METHOD OF INVESTIGATING THE 3D PRINTED DRIVE ELEMENTS

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Abstract: As part of the research described in the paper, a method of verifying the suitability of 3D prints in industrial drive applications has been developed. The structure of the testing stand has been proposed, allowing for different loads and other factors affecting the work of the motion transmission mechanism. On the example of a gear wheel test, a computer simulation of the measuring procedure was performed. It showed what situations are possible to convey using the technique under consideration and how to analyse the received information. Due to the verification carried out using the numerical model of the device, the application points and the values of forces acting on individual surfaces of the tested elements were identified at their specific installation in the area of the stand.

Key words: 3D print, drive, machine elements, methods of investigation, durability analysis.

1. INTRODUCTION

Additive manufacturing technologies are increasingly used in industry. The most available is the FFF (fused filament fabrication) method. It is associated with the so-called "Table printers", with relatively small workspace, low price and easy of use. Apart from target products for end users, machine parts are also being printed. One of the most important features of industrial mechanical systems is their strength. Drive components, in particular gear and coupling elements, are an extensive group of parts that are most often subject to fatigue wear. In the process of design, special attention is paid to the possibilities of transmitting the moment of power. The constructions are optimized in terms of appropriate stress distribution so that the body contact is characterized by applying pressure in specific places and avoiding accumulation of energy in certain points. In the operation of the device, the key is the resistance of the part to the forces that it undergoes during its intended use. It is therefore important to carry out tests in which the conditions are as close as possible to the standard operation of the machine. As part of the research described in the paper, a method of verifying the suitability of 3D printed parts in industrial drive applications has been developed. Many different additive manufacturing techniques are available, providing the variety of materials possible to be used. In the paper plastic FFF 3D printing method was investigated. The special structure of the testing stand has been proposed, which allows for different loads and other factors affecting the work of the motion transmission mechanism. On the example of a gear wheel test, a computer simulation of the measuring procedure was performed. It showed what situations are possible to convey using the technique under consideration and how to analyse the received information. Due to the verification carried out using the numerical model of the device, the application points and the values of forces acting on individual surfaces of the tested elements were identified at their specific installation in the area of the stand. This is the knowledge needed to standardize the procedures in the method under consideration to the various test conditions that can be generated (overload, technological errors of drive components, their incorrect mounting, etc.). Theoretical works gave a promising result and create the basis for further validation and implementation activities. The described solution has the marks of innovation and can be an important achievement in the development of maintenance of production plants. Additive manufacturing technologies are one of the pillars of Industry 4.0, so considerations devoted to them are of particular importance today.

Figure 1 presents the outline of the described testing stand. The system under consideration consists of first motor (A), which rotates the pinion gear (B) coupled with spur gear (C) attached to second motor (D). Both gears are mounted on shafts in bearing housings (E), which are fixed to aluminium profiles (F).

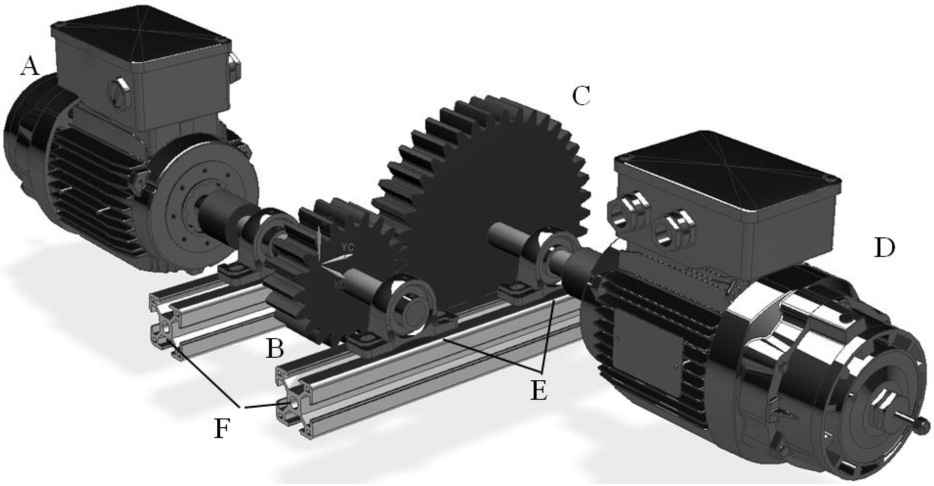

Fig. 1. System under consideration

Thanks to aluminium profiles we can easily change the mounting position of bearing housings (F) thus simulating theirs incorrect mounting or technological errors. Using the motors, we can simulate different load stays. For instance, the motor (A) can rotate the gears, while motor (D) will be responsible for creating the withstanding load and simulating the overload of the drivetrain. Both motors will be controlled by inverters, what will allow for fluent adjustments of current, resulting in change of theirs rotating speed and created torque.

2. SIMULATION

The MBS/FEM hybrid simulation method was used to show the idea of proposed investigation method.
Although the FEM and MBS approaches are separate methods from each other, it is possible to combine them to solve the system containing more subsystems. While FEM calculates the stress and strain, the MBS gives the information on acceleration, velocity and loads in moving bodies. It could be said, that FEM is more related to part stage, while MBS is related to the whole assembly or full system containing of parts (Sekar et al., 2017).

In the MBS environment (Multi Body Simulation), the structure and all kinematic parameters of investigated bodies were defined. Pinion gear has a declared constant rotating speed. On the spur gear the torque is applied to simulate the load on the exit shaft of the transmission. The structure is shown on Figure 2. This will allow to check the durability of 3D printed gearing under real working conditions and prevent the quick break down of the transmission.
To show the dynamics of the torque transmission, contact conditions have been defined as force interaction between elements in contact state as shown on Figure 3. This force between gear teeth was examined. The teeth were set in simulation as rigid bodies. The whole interaction cycle between teeth was considered. One tooth from pinion gear and one tooth from spur gear. The mentioned force causes stress on the surface of teeth, which is responsible for main damages of gear wheels: tooth break, pitting and scoring. Supervision of this force seems to be crucial for gear wheel durability and transmissions lifetime (Jaśkiewicz, 1982).

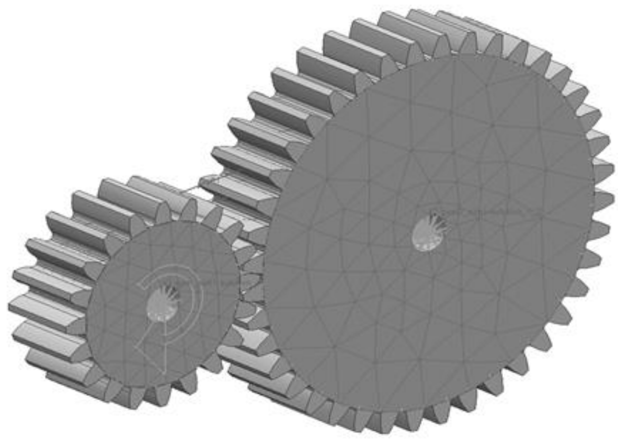

Fig. 2. Structure in Multi Body Simulation system

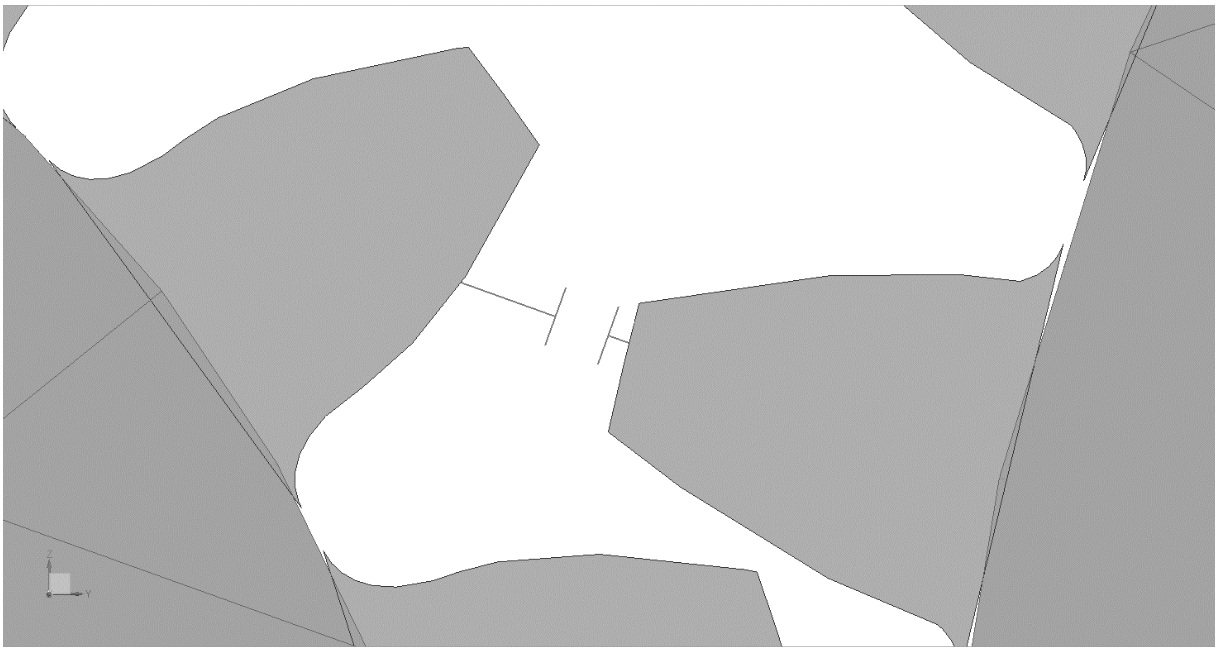

Fig. 3. Force interactions between teeth

Later, the FEM object (Finite Elements Method) was introduced to simulation. The object contained the results of modal analysis of main working part of pinion gear. It is the object in form of mesh, which allows to show the deformation and tension occurring during various kinetic interactions as shown on Figure 4. The object can be loaded and connected with different objects just in specified points. In considered example, the object was used to define the state of gear wheels in response to torsion, which appears during the work of loaded transmission as shown on Figure 5.

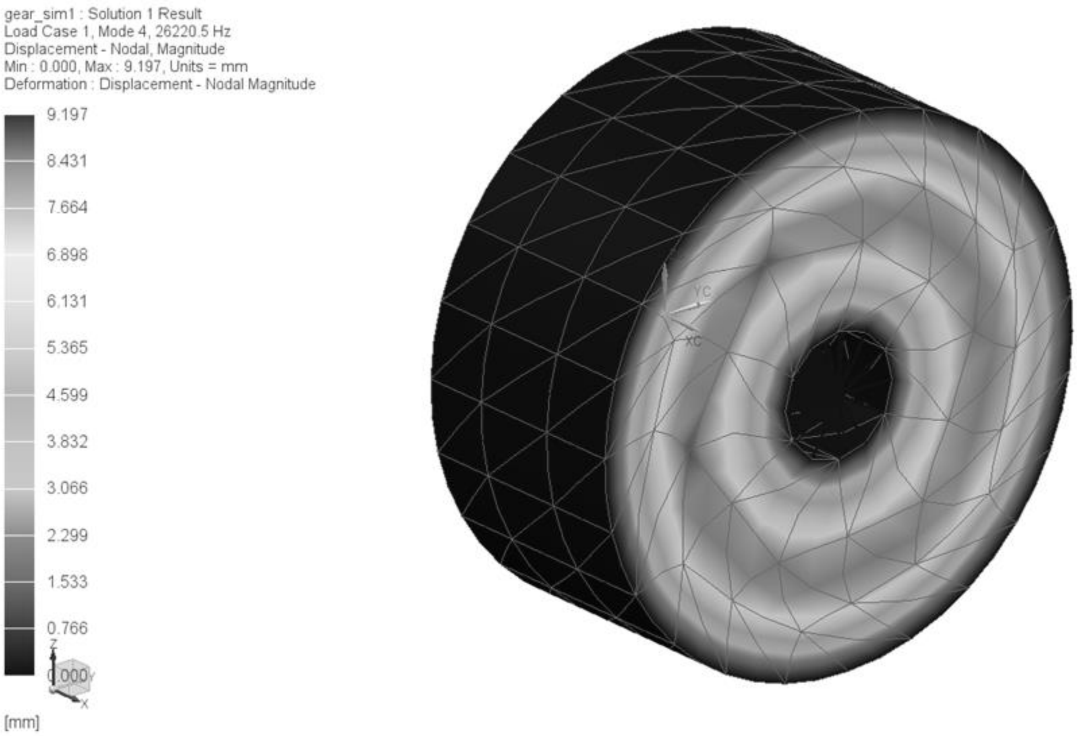

Fig. 4. Results of FEM analysis

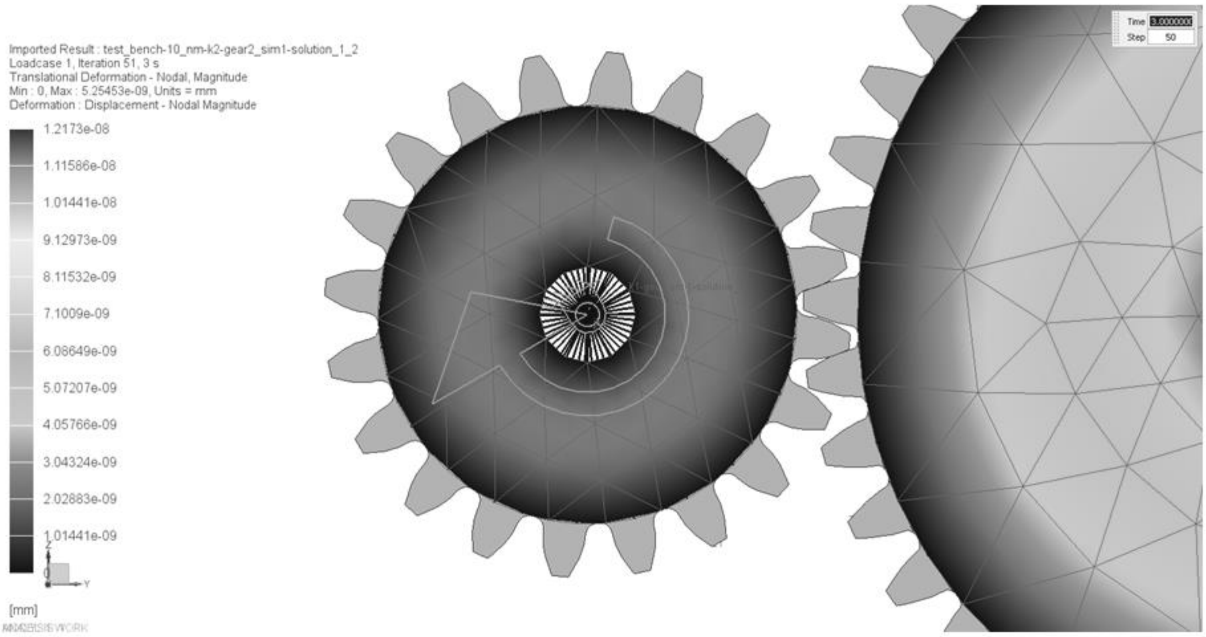

Fig. 5. FEM results of torsion state

The spur gear's cylindrical outer surface is joined with gear ring through the centre of the circle, on which the force from pinion's tooth is applied, due to defined contact conditions. The cylindrical inner surface is combined with the driving torque, which simulates the withstanding motion resistance as shown on Figure 6.

The cylindrical outer surface of the pinion is joined to the gear ring by the centre of the circle, which is affected by the resistance of the output wheel due to defined contact conditions; the cylindrical inner surface is combined with the constant speed source as shown on Figure 7.

The described manner of CAE analysis allows to track and measure the interaction force between teeth. This force has most destructive action in the last moment of contact between teeth, because the lever arm of acting force is the biggest at that particular moment (Dziama et al., 1995).

The most common destruction of gear wheels is pitting, or teeth break at its base. It is caused by too big tension focused in certain areas (Ochęduszko, 2012 a, b, c) (Żółtowski, 2004).

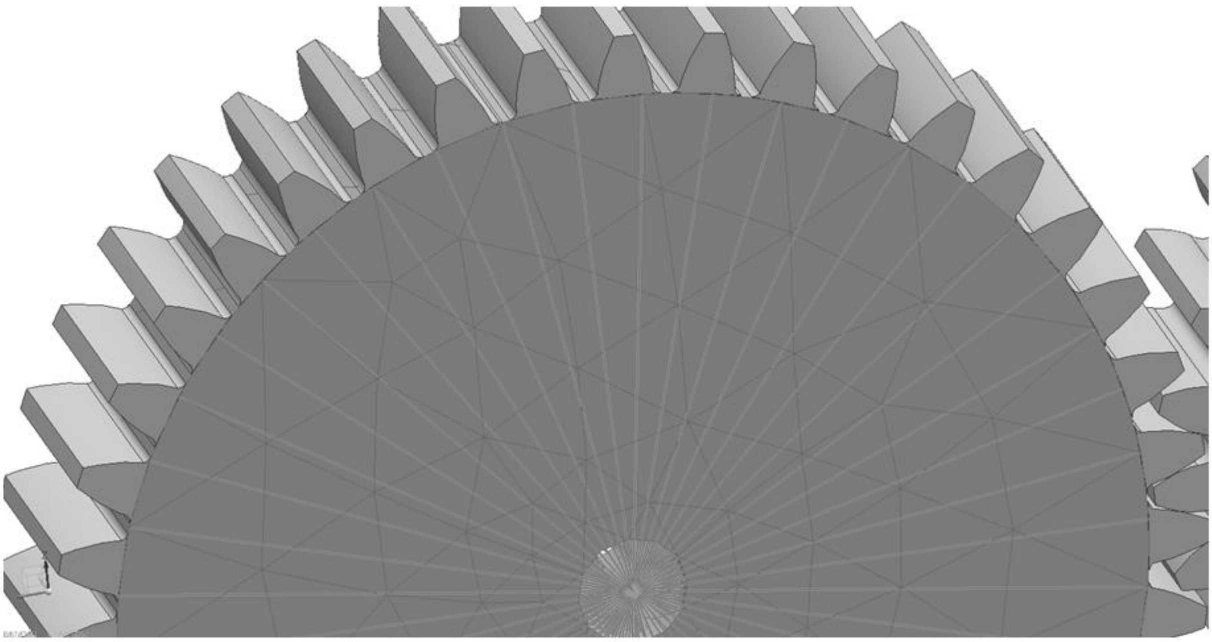

Fig. 6. Boundary conditions of spur gear in FEM analysis

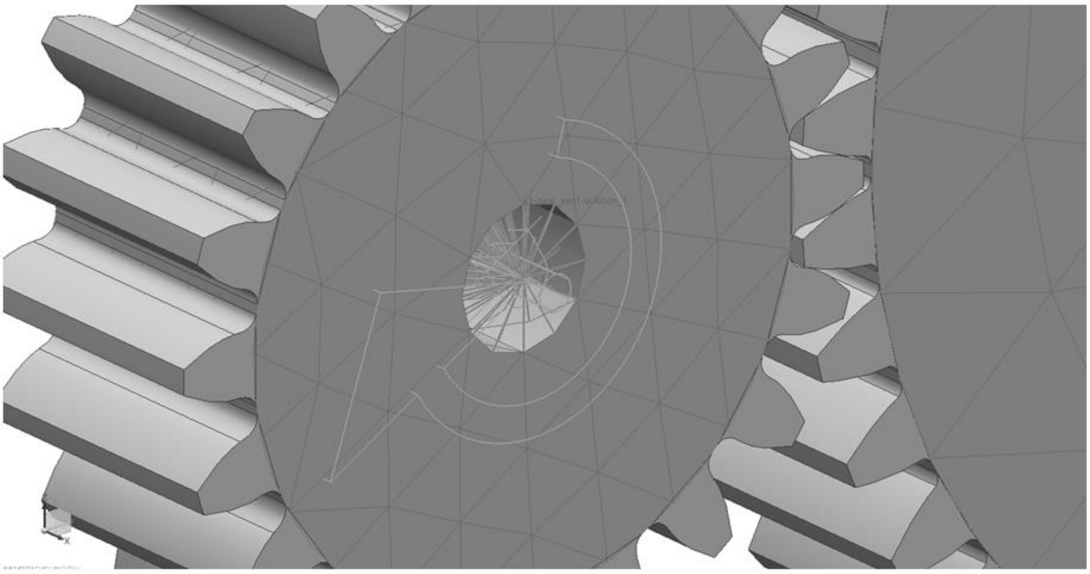

Fig. 7. Boundary conditions of pinion gear in FEM analysis

3. RESULTS AND DISCUSSIONS

It has been shown that with different gear arrangements in relation to each other and different motion resistances, forces and stresses of varying value appear. The simulation was performed in 4 different cases shown on Figures 8, 9, 10, 11: correct and incorrect teeth gearing (meshing), with 10 Nm and 50 Nm withstanding load each. In total 4 different cases were received and simulated. Based on the simulation, the plots of force acting between teeth were made for each simulation case. The graphic interpretation of results is shown below on Figure 12 and Figure 13.

On the Figure 12, it is visible, that under correct meshing, the withstanding force has big influence on force between gear's teeth. The raise of interaction force is almost proportional to the raise of withstanding force. However, it can be seen on Figure 13, that if the meshing is incorrect, the interaction force is significantly bigger and almost independent from withstanding force as the interaction force during incorrect meshing is almost ten times higher than under correct gearing.

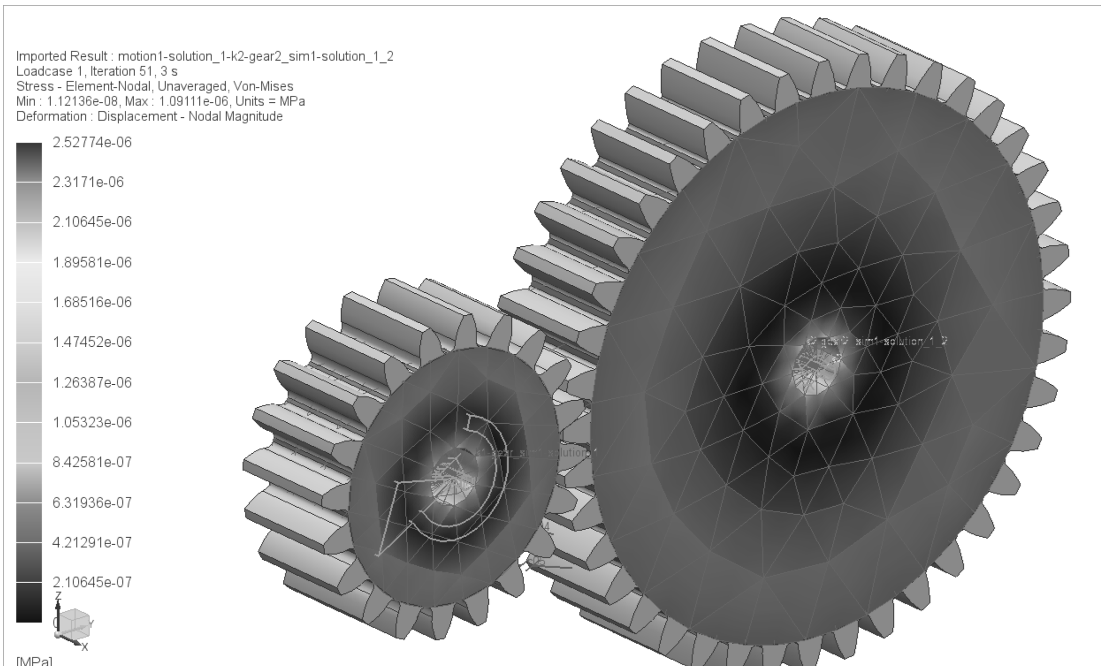

Fig. 8. Result of correct gearing, 10 Nm withstanding load

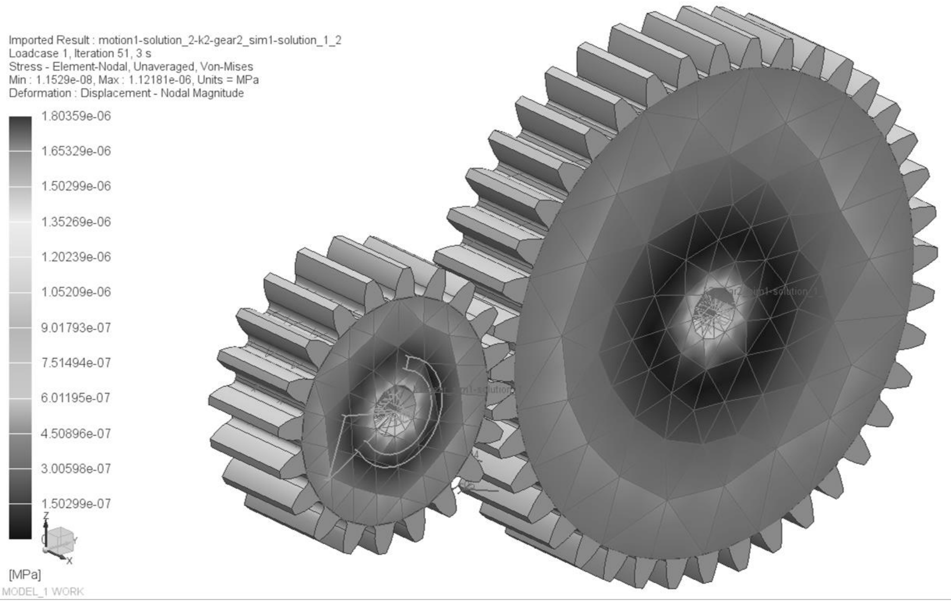

Fig. 9. Result of correct gearing, 50 Nm withstanding load

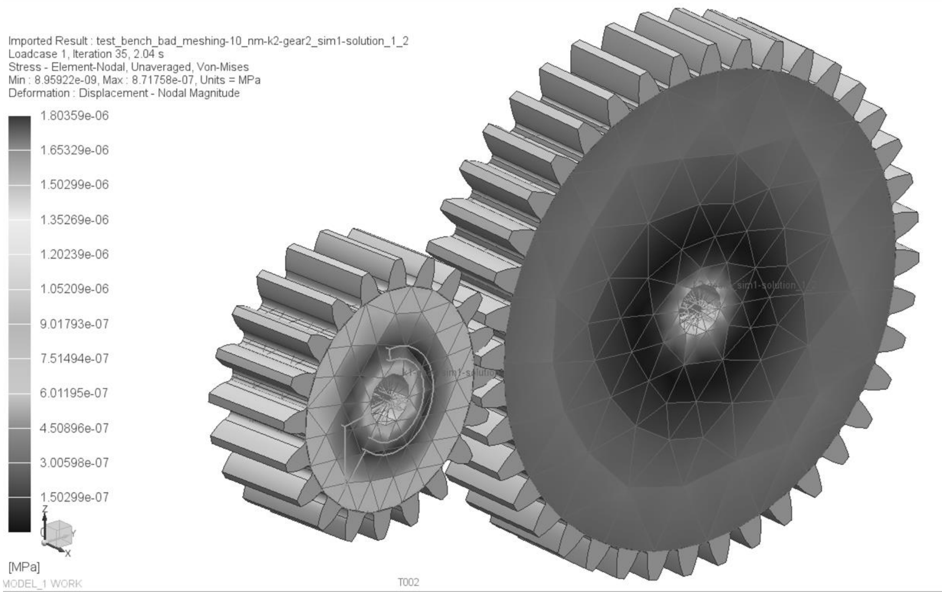

Fig. 10. Result of incorrect gearing, 10 Nm withstanding load

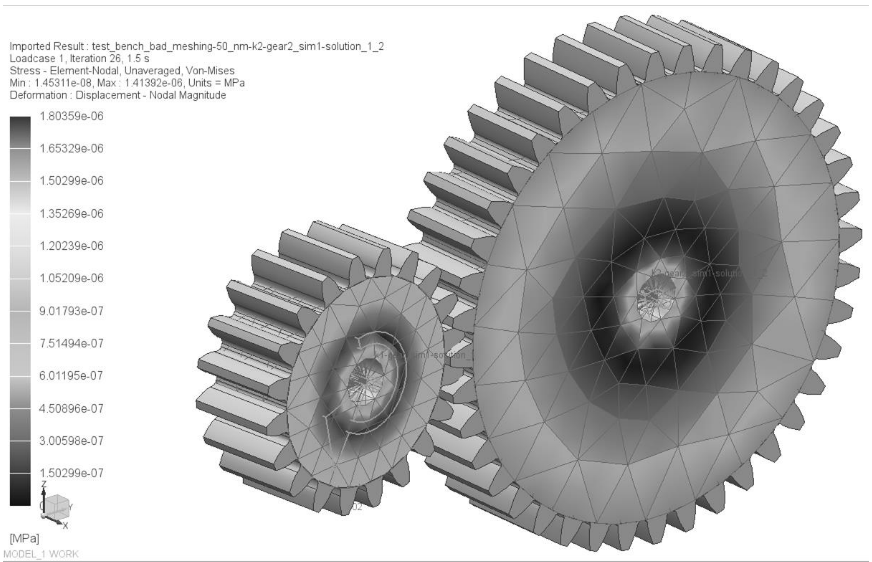

Fig. 11. Result of incorrect gearing, 50 Nm withstanding load

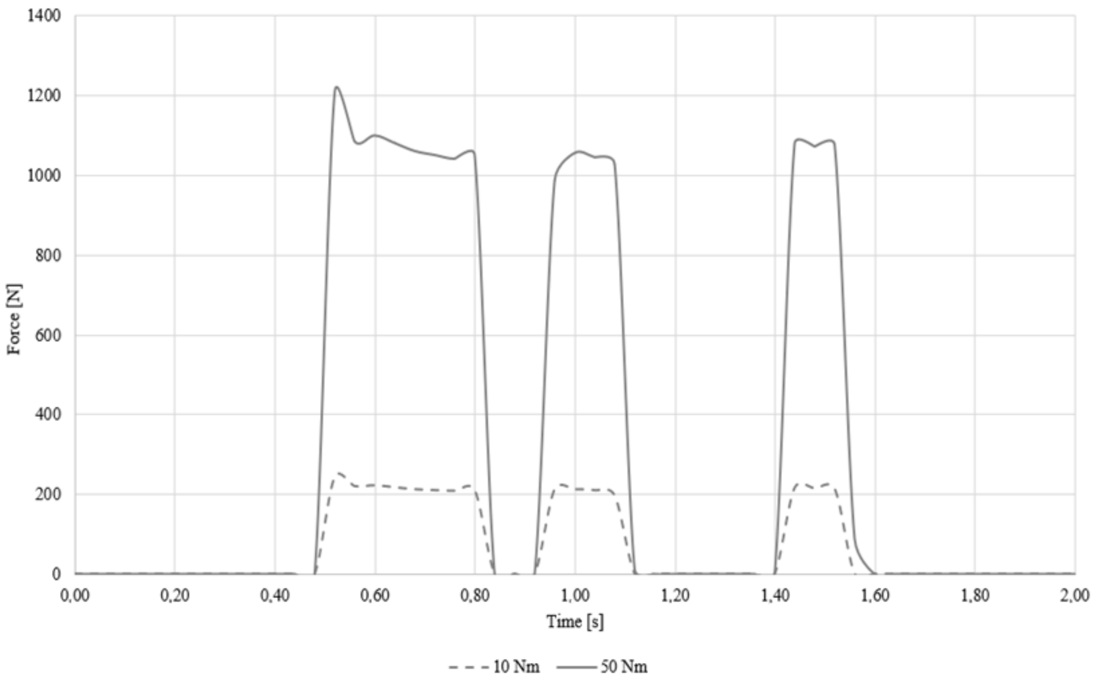

Fig. 12. Plot of force in teeth contact during correct gearing, 10 Nm and 50 Nm withstanding load

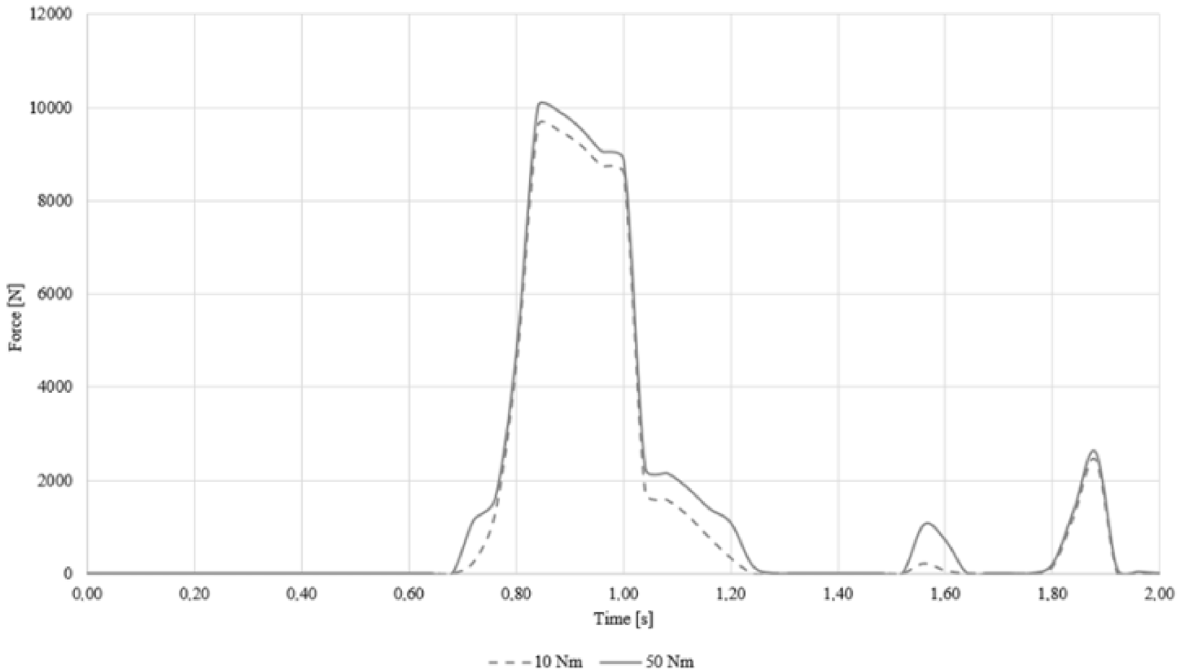

Fig. 13. Plot of force in teeth contact during correct gearing, 50 Nm withstanding load

4. DISCUSSION AND CONCLUSIONS

Thanks to the model it is possible to find the least favourable configuration case of the entire drive in terms of gear wheel durability. The first examination can be made using the simulation, what will reject the less durable solutions, saving the time and money for real testing.

In the real system, the specified conditions will be called based on the simulation. On-site tests will allow to examine how gears made with different additive manufacturing techniques and using different materials will react to the specific circumstances. Testing of few or several gear wheels made with the same technique and of the same material will show, how reliable and stabile the manufacturing process is or if there are no material faults e.g. local material lack.

Development of proper gear wheel made by additive manufacturing process can lead to time and cost saving of maintenance departments of production companies. Many of them already possess the 3D-printing devices, which are mainly used in prototyping and product development processes. However, spare parts could be manufactured as well. Letting the companies not to keep spare parts on the stock (freezing money and storage space) or not to order the parts in express delivery mode (costing extra money). Also, thanks to additive manufacturing methods, some parts can be redesigned, gaining new features or requiring less manufacturing processes to be made (because of technological point of view).

The described testing method has the marks of innovation and can be used to standardize the durability testing of gear wheel.

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