# RESEARCHES CONCERNING SHAFTS AND GEARS MILLING PROCESS

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***Abstract:*** Machining still is the unsurpassed method of producing gears of all types and sizes with high accuracy. The generating process is used to produce most high-quality gears. Hobs are generally used for such work as finishing spur gears, spiral gears, and worm wheels. Anssembled hobs could be an answer to increase versatility and universality of this method. With the wide acceptance of the PC and the availability of numerous types of engineering software, the use of computer-aided drafting (CAD) and computer-aided design and drafting (CADD) has increased greatly in recent years. The modern analytical tool for addressing such problems is finite element analysis (FEA) or finite element modeling (FEM).
***Key words:*** Gear hob, milling, gear, CAD, FEA.

## 1. INTRODUCTION

Gears are made by various methods, such as machining, rolling, extrusion, blanking, powder metallurgy, casting, or forging. Machining still is the unsurpassed method of producing gears of all types and sizes with high accuracy. Roll forming can be used only on ductile materials; however, it has been highly developed and widely adopted in recent years. Casting, powder metallurgy, extruding, rolling, grinding, molding, and stamping techniques are used commercially in gear production.
There are three basic methods for machining gears.
*Form cutting* uses the principle illustrated in Figure 1. The equipment and cutters required are relatively simple, and standard machines, usually milling, are often used.

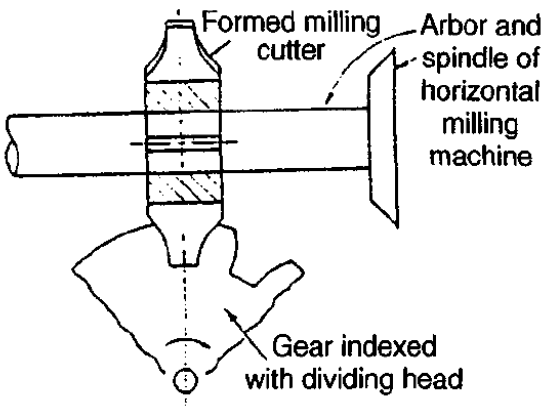



Fig. 1. Form cutting process

Theoretically, there should be different-shaped cutters for each size of gear for a given pitch, as there is a slight change in the curvature of the involute. However, one cutter can be used for several gears having different numbers of teeth without much sacrifice in their operating action. On the milling machine, the index or dividing head is used to rotate the gear blank through a certain number of degrees after each cut. The rule to use is: turns of index handle = 40/N, where N is the number of teeth. Form cutting is usually slow (Nedelcu & Pruteanu, 2000).
*Template machining* utilizes a simple, single-point cutting tool that is guided by a template (figure 2). However, the equipment is specialized, and the method is seldom used except for making large-bevel gears.

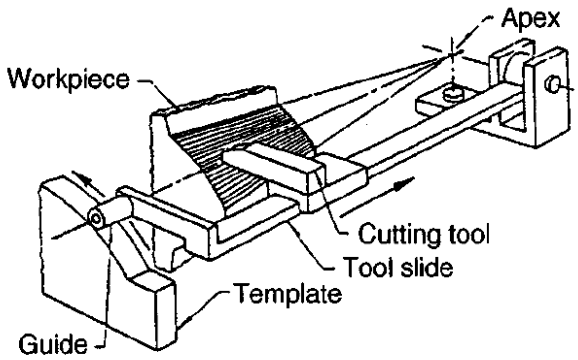



Fig. 2. Template machining

*The generating process* is used to produce most high-quality gears. This process is based on the principle that any two involute gears, or any gear and a rack, of the same diametral pitch will mesh together (Figure 3).

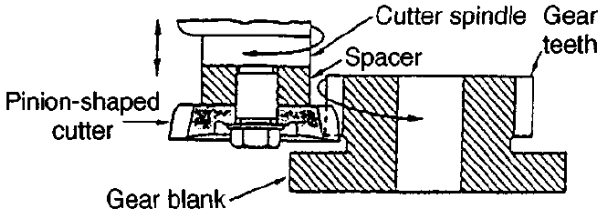



Fig. 3. Generating process with pinion-shaped cutter

Applying this principle, one of the gears (or the rack) is made into a cutter by proper sharpening and is used to cut into a mating gear blank and thus generate teeth on the blank. Gear shapers (pinion or rack), gear-hobbing machines, and bevel-gear generating machines are good examples of the gear generating machines (Nedelcu & Pruteanu, 2000).

The gear hob (Figure 4), used in gear-hobbing process (Figure 5), is a formed-tooth milling cutter with helical teeth arranged like the thread on a screw. These teeth are fluted to produce the required cutting edges.

Hobs are generally used for such work as finishing spur gears, spiral gears, and worm wheels. They may also be employed for cutting ratchets and spline shafts.

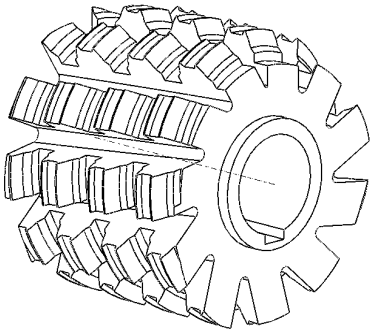


Fig. 4. Gear hob

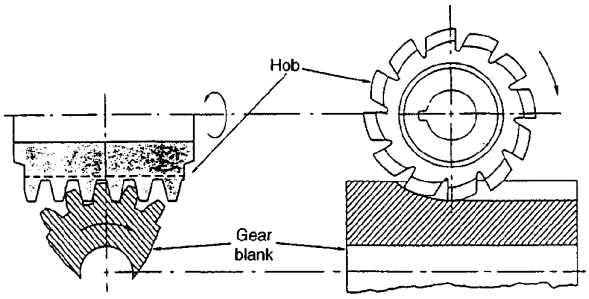



Fig. 5. Gear-hobbing process scheme

A particular case of the gear hobs are those with removable teeth, with more constructive ways of fixing the cutting blades (Figure 6).

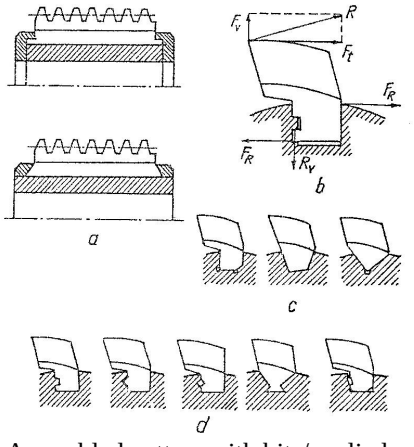
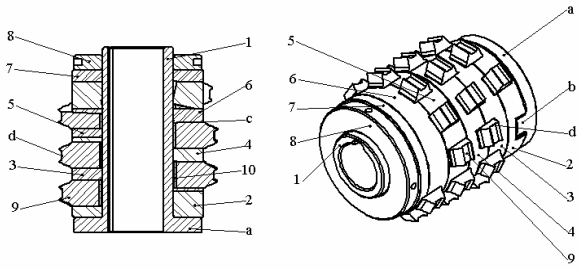



Fig. 6 Assembled cutters with bits/applied combs

As amongst the constructive types of hobbing cutters with assembled teeth met info the specialized literature, the tooth of the tool with prismatic form or the one of a small plate set on a support fillet, is set in such a way as to preserve the general geometry of the monobloc cutters, with taper shank or with generating cog rack, a new constructive form of this tooth which to allow its convenient placement on the periphery of the cutter body was searched for.

During the experiments carried out there was used a hobbing cutter with removable teeth whose construction and blades fixing are presented in (Figure 7), Patent Pending no. 2006 00184




a) b)

Fig. 7. a) Gear hob section; b) Gear hob – isometric view

As a result of the data found in the specialized literature, there can be established some criteria of classification and choice of the optimal variant in obtaining the gears using the generating process.

The following criteria of classification can be complexity:

- cutting tool complexity;
- cutting tool price;
- productivity;
- obtained products quality (precision);
- machine tools degree of diffusion and universality;
- tool durability;
- employees workmanship;
- type of production;
- cutting tool degree of universality

Analysing the technological aspects of the cutting with the hobbing cutter, we can observe a reduced productivity of these operations in comparison with other cutting machining operations, with negative consequences concerning throttling during production.

If the finishing operations using a hobbing cutter are limited under the aspect of productivity by the feed rate, surface quality, snagging operations with hobbing cutter still have enough conditions for productivity increase under the aspect of feed rate or the cutting speed increase (Enache, Şt., et al. 2000).

## 2. THEORY AND EXPERIMENTS

The universality of the constructive solutions of the cutter presented (Figure 7) is given by the possibility of keeping the cutter constituents except teeth 9, that

can be replaced with a different type of teeth with the corresponding orientation and fixing system.
With the wide acceptance of the PC and the availability of numerous types of engineering software, the use of computer-aided drafting (CAD) and computer-aided design and drafting (CADD) has increased greatly in recent years.
A key element of virtually all CAD tools for manufacturing is the need to interpret the CAD data according to manufacturing capabilities, requirements, and constraints.
Generally, this interpretation involves determining the characteristic shapes in the CAD data related to the manufacturing process of interest and applying knowledge about the process to determine the manufacturing operations and parameters. Solid models are rigorous computer data structures that contain a complete, unambiguous representation of the nominal geometry of an object (Poteraşu V. & Mihalache N., 1992).
The design started from modeling a solid (cutter body) with the dimensions of the base body of the standardized hobbing-cutter (Figure 8) on the surface of which the cutter screw was drawn

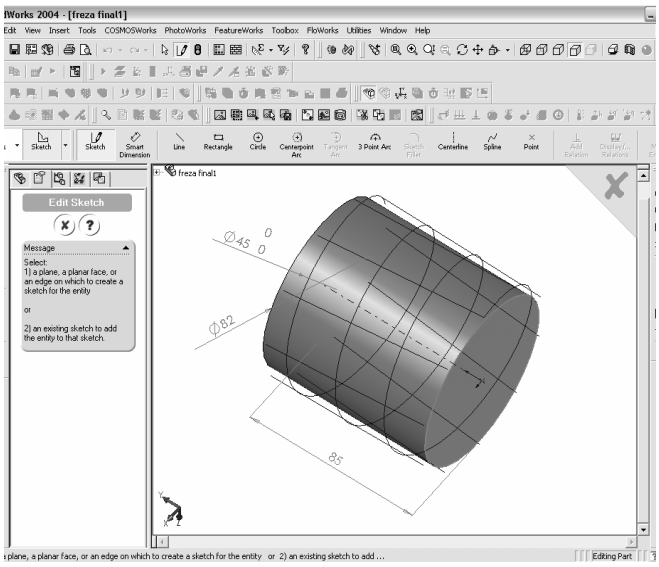


Fig. 8. Gear hob main body

At the point of intersection of the worm cutter screw and the reference cog rack paralelipipedical form holes where the blades will be fixed were made. In these holes the teeth of the cutter that respected the profile angle correction depending on the level angle were fixed (Table 1)

Table 1. Profile angle correction depending on the level angle

| $\omega^o$ | $\alpha_{n^o}$ | $\omega^o$ | $\alpha_{n^o}$ |
|---|---|---|---|
| $2^o$ | $20^o$ | $5^o30'$ | $19^o56'30"$ |
| $3^o$ | $19^o59'$ | $6^o$ | $19^o56'$ |
| $4^o$ | $19^o58'30"$ | $6^o30'$ | $19^o55'$ |
| $5^o$ | $19^o50'$ | $7^o$ | $19^o54'$ |

Efficient length of hobbing cutter:

$$L_{\min} = h_s ctg\alpha_{dn1} + p_{ax_s} + P_{axs'} = 13m_{n_1} \quad (1)$$

where:

$h_s ctg\alpha_{dn1}$ - Line of action projection;

$p_{ax_s}$ - Shifting length in connection with wear;

$P_{axs'}$ - whirls length, whirls which do not participate in cutting.

The most common problem in creating a machine or structure with good strength-to-weight ratio is to identify its critical locations and the corresponding maximum stresses or strains and to adjust the design optimally. This is difficult if a member's geometry, including the geometry and time-dependence of the loading, is complex. The modern analytical tool for addressing such problems is finite element analysis (FEA) or finite element modeling (FEM).
In order check the construction, the finite element program SolidWorks Simulation, from SolidWorks was used, where the cutting processing of the strains was simulated. This may the most disadvantageous case was the one where the teeth of the cutter stasted being processed on the cutting edge of each tooth being applied a perpendicular force on the front face of 65 daN.
In order to see how the two types of cutters behave under the action of cutting forces the finite element method was used, comparative studies being carried out for the types of cutters.
The results of the analysis using the finite element method for the modular gear hob am monobloc respectively are presented below:

Table 2. Stress results for modular gear hob

| Name | Type | Min | Location | Max | Location |
|---|---|---|---|---|---|
| Plot1 | VON: von Mises stress | 0.6967N/m^2 Node: 72976 | (-10.1704 mm, -16.9876 mm, 56.6667 mm) | 896200 N/m^2 Node: 114975 | (-1.39531 mm, -19.3178 mm, 46.2038 mm) |

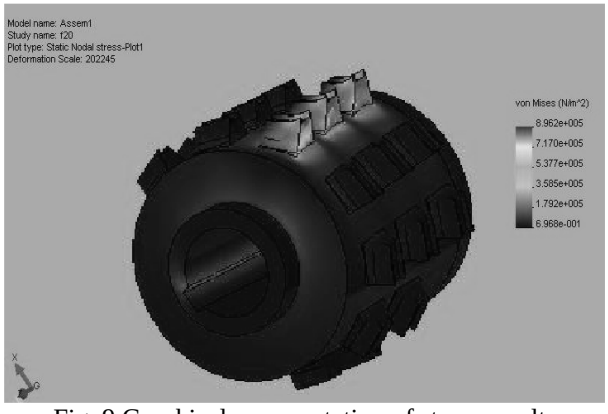


Fig. 9 Graphical representation of stress results

Table 3. Strain results for modular gear hob

| Name | Type | Min | Location | Max | Location |
|---|---|---|---|---|---|
| Plot1 | ESTRN : Equivalent strain | 3.38348e-012 Element: 44301 | (-11.7452 mm, -10.1867 mm, 64.026 mm) | 2.99845e-006 Element: 47633 | (9.31838 mm, -17.0157 mm, 74.2541 mm) |

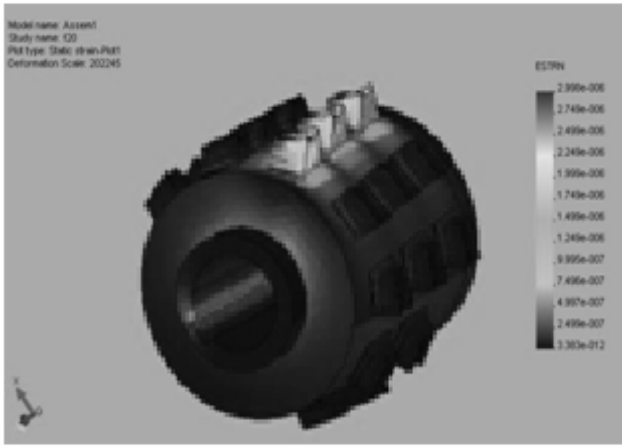


Fig. 10 Graphical representation of strain results

Table 4. Displacement results for modular gear hob

| Name | Type | Min | Location | Max | Location |
|---|---|---|---|---|---|
| Plot1 | URES: Resultant displacement | 0 m Node: 46 | (22.1036 mm, 3.84525 mm, 77.4754 mm) | 5.1976e-008 m Node: 6120 | (20.8936 mm, -41.9614 mm, 35.7651 mm) |

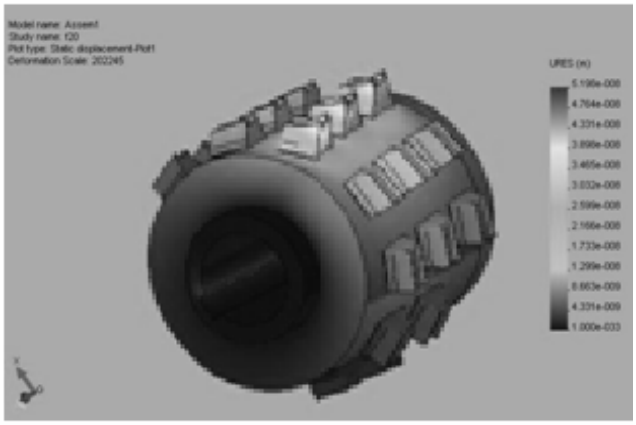


Fig. 11 Graphical representation of displacement results

Applying same changes and stress for the standardized monobloc gear hob the following results were obtained:

Table 5. Stress results for monobloc gear hob

| Name | Type | Min | Location | Max | Location |
|---|---|---|---|---|---|
| Plot1 | VON: von Mises Stress | 2.94722 N/m^2 Node: 82415 | (15.3794 mm, -53.4905 mm, 35.4498 mm) | 7.07079e+006 N/m^2 Node: 94558 | (3.22874 mm, 35.8762 mm, 26.6876 mm) |

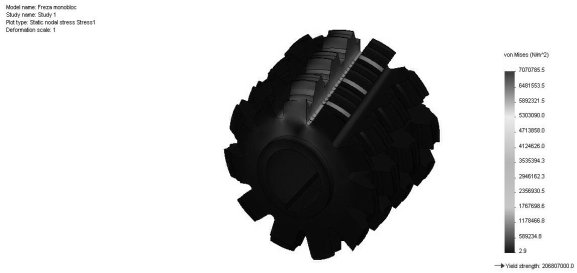


Fig. 12 Graphical representation of stress results

Table 6. Strain results for monobloc gear hob

| Name | Type | Min | Location | Max | Location |
|---|---|---|---|---|---|
| Plot1 | ESTRN: Equivalent Strain | 8.90466e-012 Element: 14939 | (18.2314 mm, -52.172 mm, -7.70814 mm) | 1.37204e-005 Element: 51224 | (5.85961 mm, 35.7987 mm, 58.1125 mm) |

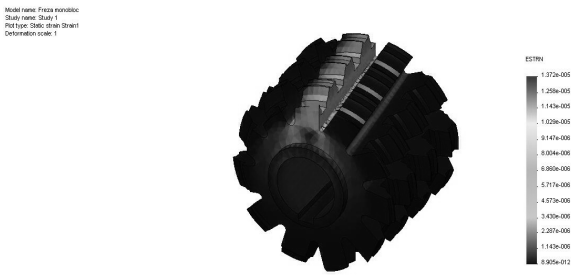


Fig. 13 Graphical representation of strain results

Table 7. Displacement results for monobloc gear hob

| Name | Type | Min | Location | Max | Location |
|---|---|---|---|---|---|
| Plot1 | URES: Resultant Displacement | 0 m Node: 123 | (5 mm, -18.3303 mm, 75 mm) | 4.60994e-007 m Node: 2458 | (0.379345 mm, 55.6791 mm, 4.16517 mm) |

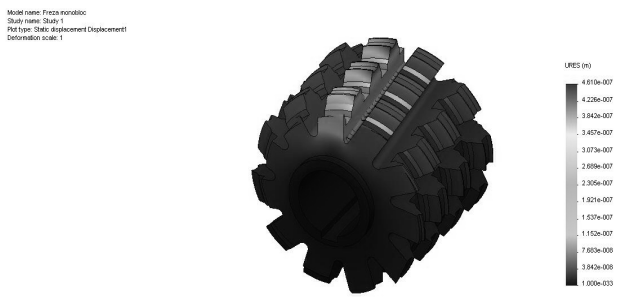
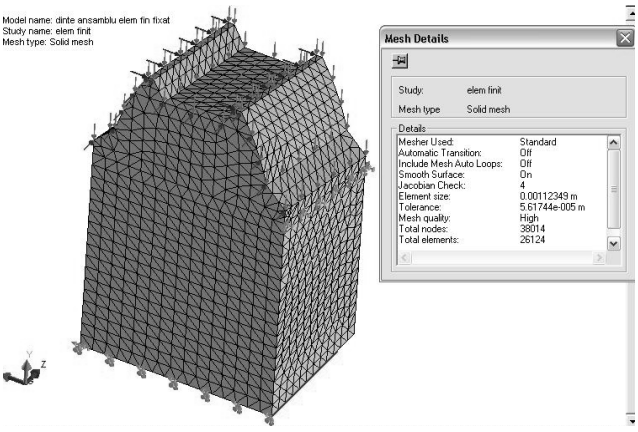



Fig. 14 Graphical representation of displacement results

In figure 15.a. is represented finite elements thedtraedrical type mesh, loads and fixtures applied – limit conditions – for one cutting tooth of the modular gear hob. In figure 15.b. are represented loads and fixtures for same cutting tooth, including those applied on hidden faces.

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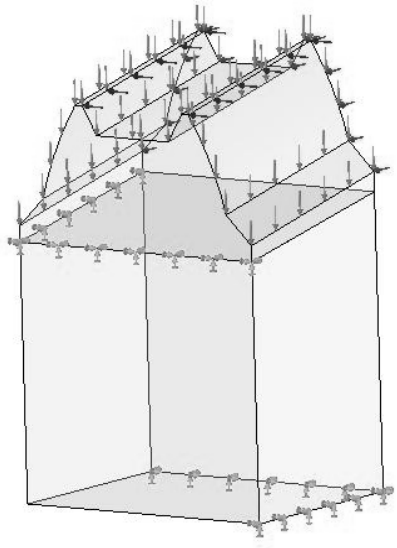
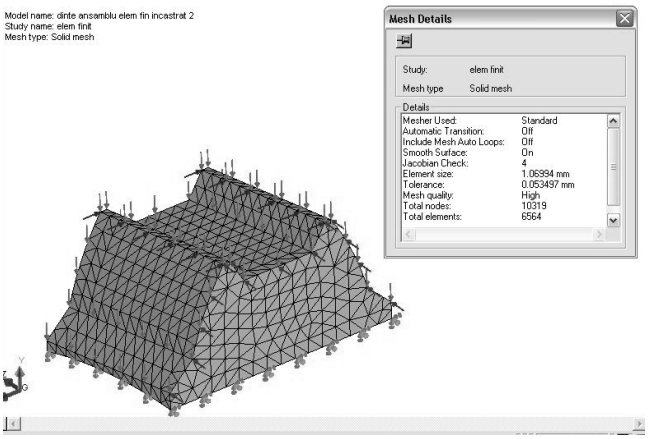


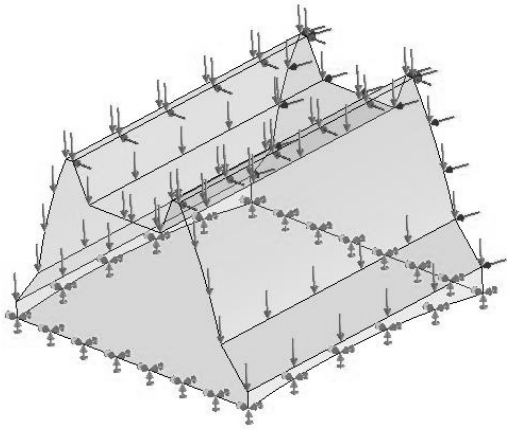
b.

Fig.15. Finite elements analysis for amovible teeth: a – thetraedral mesh; b – loads and fixtures.

Using same scenario we analize a tooth for monobloc gear hob. Instead, we consider that the tooth was flush into the main body of the hob. In figure 16.a. is represented finite elements thedtraedrical type mesh, loads and fixtures applied – limit conditions – for one cutting tooth of the monobloc gear hob. In figure 16.b. are represented loads and fixtures for same cutting tooth, including those applied on hidden faces.



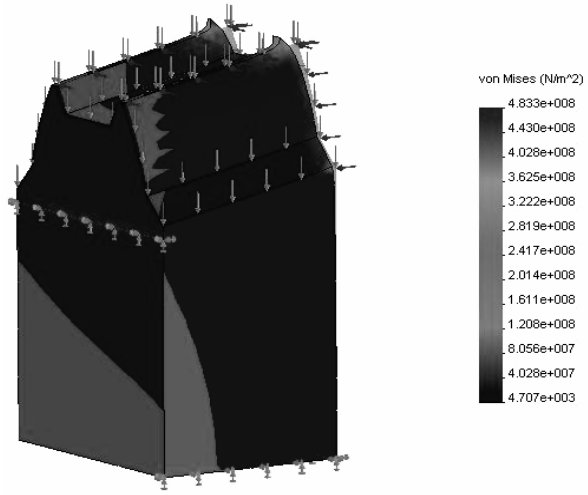

a.



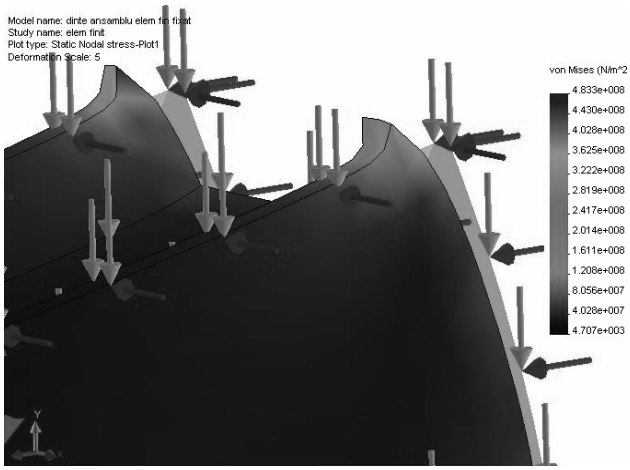
b.

Fig.16. Finite elements analysis for monobloc gear hob teeth: a – thetraedral mesh; b – loads and fixtures.

Using that two finite elemens models created, for modular and monobloc gear hobs, we apllied material propreties from software library. In Figure 17 is presented equivalent stress using Von Mises criteria (deformed representation) for a cutting tooth of the modular gear hob.



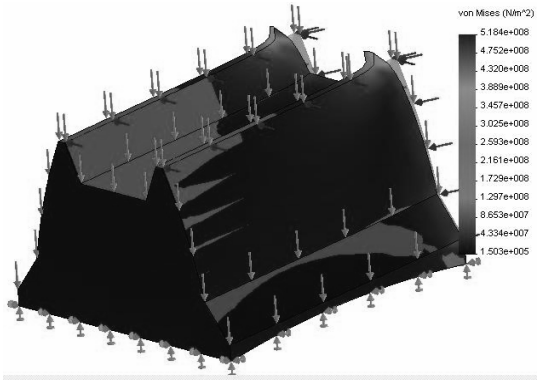

a.



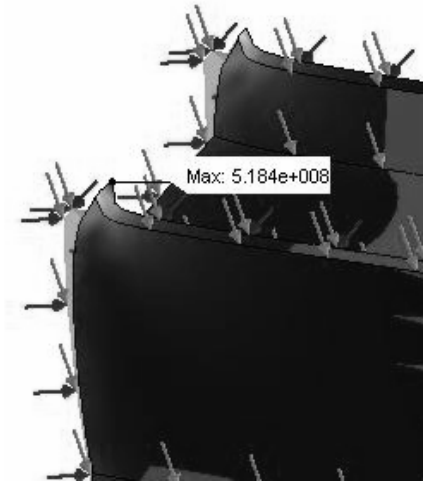

b.

Fig.17. Finite elements analysis for modular gear hob teeth using von Mises criteria: a – representation of the equivalent stress and loads; b – detailed view.

In Figure 18 is presented equivalent stress using Von Mises criteria (deformed representation) for a cutting tooth of the monobloc gear hob.




a.




b.

Fig.18. Finite elements analysis for monobloc gear hob teeth using von Mises criteria: a – representation of the equivalent stress and loads; b – detailed view.

## 3. CONCLUSIONS

The most attractive feature of the FEM is its ability to handle complicated geometries (and boundaries) with relative ease. While FDM in its basic form is restricted to handle rectangular shapes and simple alterations thereof, the handling of geometries in FEM is theoretically straightforward.

The developed gear tooth mathematical model may help us to explore the possibility for further investigations, such as sensitivity analysis, kinematic errors and contact stress analysis. The analysis results are most helpful to the designers and manufacturers to design and choose proper parameters for milling worm gear sets.

The models have used true three dimensional gear mill tooth profiles with micro-geometry modifications under real load conditions.

Milling hob with assembled teeth provides a relatively low stiffness to the monobloc milling hob teeth, because these teeth are fixed in slots provided in the cutter body. This leads to displacement of peak cutting edges of teeth by about 11% higher than for snail piece mills. Instead the criterion von Mises equivalent tensions are reduced by 6.77% than with monobloc milling hob.

The superior quality of cutting materials of the new type of hob – milling hob with removable teeth made from RP3 steel – comparing with the quality of materials used on monobloc milling gear hob, could not be shown and predicted in finite element analysis.

Also, the influence of tooth geometry of the removable cutting party with a positive angle and angle of placement consistently exceeds geometry of the monobloc milling hob tooth, implicit characteristics of the gear milling hob.

To highlight the positive influence of geometry and material of the removable teeth should be carried out experimental research.

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