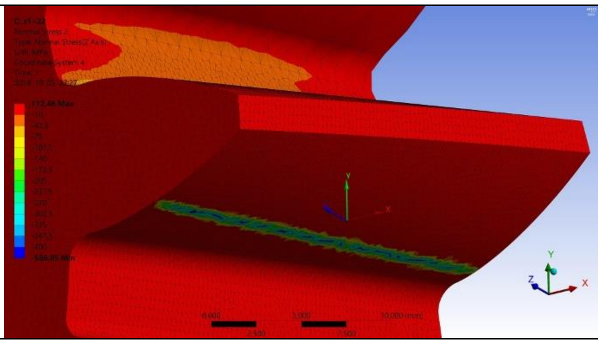
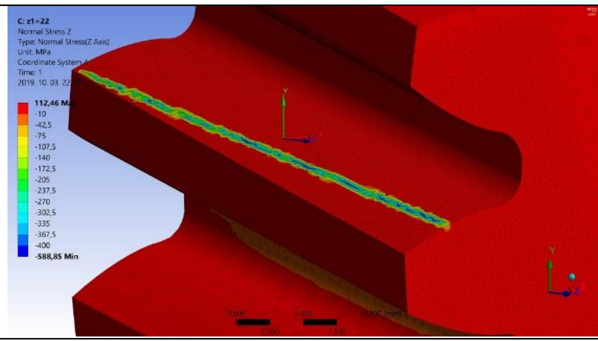
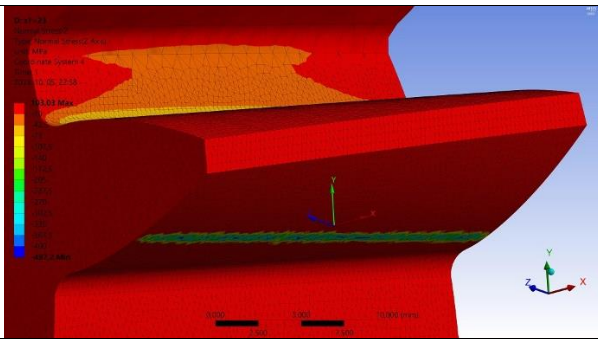
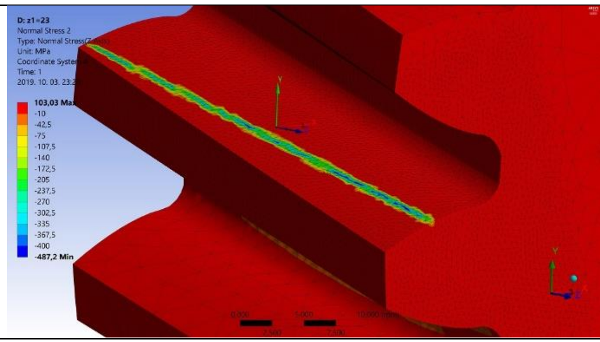
Fig. 7. The number of teeth of the pinion – *'x'* directional normal stress diagrams

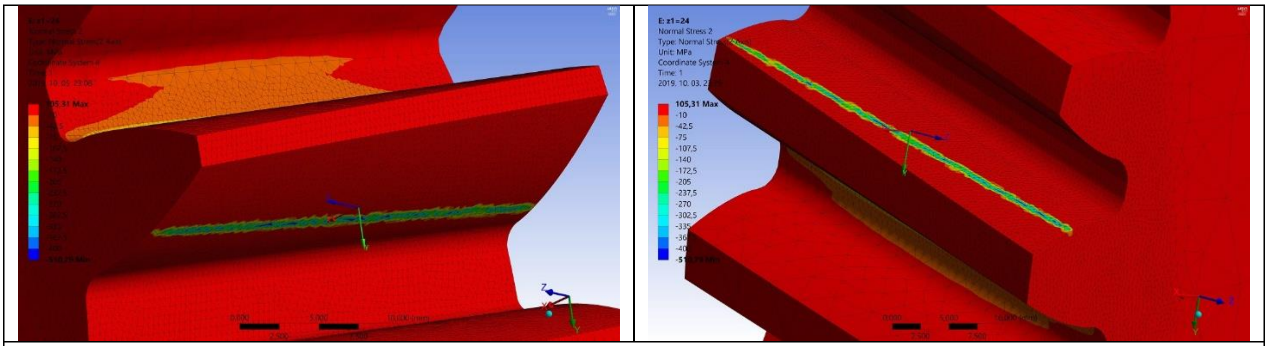
Based on Figure 7.a. the highest results are on the $z_1=21$ and the $z_1=22$ on the pinion's surface. The lowest values are on the $z_1=23$ and the $z_1=24$. Based on Figure 7.b. the received results are continuously being reduced from the $z_1=20$ to the $z_1=24$.

Based on the received diagrams the *'x'* directional normal stresses are the lowest in case of the $z_1=23$ and the $z_1=24$ number of teeth on the pinion beside of the constancy of the number of teeth on the driven gear.

The received *'z'* directional normal stresses [19] could be seen on Figure 8. These direction is significant because this is the axial direction of the gear pair. The received normal stresses on the surfaces were averaged (Figure 9).

Based on Figure 8 the received diagrams are similar to a sinus form. Based on Figure 9.a. the lowest values are on the $z_1=23$ and the $z_1=24$. This highest value is on the $z_1=21$. Based on Figure 9.b. the lowest values are on the $z_1=21$ and the $z_1=23$. The highest value is on the $z_1=22$. In case of the $z_1=20$, the $z_1=21$, the $z_1=22$ the normal stresses of the pinion are almost twice than in case of the driven gear.

Pinion	Driven gear
	
z_1=20	
	
z_1=21	
	
z_1=22	
	
z_1=23	



z

Fig. 8. The *‘z’* directional normal stress’s distributions

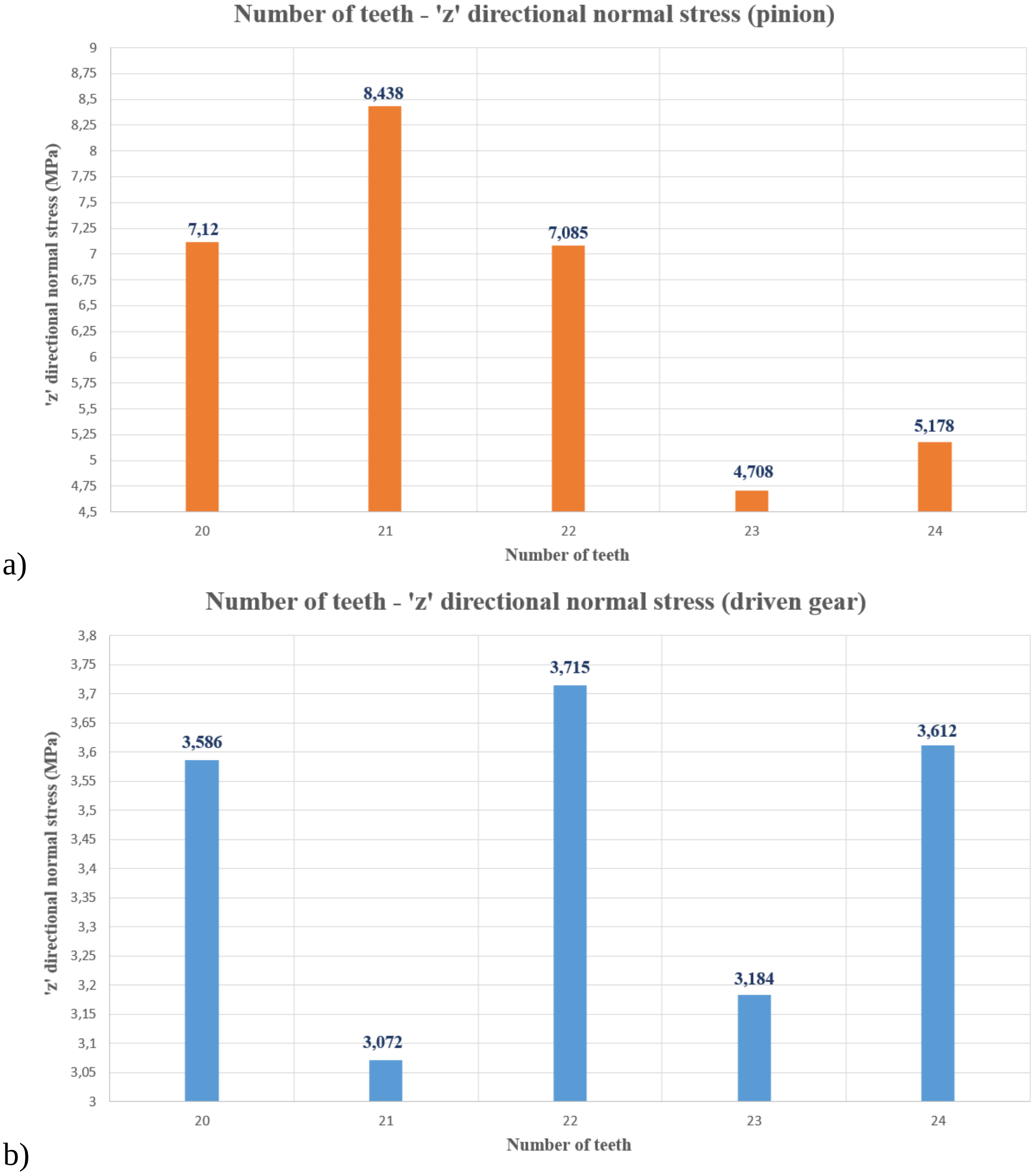


Fig. 9. The number of teeth of the pinion – *‘z’* directional normal stress diagrams

3.2. Analyses of normal deformations

The received *‘x’* directional normal deformations [19] could be seen on Figure 10. The received normal deformations on the surfaces were averaged (Figure 11).

Based on Figure 11.a. the highest *‘x’* directional normal deformation is on the z_1=21. After this point the normal deformation is continuously being decreased in the function of the number of teeth of the pinion. The lowest result is on the z_1=24.

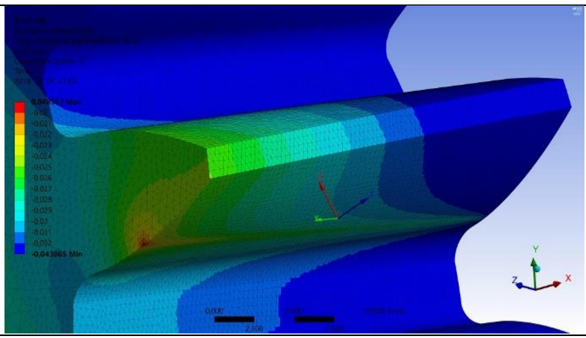
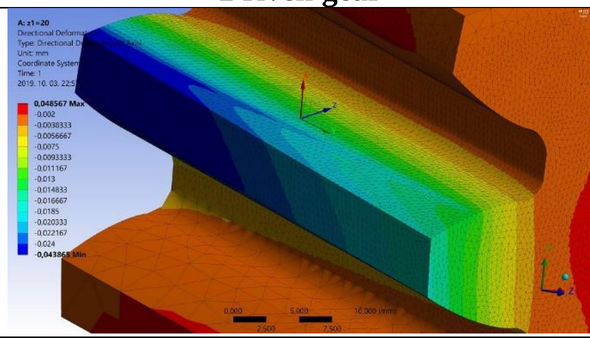
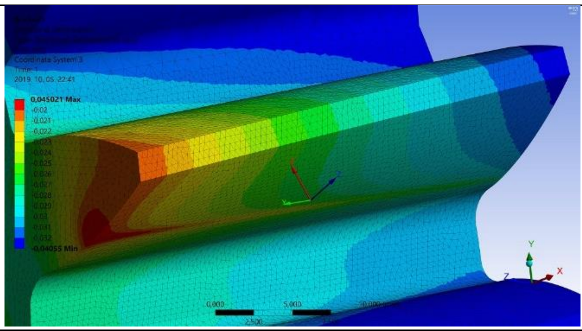
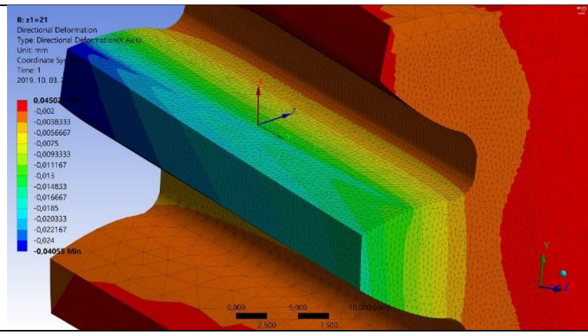
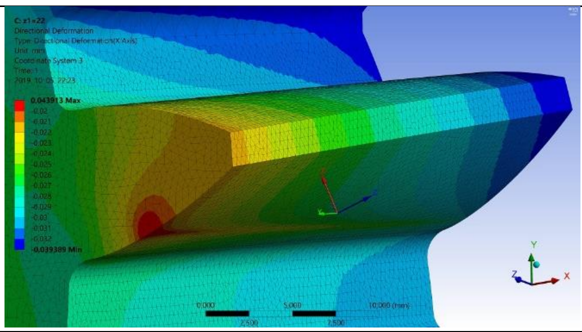
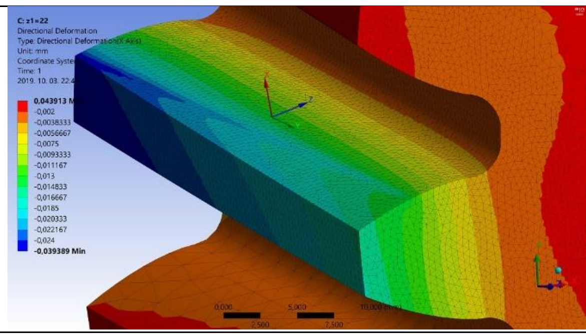
Based on Figure 11.b. the highest ‘x’ directional normal deformation is on the z_1=20. This deformation is approximately being decreased. The lowest result is on the z_1=24.

Consequently, the lowest ‘x’ directional normal deformations of both elements are on the z_1=24, that is why the higher number of teeth is advantageous on the pinion.

The received *‘z’* directional normal stresses [19] could be seen on Figure 12. These direction is significant because this is the axial direction of the gear pair. The received normal stresses on the surfaces were averaged (Figure 13).

Based on Figure 13.a. the function is similar to the sinus form. The highest result is on the z_1=20. The lowest result is on the z_1=21.

Based on Figure 13.b. the deformation results are continuously being decreased in the function of the number of teeth on the pinion. Consequently, the highest *‘z’* normal deformation results are on the z_1=20.

Pinion	**Driven gear**
	
z_1=20	
	
z_1=21	
	
z_1=22	

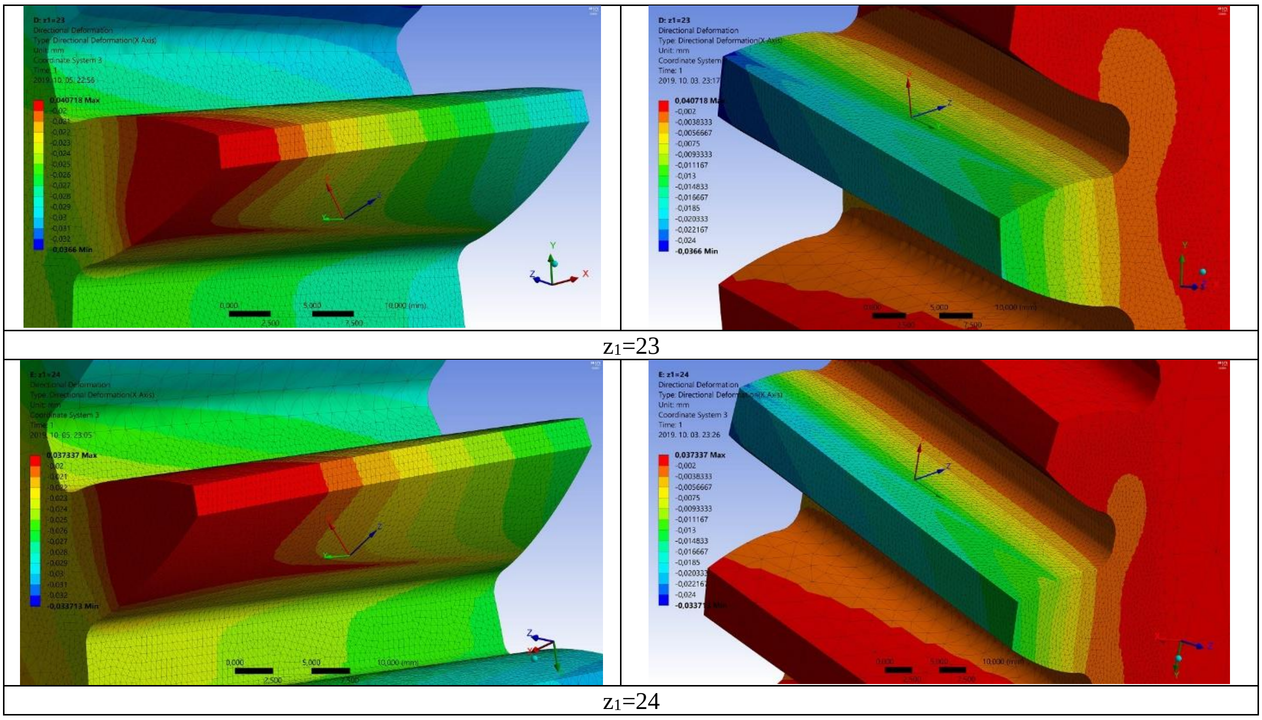
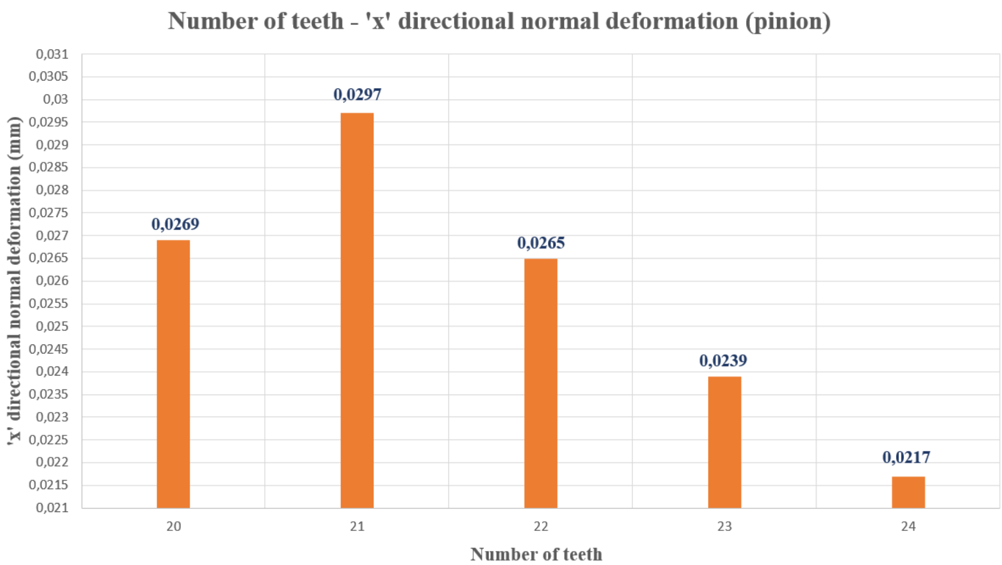
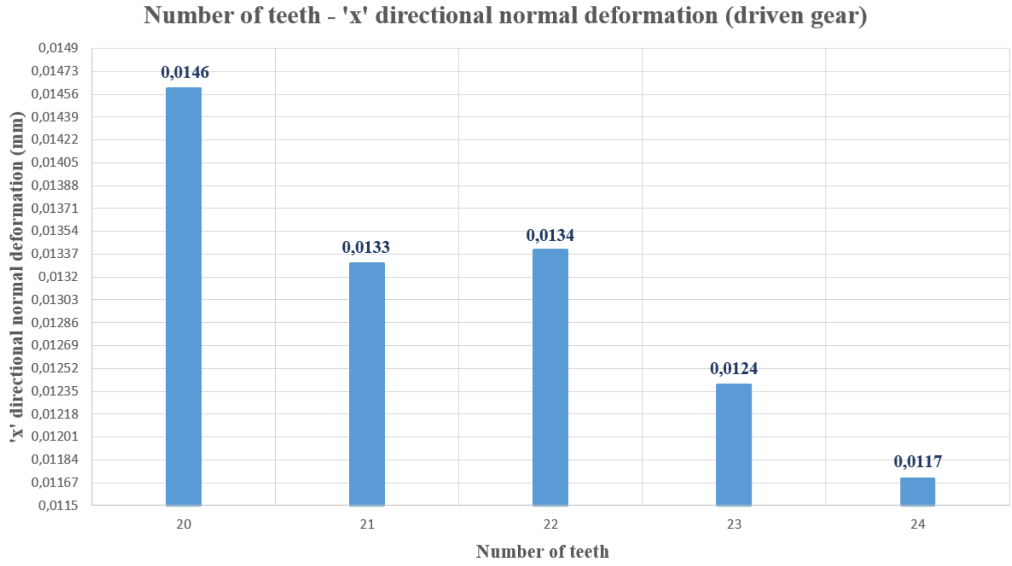


Fig. 10. The *'x'* directional normal deformation's distributions



a)



b)

Fig. 11. The number of teeth of the pinion – *'x'* directional normal deformation diagrams

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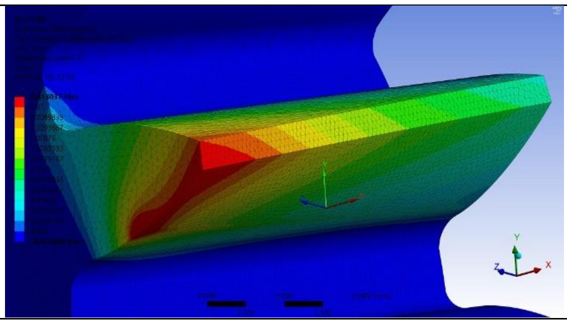
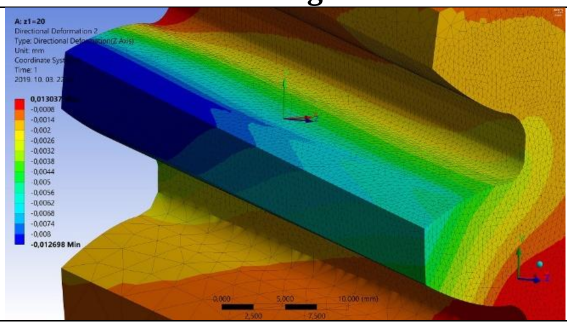
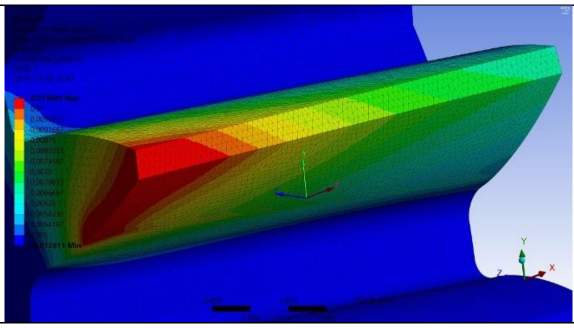
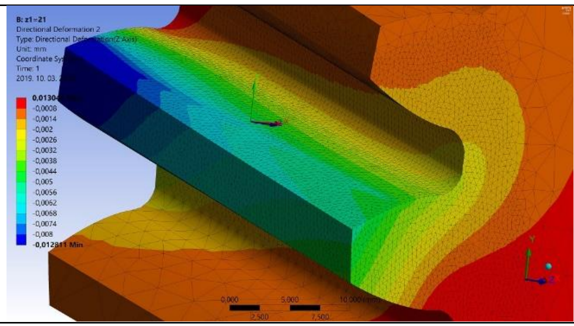
<tr><td></td><td></td></tr>
<tr><td colspan="2">z_1=20</td></tr>
<tr><td></td><td></td></tr>
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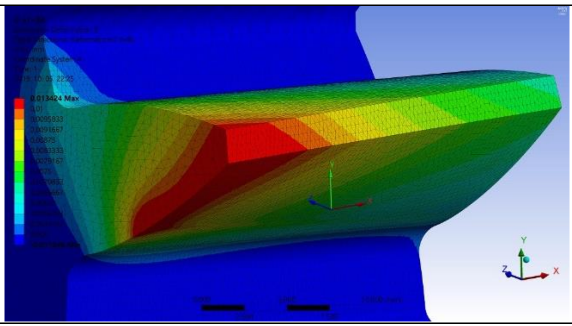
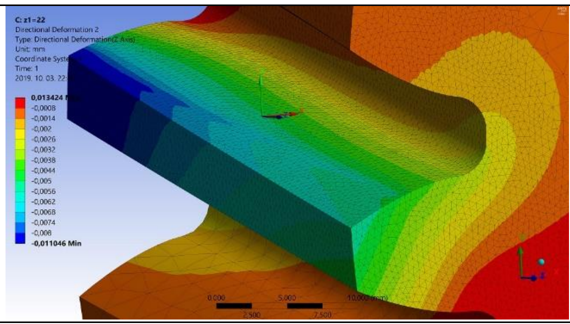
<tr><td></td><td></td></tr>
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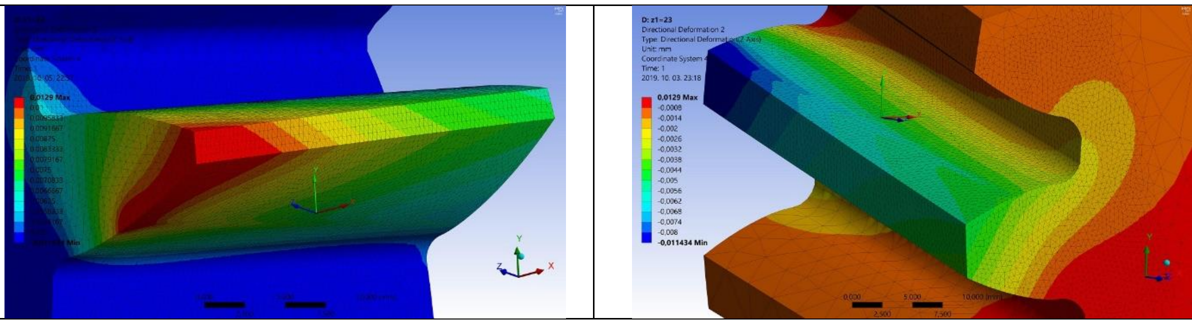
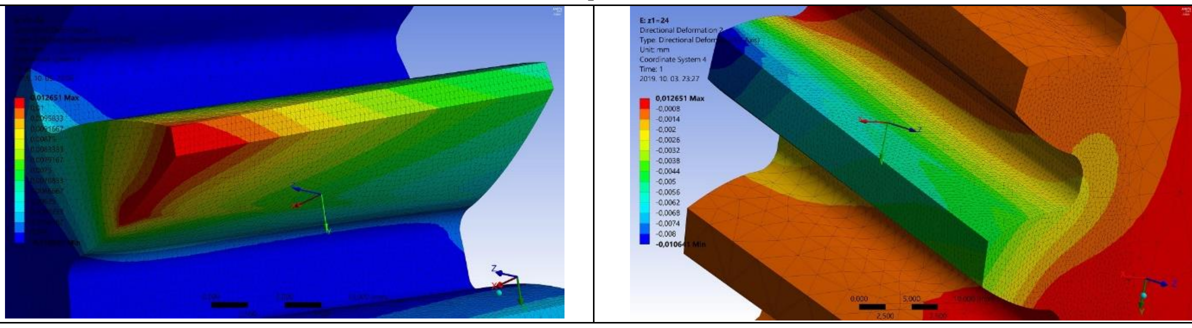
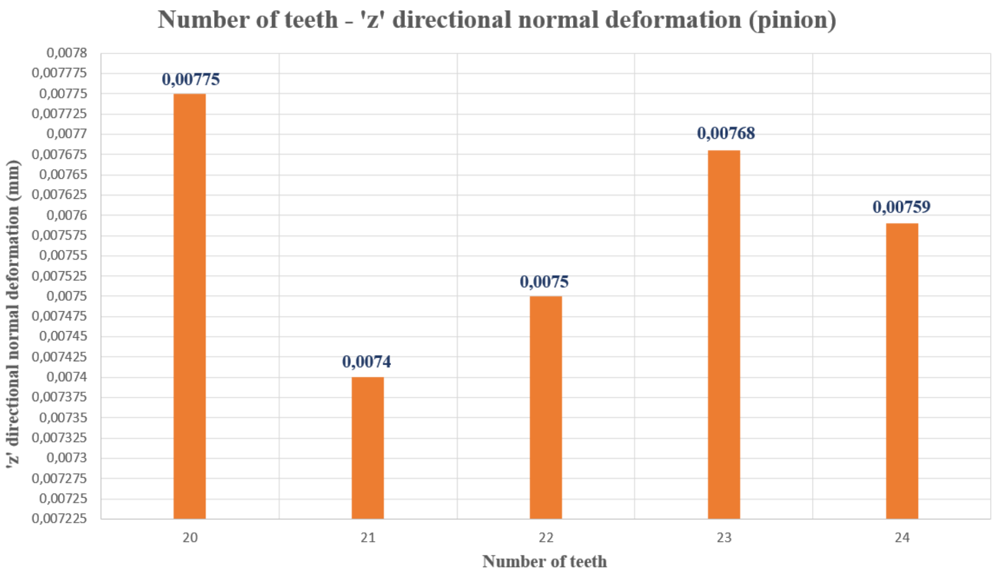


z_1=23

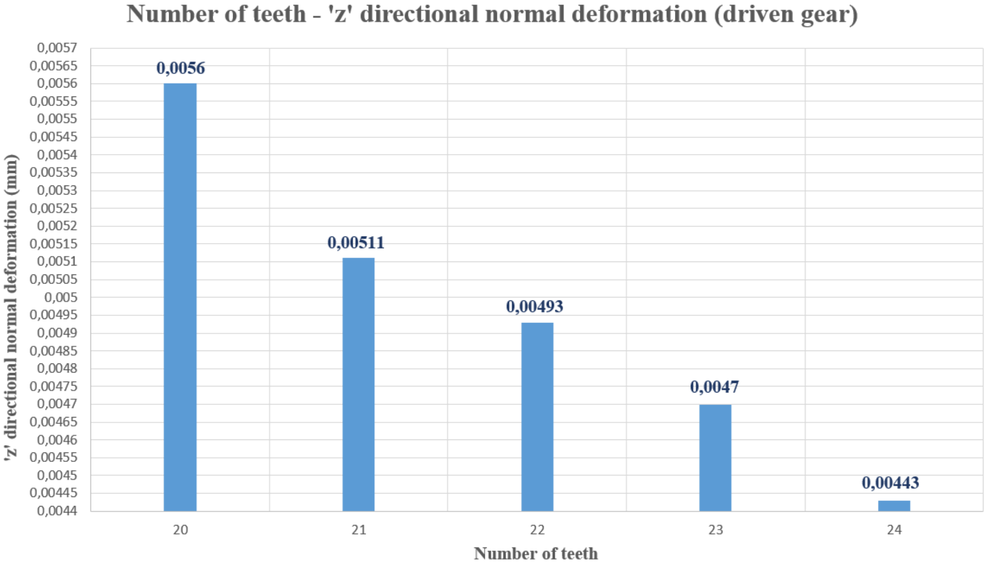


z_1=24

Fig. 12. The ‘z’ directional normal deformation’s distributions



a)



b)

Fig. 13. The number of teeth of the pinion – *'z'* directional normal deformation diagrams

CONCLUSION

The research of helical gears is important nowadays, because these pairs are used in many different gear boxes especially in the vehicle or working machine industries. The advantageous of them is the low noise, the vibration, the higher power transmission, better connection results and efficiency opposite to the spur gears. There are many types of helical gears such as x-zero, having normal and having modified straight teeth types.

The aim of this study was the analysis of the received mechanical parameters for geometrically different helical gear pairs based on same load torque. We designed five different types of helical gears having modified straight teeth in the function of the number of teeth on the pinion. All of the other input parameters were unchanged. A new-type computer program was created for the facilitation of the designing process. Knowing of the calculated parameters the CAD models were designed by Solidworks software. Motion and connection analysis could be also done by the help with this software.

The TCA was done by Ansys FEM software. We analysed the normal stresses and deformations into two directions (normal and axial) on the tooth contact area for both gear elements. After this connection analysis functions could be done by the modified geometric parameter (number of teeth) and the received mechanical parameters (stresses and deformations). Consequences could be determined based on TCA results and diagrams' shapes which could be useful for the geometric gear designing process and gearbox designing.

We determined the correlations between the mechanical parameters and the number of teeth on the pinion in case of the pinion and the driven gears. Consequences were determined based on the received results.

ACKNOWLEDGEMENT

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