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# MODELING OF TRANSMISSION GEARS: SPUR (WITH STRAIGHT TEETH) AND WORM, USING PROGRAM INVENTOR PROFESSIONAL AND SIMULATION MECHANICAL. APPLICATION TEST

*The article presents designing of gearboxes using Inventor Professional 2017 and the ability to implement these projected models to the Simulation Mechanical 2017. For comparison there were design purposes transmission gears as: spur gear with straight teeth and worm gear. The results of calculations and parameters of the transmission gears are presented in tabular form. Shown dynamic analysis- nonlinear allowing to examine the transmission gears for endurance.*

## INTRODUCTION

Gearing drives were invented back in the 30s of the last century, but until now their use is becoming more common with the progress of computer automated production. The manufacturing process is relatively expensive and requires high skills. The design of the planetary gear has a big advantage compared to traditional transmission, especially in the case of applications requiring both high torque and small dimensions of the drive. Nowadays an increasing demand for modern gears, which have many advantages over conventional gearing [3].

Mechanical gears is a mechanical drive for transferring rotational motion from the active (driving) on the output shaft (driven).

The main task of the gearbox is a change in the rotational speed and torque - reduction or multiplication, which can be described by the following equation:

$$T_1, \omega_1 \Longrightarrow T_2 \omega_2 \qquad (1)$$

The purpose of the transmission gears may be:
– transfer mechanical energy from one place to another,
– change the character of the movement,
– change motion parameters such as strength and speed,
– change the plane of motion.

The largest group among the transmissions are gear trains, because they have several advantages such as a wide range of application, high efficiency and depending on the shape of the teeth:
– with straight teeth: simple implementation;
– with oblique teeth: silent operation;
– with chevron teeth: quiet operation, high load capacity.

The simplest transmission gear consists of two gears working together in a rotating motion. And the rotation torque is transferred from one wheel to the other, by engagement (coupling the enclosed design). Depending on the geometric shape of the block, the teeth were scored distinguishes between the wheel and the cylindrical pinion and the individual variations [1, 3].

The traditional gears (Fig. 1.) such as Spur, Bevel or worm gearing type with Involute tooth profiles Modern high transmission ratio gear drives are enriched with serial connections.
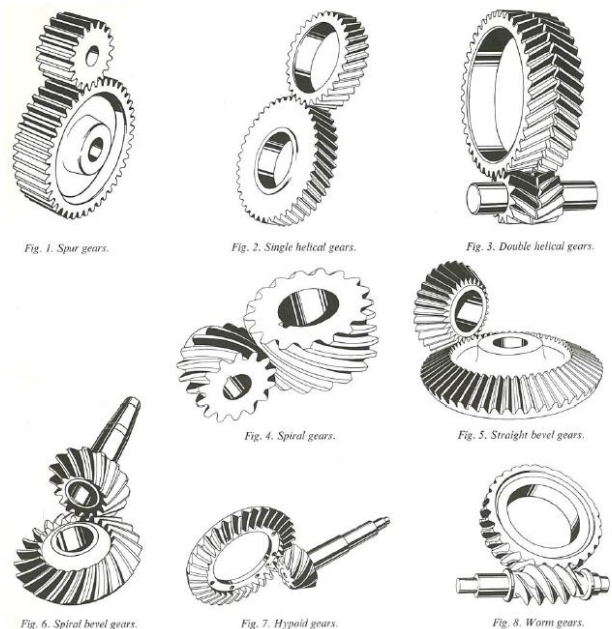


**Fig. 1.** *Conventional gearing systems [2]*

In modern drive systems it is necessary to quickly reduce high speed. For several years, they are commonly used cycloidal gearboxes, but besides low mass, maintenance there are problems occur over their lifecycle. The idea of planetary gear train (also called circulation gearbox) is based on the teams on the planet, which, through multipoint mesh transmit power with an appropriate gear ratio. Each such unit consists of: the sun gear, the band satellites placed on the yoke and the ring gear. In the planetary gear drive assembly is transferred to a multitude which results in less stress on the individual teeth and hence they have smaller dimensions. In the case of operation of the hammer, the loads in the gear stage are moved at the same time for a few teeth, which minimizes the risk gear damage and is a major advantage compared to the traditional gear, where the torque is transmitted by a single point.

Other high ratio gears trains such as harmonic drives have been attractive for high precision applications, but have some disadvantages – an increasing trend in the small initial backlash due to wear, higher wear-rate due to friction, lost motion due to low overall

drive-stiffness, poor shock resistance and relatively low overall efficiency [2].

## 1. GEAR TRAIN DESIGNING IN 3D CAD PROGRAMS

Designing a gear is not a major problem- on the basis of standards (i.e. PN-ISO 6336-1: 2000, PN-ISO 6336-2: 2000, PN-M-88509-03:1990), there is need to select the type of gear, calculate load capacity and choose the right type of incision tooth. Designing gears as a working drawing (2D) come down to the use of certain simplifications and placing parameters in the table. Currently designing a gear, as well as all sorts of transmission gears carried out using CAD software. They allow to use wizards to facilitate the work of the designer [4].

This publication will discuss the process of construction transmission gears in the Inventor Professional 2017 and Mechanical Simulation 2017. In addition, the parameters toothed wheel will be defined as a function and tabulated.

Inventor is kind of CAD software used to design parts, equipment, assemblies as 3D models. On the basis of this model it is possible to make preliminary drawings, working drawings, assembly drawings, section drawings, detail drawings and others. Autodesk Inventor is designed to work with the assemblies reaching several thousand items.

Additionally, the program contain:
− module designed to test endurance of a single part or assemblies, this analysis is based on the ANSYS solver.
− module for creating assemblies have the ability to create animation and rendering.

Mechanical Simulation allows for making dynamic simulations to be able to predict performance, optimize designs, and verify the operation of designed mechanisms. This program allows you to perform calculations, simulation and analysis of mechanical equipment. It is possible to import CAD models from a variety of 3D systems, creating meshing (using MES), designing the boundary conditions, etc.

In the Simulation Mechanical, it is possible to conduct analyzes such as static analysis in the field of linear, non-linear analysis, fatigue analysis, dynamic analysis in the field of linear, buckling analysis of large strain and stress, thermal analysis in a state fixed and variable analysis range, buckling and permanent deformation.

### 1.1. Draft of transmission gears

For further considerations adopted simplified models of transmission gears: spur and worm. In the process of the formation of structures used in the application of Autodesk Inventor of Professional 2017. It started with the design of mechanisms for cooperating gears. For purposes of analysis used the generator gear. On the ribbon we choose 'Design', next 'Power Transmission panel' and prefer type of transmission gear (spur with straight teeth or worm). Next is choosing the appropriate widths, diameters, materials and modules designed three simple gears. Calculation table, allows for perform calculations. If you design the gearbox incorrectly for example: not taking into account the appropriate safety coefficients calculation results are shown in red, which indicates inappropriate task parameters.

The figures below show the construction of transmission gears created in Inventor Professional (Figure 2 and 3).
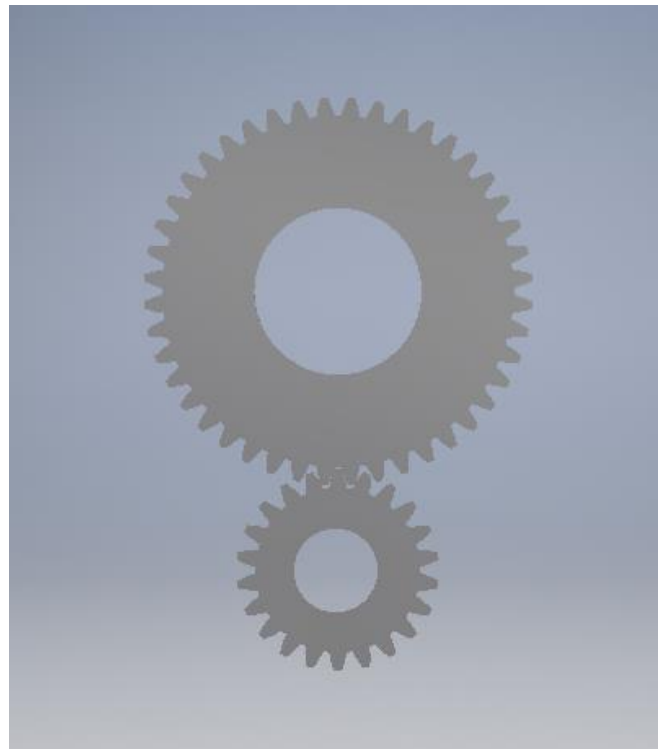
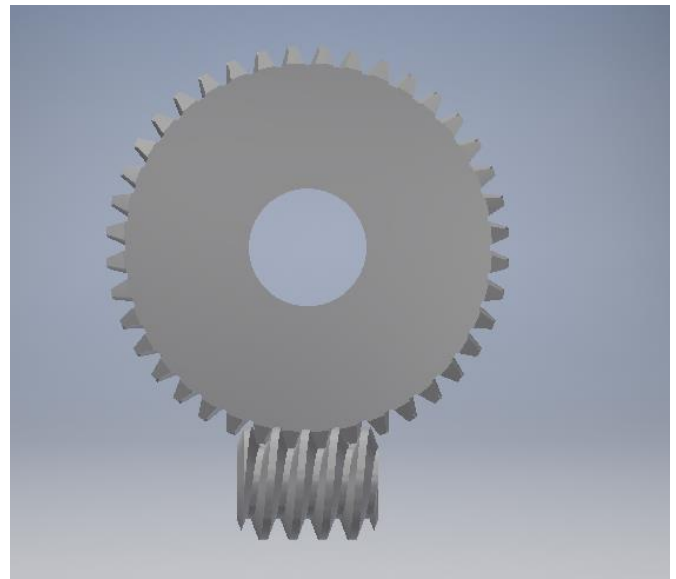

***Fig. 2.*** *Spur gear with straight teeth*



***Fig. 3.*** *Worm gear*

The parameters describing the characteristic dimensions of wheels designed gear and load values of each of their degrees awarded in pictures consist of tables (Figures: 4, 5).

| Parameter name | Symbol | Spur gear |
|---|---|---|
| Gear ratio | i | 2 |
| Modulus | m | 6 |
| Tooth contact ratio | ε | 1,5709 |
| Spiral angle of the teeth | β | 0 |
| Centre distance | aw | 200 [mm] |
| Shearing force | Fr | 56,479 [N] |
| Longitudinal force | Ft | 143,239 [N] |
| Normal force | Fa | 0 [N] |
| The number of teeth | $z_1/z_2$ | 22/44 [mm] |
| Reference diameter | $d_1/d_2$ | 132/264 [mm] |
| Space width | $b_1/b_2$ | 20/20 [mm] |
| Velocity | $n_1/n_2$ | 1000 / 500 [rpm] |
| Torque | $T_1/T_2$ | 9,549 / 18,717 [Nm] |
| The efficiency of the cooperating pair of gears | η | 0,980 |
| Gear material | - | C45/C45 |

**Fig. 4.** *The most important parameters of spur gear.*

| Parameter name | Symbol | Worm gear |
|---|---|---|
| Gear ratio | i | 40 |
| Modulus | m | 3,9 |
| Tooth contact ratio | ε | 2,0063 |
| Spiral angle of the teeth | γ | 5,7106 |
| Centre distance | aw | 100 [mm] |
| Shearing force | Fr | 116,855 [N] |
| Longitudinal force | Ft | 47,746 [N] |
| Normal force | Fa | 340,231 [N] |
| Number of turns (worm) | z | 1 |
| Reference diameter (worm/worm wheel) | $d_1/d_2$ | 40/160 [mm] |
| The number of teeth (worm wheel) | z | 40 |
| Velocity (worm/worm wheel) | $n_1/n_2$ | 1000 / 25 [rpm] |
| Torque | $T_1/T_2$ | 0,955 / 25,337 [Nm] |
| The efficiency of the cooperating pair of gears | η | 0,663 |
| Gear material (worm/worm wheel) | - | Steel/Grey cast iron |

**Fig. 5.** *The most important parameters of worm gear.*

## 2. STRENGHT ANALYSIS IN THE SIMULATION MECHANICAL

Prepared transmission gear models are transported to the Simulation Mechanical program using the overlap "Simulation" and "Launch Active Model".

In this case it would be used nonlinear analysis calling MES, which is does not mean exactly the analysis using finite element method. MES in Simulation Mechanical means Mechanical Event Simulation combines kinematic, rigid, and flexible-body dynamics and nonlinear stress analysis capabilities. It is dedicated for moving elements in a dynamic event such as buckling, swinging, rotation, or oscillation. As a result, MES can simultaneously analyze mechanical events involving large deformations, nonlinear material properties, kinematic motion, and forces caused by that motion and then predict the resulting stresses.

One of the main advantage of MES is the need to make fewer assumptions. With MES, there is no need for elaborate hand calculations, interpretation of results or experiments to determine equivalent loading. The fewer assumptions that must be made lead to a smaller chance for errors.

Event simulation is performed in three basic stages:
1. Setting up the model: generate the model and set up the event simulation parameters.
2. Analyzing the model: execute the event simulation and monitor its progress.
3. Results evaluation: examine the results of the event simulation, including its animated history.

To perform event simulations, we need to follow below general steps.

After implementing the model we need to determine what type of analysis will be carried out. We can choose from the analysis presented below:
- Static Stress with Linear Material Models;
- Static Stress with Nonlinear Material Models;
- MES with Linear Materials Models - considers vibration, impact, and motion on the part or connected parts. Loadings resulting from changes in motion are computed and applied internally and automatically. Any local buckling is detected and shown on the screen.
- MES with Nonlinear Material Models - in addition to the MES with Linear Material Models analysis, this analysis can include nonlinear material behavior and nonlinear deformation.

In this case, the choice of nonlinear analysis in order to check the gear unit for endurance.

Second step is to generate a mesh: solid, midplane (mesh consists of a web of 3-noded triangular elements and forms a 2D representation of a solid model) or surface for individual parts and define the types of elements in the model- we determine the type of element to use. Select from bricks, tetrahedral, beams, plates, 2D to represent the geometry and type of analysis required.

Next is defining and specifying the boundary conditions such as, inter alia:
- nodal prescribed displacement,
- joints and pinned connections for rotational purposes,
- restrict movement in planes- set reference points with varying degrees of freedom,
- gravity or acceleration (if it is necessary),
- revolutions or angular acceleration that the model can be experiencing,
- forces, pressures and initial directions of pressures,
- mass density of materials.

It is also necessary to assign materials for all parts of the gearbox and an indication of the detailed analysis parameters, are here to choose from, there are many options, depending on the purpose of the analysis. We can specify (inter alia):
- the length of the time in which the device / mechanism (in this case: transmission gear) will work,
- the number of steps to take per second to calculate the displacements and stresses over time,
- operating temperature,
- the influence of gravity and others, depending on results, which we want to obtain.

For all the transmission gears are designed the same time data analysis, the same number of revolutions completed within the set time and the same rotation speed. They generated the same number of calculation steps. The following presents the results of dynamic

analysis for each gear unit work- and thus shows the possible deformations and displacements of the gears.

As a result of the event we obtain monitoring of motion, deformations, and stresses as they occur. Both graphical plots of values vs. time and graphical visual displays are available. Velocities and accelerations at points on the model can be monitored. Mechanical Simulation also produce graphical plots of stress contours, motion, actual deformations for each step recorded during the event simulation. As a result of simulation we obtain the minimum and maximum stresses during the event to facilitate fatigue analysis. In the article results of the analysis presented as the pictures showing deformations occurring during operation. There is also legend showing color as the size of the deformation in mm. The drive shaft gear has been replaced by the so-called. joint adequate for the move in a given case load- the figure presented in the form of thin blue beams.

Figure 6 shows the results of dynamic analysis carried out for the spur gear. On the left shows the scale of deformation in the form of 'Displacement Magnitude [mm]', where the color blue means no deformation, along with warmer colors mapped more local deformation. As follows from the presented analysis the greatest strain during the gear unit will be present at the end of the gears, and the contact elements being in the then given to the buttress.
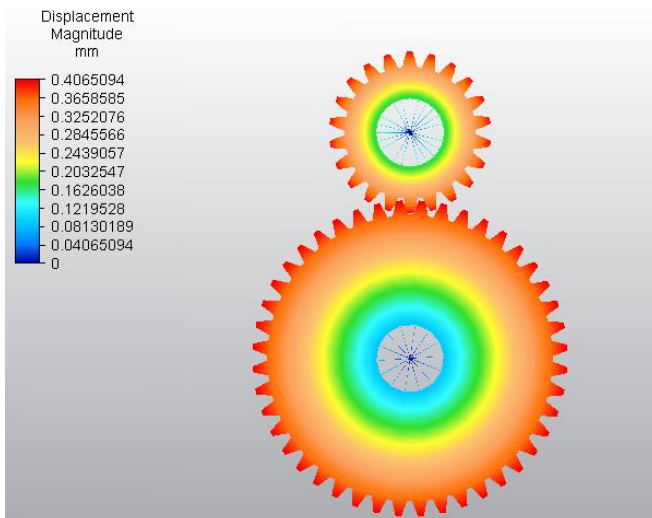


**Fig. 6.** *The results of dynamic analysis for spur gear*

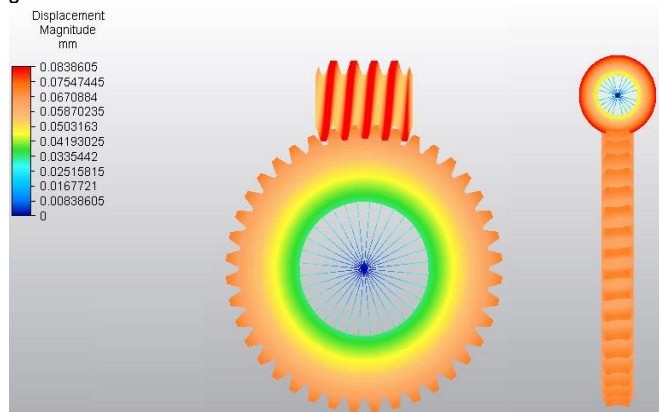In the following figure 7 shows the result of analysis for the worm gear.



**Fig. 7.** *The results of dynamic analysis for worm gear.*

## SUMMARY

Inventor Professional is a program, which allows you to generate the transmission gears of given parameters, assigning a particular material from which the gearbox should be manufactured. It is a simple tool for using the generator to quickly design any gear trains.

Simulation Mechanical allows you to perform advanced dynamic analysis, allowing you to check the strength of the mechanism of possible emerging during work deformation and tasks of additional parameters affecting the quality and speed of work. This program allows for a relatively quick to make dynamic analysis, without the need for painstaking research using experimental. It allows for early detection of fatigue damage and optimize the operation of the equipment. In this article it is shown the possible deformation arising under the given conditions and chosen material. It was also shown that areas of the elements are the most vulnerable to overload. This can be the basis for design improvements, for example: in the geometry of gears, change materials (which turn out to be more durable), reducing the number of revolutions during operation, change the type of oil, reduce the influence of temperature, change the working parameters.

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**Modelowanie przekładni ślimakowej oraz walcowej przy użyciu programów Inventor Professional oraz Simulation Mechanical. Test aplikacji**

*W artykule przedstawiono proces projektowania przekładni przy pomocy programu Inventor Professional 2017 oraz możliwość zaimplementowania tychże modeli do programu Simulation Mechanical 2017. Dla celów porównawczych zaprojektowano przekładnie: walcową (o zębach prostych), a także przekładnię ślimakową. Wyniki obliczeń oraz parametry przekładni przedstawiono w postaci tabelarycznej. Przeprowadzono analizę dynamiczną- nieliniową pozwalającą na zbadanie przekładni pod kątem ich wytrzymałości.*

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