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ANALYSIS OF STRESSES AND DEFORMATIONS OF A GEAR WITH MODIFIED INTERNAL STRUCTURE

Summary: The paper presents FEM simulation research performed with the use of geometric models of gears, classic gear and gear with a modified internal structure. The aim of the research was to determine the maximum values and the distribution of stresses and displacements of the gear structure as a result of the tooth load. The analysis of the results showed a significant influence of the structure of the gear, and in particular the damping ring material, on the obtained maximum values of stresses and displacements.

Keywords: gearbox vibrations, gearbox vibroactivity, modified structure of gear.

ANALIZA NAPRĘŻEŃ I ODKSZTAŁCEŃ KOŁA ZĘBATEGO O ZMODYFIKOWANEJ BUDOWIE WEWNĘTRZNEJ

Streszczenie: W pracy przedstawiono badania symulacyjnych wykonane metodą MES z wykorzystaniem geometrycznych modeli kół zębatych, koła o klasycznej oraz koła o zmodyfikowanej budowie wewnętrznej. Celem badań było wyznaczenie maksymalnych wartości oraz rozkładu naprężeń i przemieszczeń konstrukcji kół w wyniku obciążenia zęba. Analiza wyników wykazała znaczący wpływ konstrukcji koła, a w szczególności materiału pierścienia tłumiącego, na uzyskane wartości maksymalne naprężeń i przemieszczeń.

Słowa kluczowe: drgania przekładni zębatej, wibroaktywność przekładni, modyfikacja koła zębatego.

1. Introduction

Gearboxes are a very important component in many means of transport, despite constantly developing alternative drive systems. Along with the development of the number of alternative drives for means of transport, in particular for motor vehicles, there is a noticeable increase in patent applications submitted by leading companies

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in the drive train industry for innovative design solutions of gears and other transmission components. The innovation of the above-mentioned patent applications is focused on designing the drive systems which are quiet in terms of vibrations and noise. This fact is extremely important in the case of means of transport due to aims to increase the comfort of passengers and other users [1-3].

The subject of the vibroactivity of gearboxes is taken up in many worldwide scientific publications. The research papers are aimed at looking for the possibility of reducing the vibration emissivity of the transmission in many areas related directly to the construction of the transmission itself, but also at the drive systems of means of transport as all [3-5]. It is worth emphasizing, in the case of gearbox operation, one of the main areas which is the great source of vibrations is the meshing zone [1-3]. Limiting the transmission of vibrations from the above-mentioned area for the remaining elements of the transmission may result in a significant reduction in the emission of vibrations and noise of the entire construction. For this purpose, solutions are being sought that would allow vibration damping in the section between the meshing zone and the gearbox housing [4-8].

One of the solutions enabling the reduction of the vibrations transmission from the meshing zone to the remaining elements of the gearbox is the innovative design of the gear, described in patent application P.435585. The described concept of gear is about dividing the classic gear into three components: a hub, toothed rim and a ring made of a damping material. The ring connects the other two elements. This design of the gear is aimed at limiting the propagation of vibrations generated in the meshing zone to the remaining elements of the gearbox and allows for partial compensation of elements and assembly deviations resulting in uneven load distribution over the meshing width. Due to the high innovativeness of the solution, there is a need to conduct the analysis of the proposed structure. For this purpose, geometric models of gears and the FEM (Finite Element Method) were used. The FEM is widely used in solving many technical and engineering issues, i.e. determining the stresses of a structure, simulating liquid flow, simulating heat transport. Such action enables the estimation of the behavior of the analyzed structure in the assumed operating conditions already at the stage of design. The validity of using the FEM to analyze the prototype design solution of a gear is also confirmed by the fact that a significant advantage of the described method is the possibility of obtaining solutions for figures and areas with complex shapes, for which carrying out precise analytical calculations may be very complicated or even impossible. It is extremely important, because the shapes of the complex geometry include gears due to the specific shape of the teeth. In addition, in the case of modification of the classic design of a gear wheel, the geometric complexity of the newly formed body increases, and the use of several components, made of materials with different mechanical properties, does not exclude the use of the FEM method.

The paper presents the results of researches carried out with the FEM aimed at determining and comparing the stresses and deformations of a gear with a modified internal structure in accordance with the description of patent application P.435585, and comparison these result to a gear with a classic internal structure.

2. Research methodology

In order to analyze the maximum stresses and strains described in the patent application P.435585 of the prototype gear design, a geometrical model of the gear was prepared reflecting its key features. Model geometry was developed in Autodesk Inventor software. The prepared geometric models of gears intended for further analysis are shown in Figure 1.

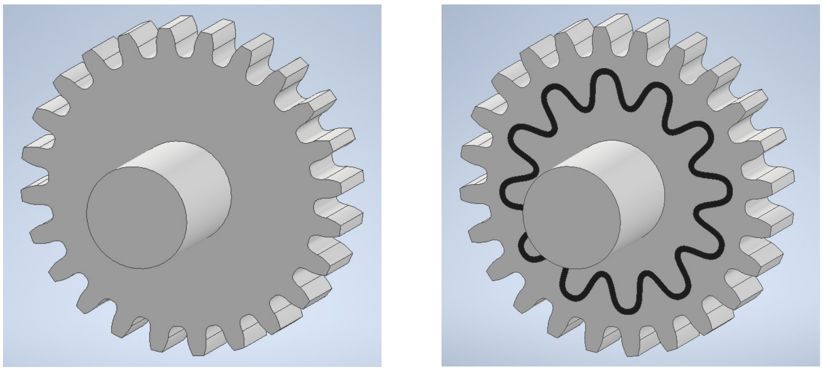

Figure 1. Models of tested gears with a fragment of the shaft. On the left gear with a classic design, on the right gear with an innovative design according to patent application P.435585

The models' meshes necessary for the FEM analysis were generated in the Autodesk Inventor Nastran InCAD software. Due to the fact that the prepared models consisted of several components, their meshes were prepared in such a way that their border nodes coincide with the border nodes of the neighboring element. Additionally, in order to increase the accuracy of the analysis, in the case of the modified gear model, the resolution of the model mesh was locally increased in the area of the damping ring. The models with the prepared meshes are shown in Figures 2 and 3.

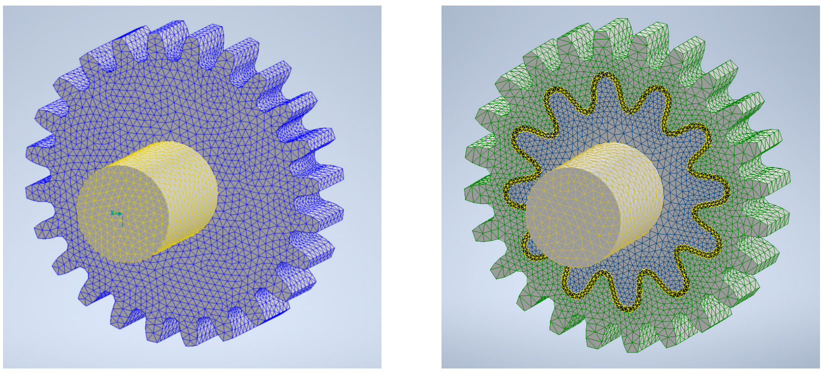

Figure 2. The models with the prepared meshes

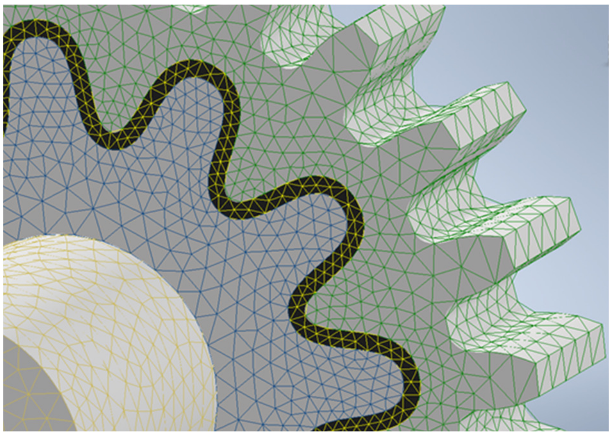

Figure 3. Area of increased mesh resolution

At the stage of preparing the models for analysis, the occurrence and types of contacts between the components of the model: the hub, damping ring and toothed rim, were defined. All contacts are defined as bonded with the exception of interpenetration of solids. In the defined model, stainless steel for highly loaded machine elements was used as the material of the gear, designated as AISI 304. Nitrile rubber and a mixture of polyurethane were defined as the flexible material of the damping ring. During the tests, the stress and strain distribution was analyzed for the load acting on the selected wheel tooth in the normal direction to the Surface of tooth flank. The analysis was carried out for four values of the force loading the tooth: 15, 30, 45 and 60 kN, which, taking into account the geometric parameters of the wheel, translated into torque values similar to those commonly found in passenger motor vehicles. Additionally, the analysis was performed in two series, the first for the tooth above the outer apex of the damping ring (series A) and the second for the tooth above the inner apex (series B).

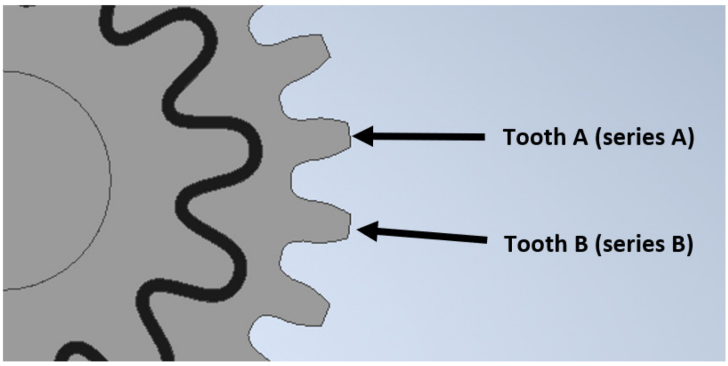

Figure 4. Teeth selected to analysis – series A and series B

3. Results of conducted studies

For each analyzed case, the distribution and values of maximum stresses as well as total displacements were determined. The results obtained as a result of the simulations are presented below in the form of a graph, and for selected cases also in a graphical form.

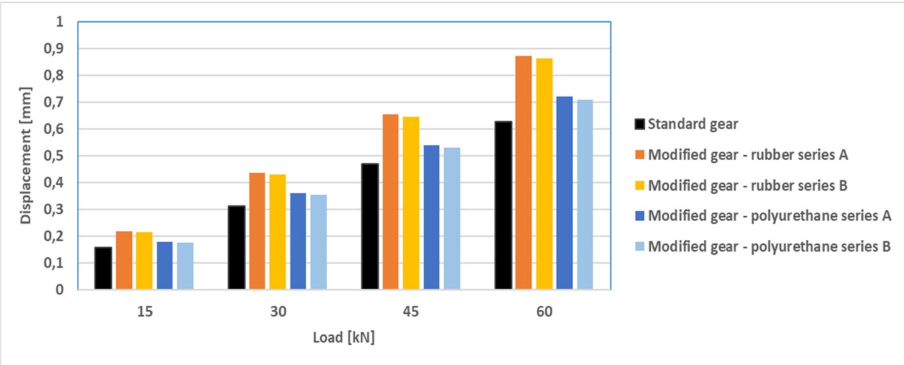

Figure 5. Maximum values of displacement of tested gears for selected loads and damping materials

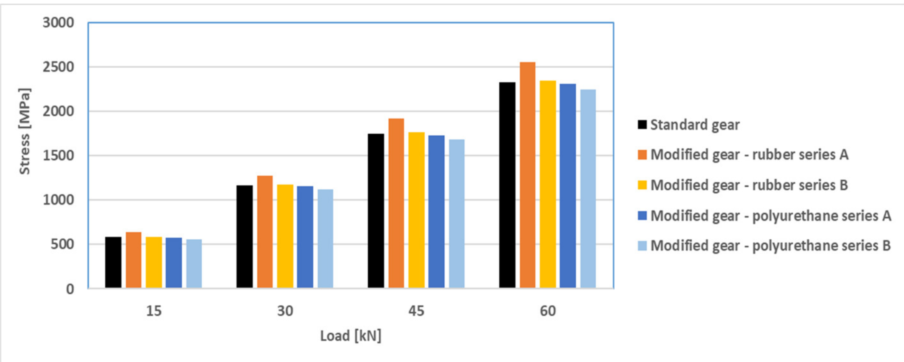

Figure 6. Maximum values of stress of tested gears for selected loads and damping materials

Percentage values of maximum displacement and stress according to standard gear were shown in table 1.

Table 1. Percentage values of maximum displacement and stress according to standard gear

	Load [kN]	15	30	45	60
Displacement [Δ%]	Mod. gear - rubber series A	38,85%	39,30%	39,19%	39,12%
	Mod. gear - rubber series B	36,94%	37,38%	37,45%	37,32%
	Mod. gear - polyurethane series A	14,65%	14,70%	14,68%	14,67%
	Mod. gear - polyurethane series B	12,74%	13,10%	12,98%	12,76%
Stress [Δ%]	Mod. gear - rubber series A	9,74%	9,71%	9,73%	9,73%
	Mod. gear - rubber series B	0,83%	0,81%	0,82%	0,83%
	Mod. gear - polyurethane series A	-0,97%	-0,99%	-0,98%	-0,98%
	Mod. gear - polyurethane series B	-3,62%	-3,64%	-3,63%	-3,62%

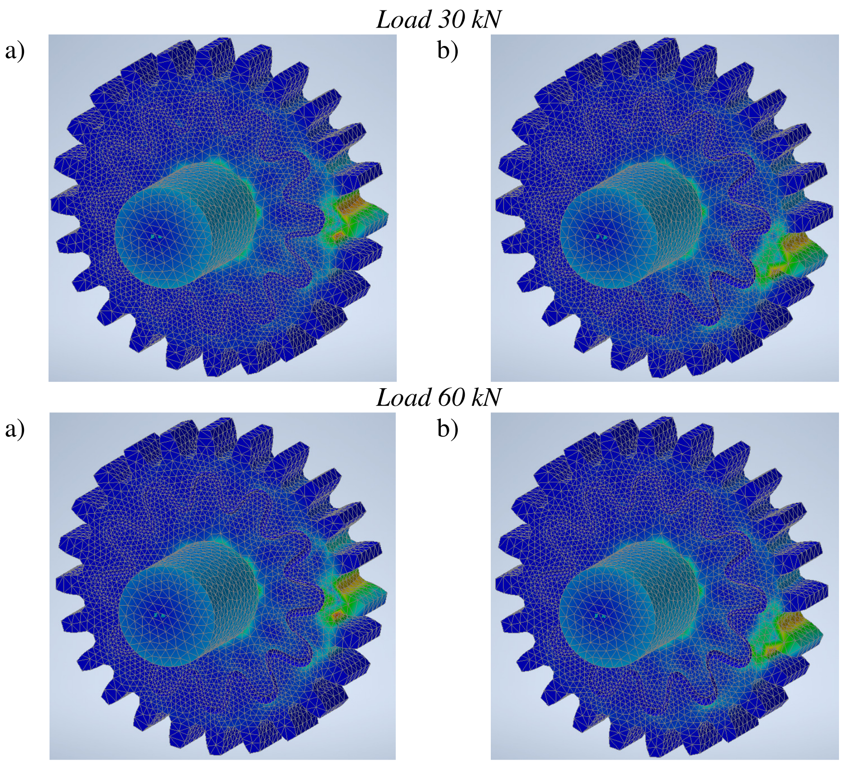

Figure 7. Graphical form of obtained results – maximum stress analysis for load 30 kN and 60 kN. Description: a) damping material rubber - series A, b) damping material rubber – series B

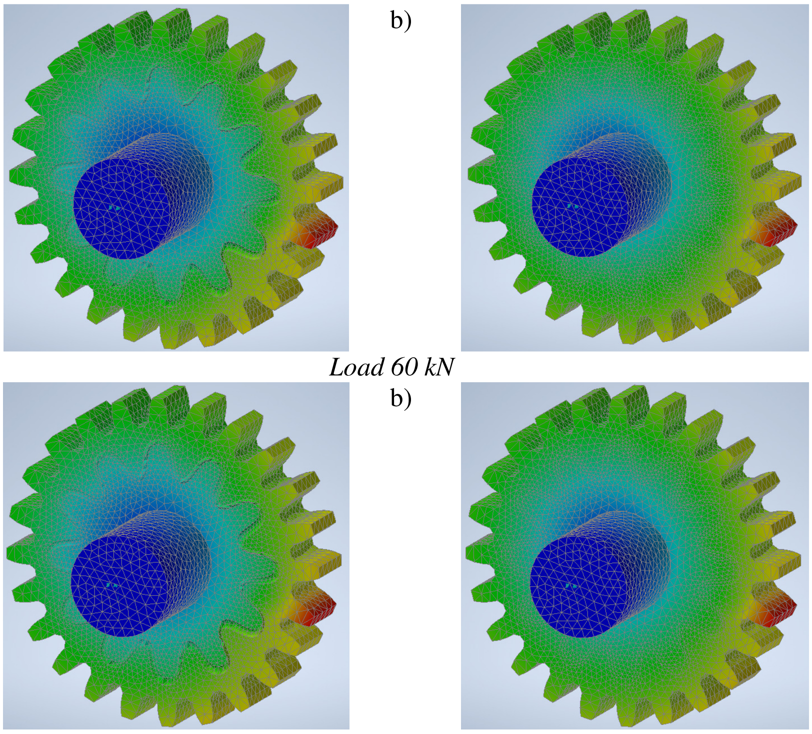

Figure 8. Graphical form of obtained results – maximum displacement analysis for load 30 kN and 60 kN. Description: a) damping material rubber - series B, b) damping material polyurethane – series B.

4. Summary

The analysis of the standard structure gear and the gear with modified internal structure showed significant differences in the obtained values of the maximum stress and deformation.

In the case of the gear with modified structure with a damping ring made of rubber, significantly greater deformations were obtained compared to the standard structure gear, the differences of which exceeded 36% for A nad B series. The maximum stress for tooth A increased by 10%, while for tooth B the difference did not exceed 1%.

In the case of the gear with modified structure with a damping ring made of polyurethane, greater deformations were obtained compared to the standard structure gear, the differences of which did not exceeded 15% for A nad B series. The maximum stress for tooth A and tooth B decreased by few percent compared to the standard structure gear.

The analysis of the obtained results showed a significant influence of the selection of the damping ring material on the achieved maximum stress and deformation values. Before using a wheel with a modified internal structure, it is recommended to perform further tests in order to select the optimal ring material depending on the transferred load and other operating parameters of the transmission. Selection of a damping ring material with too low stiffness may cause too large displacements of the toothed rim. This phenomenal may have a negative impact on the meshing work. Correct selection of the damping ring material may contribute not only to lowering the transmission of vibrations from the meshing zone to the remaining gearbox's elements, but also, as in the case of polyurethane, can lower the maximum stress values of gear.

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