

# Studies on wheel mounting options on shafts

*Carmen Purcar*<sup>1</sup>, *Mircea Bădescu*<sup>\*,1</sup>, and *Marinela Ință*<sup>1</sup>

<sup>1</sup> Lucian Blaga University of Sibiu, Industrial Engineering and Management Department, Victoriei, 10, 550025, Sibiu, Romania

**Abstract:** The paper presents a general description of chains and chain transmissions, their advantages and disadvantages. A triple chain wheel is then projected into the CATIA V5 program. A static analysis of some wheel mounting variants on a camshaft with the Generative Structural Analysis module in the CATIA V5 program is then made. The orientation-fastening variants with a wedge, two feathers or three screws positioned equidistant at 120 degrees on a diameter are analysed. As a result of the finite element analysis, the conclusion is that the three-screw variant is the most appropriate. Material stresses and deformations are smaller, simpler processability, fewer types of components are present overall, maintenance is simpler, and the eccentricity of the assembly is lower, with lower vibrations in operation.

## 1 INTRODUCTION

The mounting of wheels (gear, chain, belt, flyers, etc.) on shafts is often found in technical systems in many areas of activity. Therefore, this operation requires special attention. Manufacturing the gear and chain wheels raises several problems due to the high precision and the constructive-functional complexity. They range in size from those used in fine mechanics to those used in heavy industry (in ship gears). The multitude of constructive variants involves numerous computational variants and a complex range of machines used to manufacture them.

The high-speed variation, heavy duty operation (dust, moisture, high temperature, etc.) as well as the fatigue resistance make chain transmission one of the most efficient ways to transmit the rotation between two or more parallel shafts. The chain is also a key element of these transmissions, having several constructive variants, depending on the requirements to be met (low noise, transmission of great moments, etc.).

Even a small improvement in technology, in the automotive industry, can bring benefits to manufacturers' performance, machine reliability and customer satisfaction.

---

\*Corresponding author: [mircea.badescu@ulbsibiu.ro](mailto:mircea.badescu@ulbsibiu.ro)

Chain transmissions serve to transmit a torque between two or more parallel shafts. They belong to the category of indirect mechanical transmissions. Currently, this way of transmitting the movement is more and more widespread in a multitude of drive mechanisms in different areas: agricultural machinery, lifting equipment, drilling equipment, motorcycle construction, automotive industry (an industry in a continued development and fierce competition).

It must consider that the way the shaft wheels are assembled influences the entire functioning of the system, the reliability and the maintenance, the costs of all of these. Assembling errors causes drive component damage and costly equipment downtime. Problems may occur due to faulty assembly with radial and front beats, due to fatigue, microfiches and fissures in welding areas, or because of stress concentrators (feeder channels, due to inadequate repairs and for many other reasons). In the literature, these problems have been largely analysed. Such a case was described in [1], when the shaft of a conveyor belt drive pulley failed in service. Failure of the shaft during the routine overhaul was performed by a finite element analysis to quantify the stress distribution in the shaft [1].

It can simplify and reduce the weight of a mechanism by reducing the number of components. One variant could be the manufacture of the chain wheel and the afferent shaft from a single piece of material. However, it has been attempted to evaluate the suitability of composite material such as E-Glass / Epoxy for the purpose of automotive drive shaft application. The aim was to minimize the weight of the shaft, which is subject to the constraints such as torque transmission, critical torque buckling capacity and bending natural frequency [2]. The industrial belt drive components are intended to start with a basic understanding of the various types of mounting devices used to attach pulleys to shafts. Several types of tapered bushings can be used to mount belt to drive shafts. Flanged bushings have three mounting screws. Pulley is mounted by sliding it over the bushing hub and tightening the screws. Tapered bushings drive is made by keyway. Screws are used only for fixing [3].

A study of the bend shaft used in prototype shows how vulnerable such a rotating component can be to failure by fatigue if basic preventative design actions are not taken. The detail design of the wheel shaft assembly is found wanting. Must be taken fatigue preventative measures at the detail design stage. It is essential to avoid having high stress concentrations at locations of greatest nominal stress, if it is possible [4]. In vibration field, some authors present a design, a numerical analysis, a build-up and dynamic testing of an engineered and fabricated wheel with a passive vibration damping system for a roller coaster system. The study shows an approach with a special wheel design and viscoelastic inserts used to reduce vibrations. The application of the system of resilient wheel webbing and the resilient insert provided a vibration damping effect, which reduced the total vibration levels of the system [5]. Different materials are used for optimal design and strength analysis of the wheel hub. The purpose of a wheel hub is to attach a wheel to a motor shaft. Fasteners are usually the most suitable method for attaching the wheel to the hub. A hub of a wheel has been designed and modelling with Pro-E Creo version 2.0 package that is enrolled for varied automotive applications. The static analysis of wheel hub was done over different materials and was carried out on finite element analysis package. For the proposed material and upgraded model, the total deformation values were compared to the conventional model [6]. Studying structural analysis of a key coupling, the conclusion was that the stress concentrations are distributed around the key, but also around the shaft and hub keyways.

Moreover, the key will be modified as general shape, but also as the relative position with respect to the shaft and the hub [7]. About structural analysis of a conical shrink, it was observed that the contact pressure between the shaft and the belt pulley is uniform distributed. Equivalent stress and the displacement are not uniform distributed along the radial direction because of the non-uniform radial mass distribution of the belt pulley. The non-uniform deformation is the reason for the non-uniform shape modification of the external ring of the belt pulley [8].

The use of such transmissions involves several advantages and disadvantages.

Advantages refer to:

- ✓ transmission of high torque moments (compared with belts);
- ✓ a wide range of axle distances (this distance being adjustable);
- ✓ slip-free operation;
- ✓ thinking greatness;
- ✓ exploitation under heavy conditions (dust, high temperatures up to 200 ° C);

A big disadvantage is linked to the polygonal chaining of the chain on the chain wheels, which produces additional dynamic loads:

- ✓ vibration, noise and shocks;
- ✓ variable speeds.

To increase the chain strength and operating life, its joints are made of wear-resistant materials. To reduce dynamic loads, chains should be executed with the smallest steps.

In such a transmission, it is intended to replace the mountain of the chain wheels on the shaft by the feather, because the key-way is difficult to process and it is also a stress concentrator.

The feather doesn't fill the hole key-way, and there's why there may appear a misalignment and because of this, vibrations during the rotation.

The authors propose the assembly of the chain wheel on the shaft through three screws, equidistant positioned. The holes are easier to process, there are no stress concentrators anymore and there is no vibration anymore.

The study performs a finite element analysis of 3 different assembling modes to determine how strains and deformations change in the three cases.

## 2 CHAIN WHEELS ANALYSIS USING THE FINITE ELEMENT

Finite Element Method (FEM) is one of the best ways to achieve various engineering calculations and simulations. This method and the programs that incorporate it have become basic elements of modern computer-assisted design systems. The FEM analyses are indispensable today in all high-performance engineering activities.

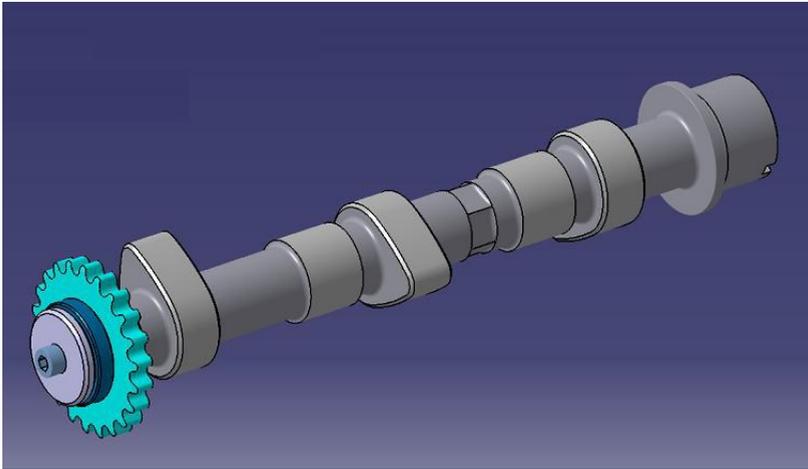
FEM calculations represent an important stage of design. They are generally carried out only after clarification of other aspects, such as: the requirements of the beneficiary, imposed costs, delivery times, available materials and technologies, product sustainability, production volume, environmental requirements, etc.

Thus, for a product, some limitations can be considered: the number and maximum value of static and / or dynamic loads, maximum deformation values, various safety factors (buckling, breaking or fatigue), execution imperfections, installation or operation, vibration frequencies, product life, weight, material and moments of inertia, stiffness at different stresses, static and / or dynamic stability, behaviour at different simultaneous loads.

To perform the analysis, it was used the Generative Structural Analysis from the Catia V5R21 software, a module that allows both static model analysis and dynamic analysis.

The study was carried out on the sprocket chain of the Mercedes M 272 E 35 internal combustion engine from the distribution subassembly.

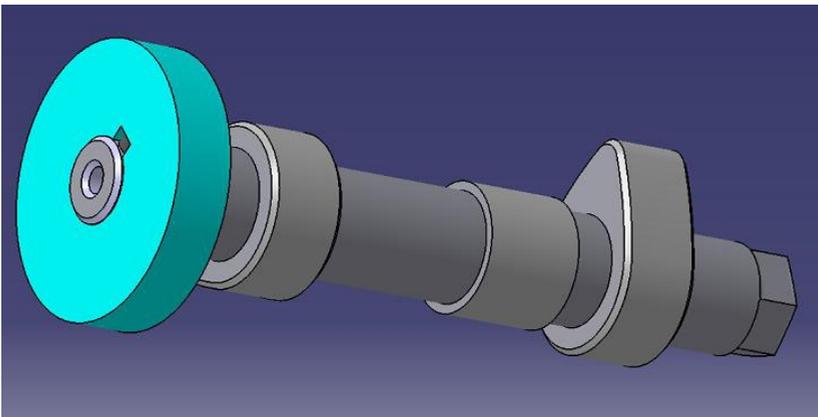
According to the principles of the finite element analysis, the final model on which the study is made does not coincide with the projected model (Figure 1)



**Fig. 1.** The model realised

These changes are made to simplify and reduce simulation time without altering the result. In the analysed case, some elements and constructive geometries were dropped (Figure 2):

- ✓ the wheel's teeth have been removed;
- ✓ abandonment of the axle movement of the wheel;
- ✓ removing connecting rails between the shaft steps;
- ✓ changing shaft length;
- ✓ replacement of bolt fastening screws;

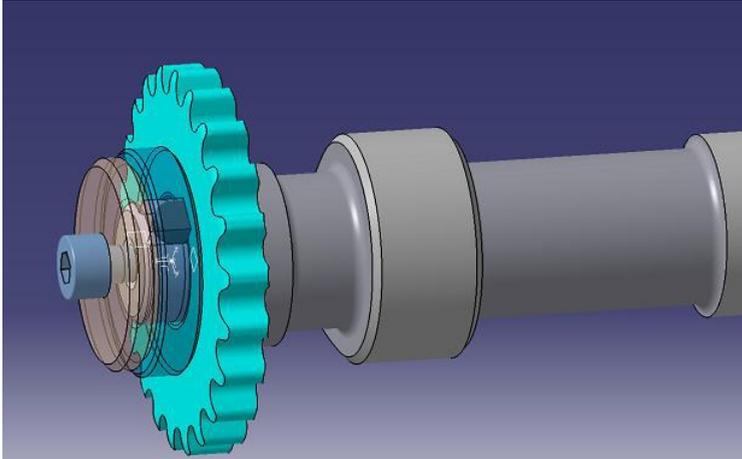


**Fig. 2.** The model used for FEM

More specifically, the research was carried out by considering three sprocket assemblies on the camshaft. It was intended to find the mounting variant that would

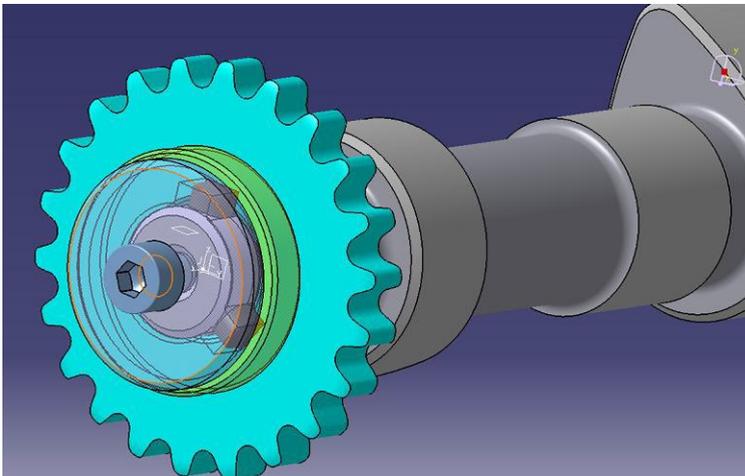
involve minimal strains and deformations in the material but would also have technological and economic advantages.

The first variant is to orient the chain wheel by means of a parallel feather and central screw fixing (Figure 3). It is a method commonly used in transmitting a torque. Due to the material fibre breakdown, stress concentrators (wedge channel area) appear. That is why this variation is used to transmit relatively small torques and low vibrations of the system.



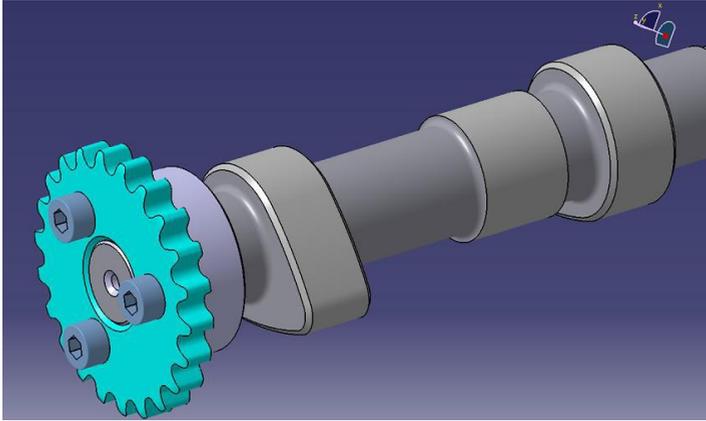
**Fig. 3.** First variant: with a parallel feather and central screw

The second embodiment of the assembly is by means of two parallel feathers disposed at  $120^\circ$  (Figure 4). The fastening is also done with a central screw. From a technological point of view, it is a more complicated version than the first one, but it can transmit higher torque moments. This variant is not preferred at high shaft speeds, as the presence of the feeder channels leads to a great excentricity.



**Fig. 4.** The second variant: with two parallel feathers disposed at  $120^\circ$

The third mounting variant is with 3 screws at  $120^\circ$  from each other (Figure 5). The orientation and fixation are done through the three shrimps. The main requirement is to screw the screws. For this, they must be designed and made with an area sliding assembled into the wheel bore before screwing.



**Fig. 5.** The third variant: with 3 screws at 120° from each other

This option also offers other advantages:

- ✓ simpler technology for shaft and wheel
- ✓ lower manufacturing costs;
- ✓ fewer different parts overall;
- ✓ quicker and easier installation / demounting (better maintenance).

In order to achieve the simulation, there are three stages:

a) Pre-processing

- Defining the geometric model. At this stage all modifications are made to the model received from the designer. These changes (mentioned above) are intended to simplify the configuration of the piece by preparing for the analysis. "

- Generating an appropriate finite element grid. It consists of dividing the piece into tetrahedra (mesh), linear or parabolic. The size of these tetrahedra can be set accordingly. The lower the result of the analysis will be closer to reality, but the processing time is higher. The tetragonal mesh was constructed so that the length of the tetrahedron side does not exceed 2 mm. Once the network has been established, the maximum error percentage has been verified and it was smaller than 3%. "

- Defining material properties. The Catia V5 program features a wide range of materials. With the choice of the material (steel in the analysed case), its mechanical properties are also loaded. One may introduce the value of  $E = 210000 \text{ Mpa}$  and the Poisson coefficient = 0,3.

- Defining the constraints. The program provides some of the most common forms of taking the degrees of freedom. You can also use the user-defined variant, which can create the constraints in the desired way.

- Defining the loads. At this stage, the track is "loaded" with the necessary demands: torque, pressure, compression, traction, etc. In this case it was assumed that the shaft is embedded at one end, and at the other end there is a torque of  $80000 \text{ N*mm}$

- Model check. With this command, the program checks if all the above steps have been performed correctly, so it can go further.

b) Processing. After defining the problem, the computer proceeds to determine the solutions.

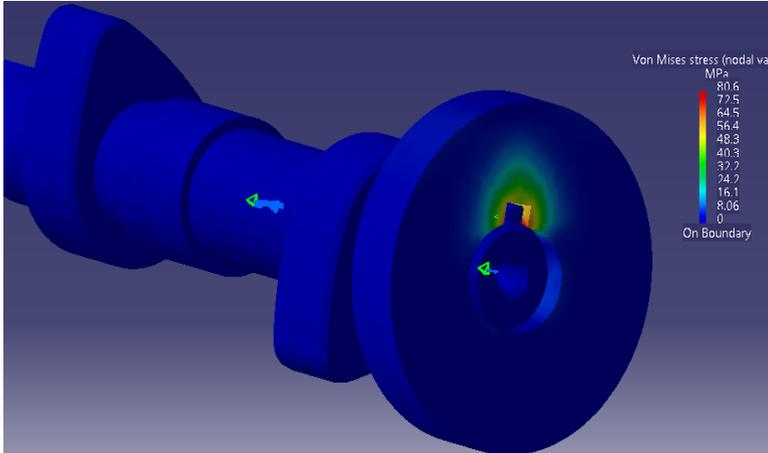
c) Post-processing. Using the features of the program, one can view and interpret several types of data:

- ✓ deformations;
- ✓ stress map (Von Mises Stress) – to compare with Yield stress;
- ✓ translational displacements – to see how large the deviations due to nodal movements are.

### 3 PRESENTATION OF THE RESULTS

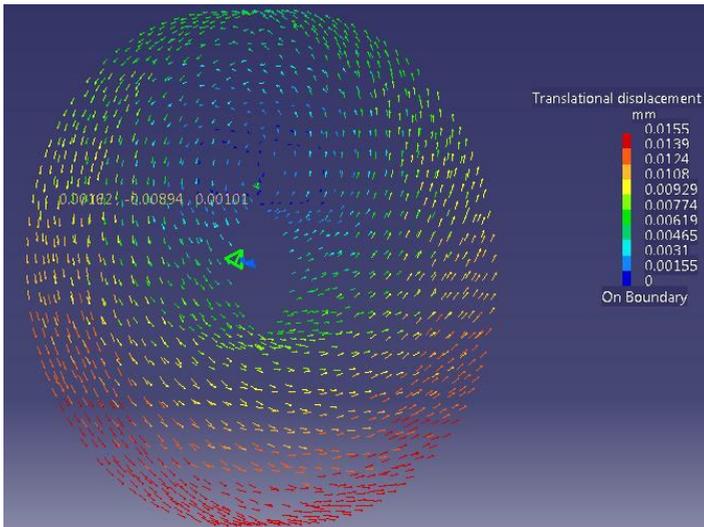
#### 3.1 Variant I (pin point and screw fixing)

Analysing the map of stress (Von Mises) (Figure 6), it can be noticed that the main stress is that of crushing between the feather flank and the key-way. It is noted that in this area a maximum value of 80.6 MPa is reached.



**Fig. 6.** The map of stress in the first variant

Figure 7 shows the map of the displacements. The displacements are low, reaching the maximum value of 0.015 mm.



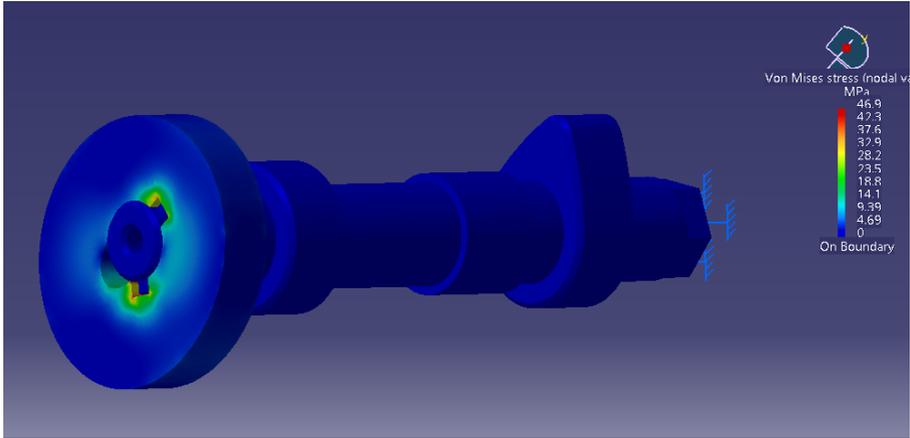
**Fig. 7.** The map of the displacements in the first variant

#### 3.2 Variant II (orientation on two feathers and screw fixing)

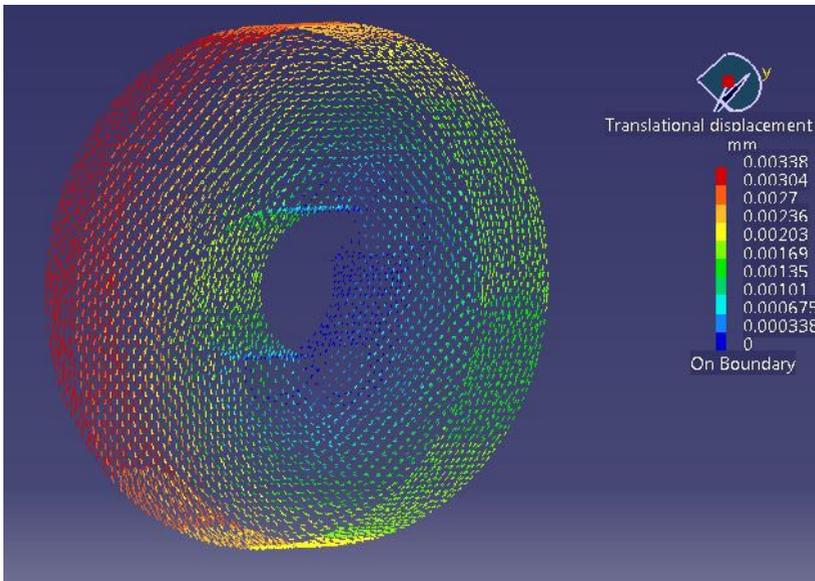
In this variant, the chain wheel is mounted by means of two parallel wedges arranged at 120°. The method brings a plus in terms of material resistance, the maximum stress being only 46.9 MPa (Figure 8) at the same torque transmitted. The

drawbacks of this method are the weak processability and the excentricity at high speeds.

The deformations are smaller in this case, reaching a maximum value of 0.00338 mm (Figure 9).



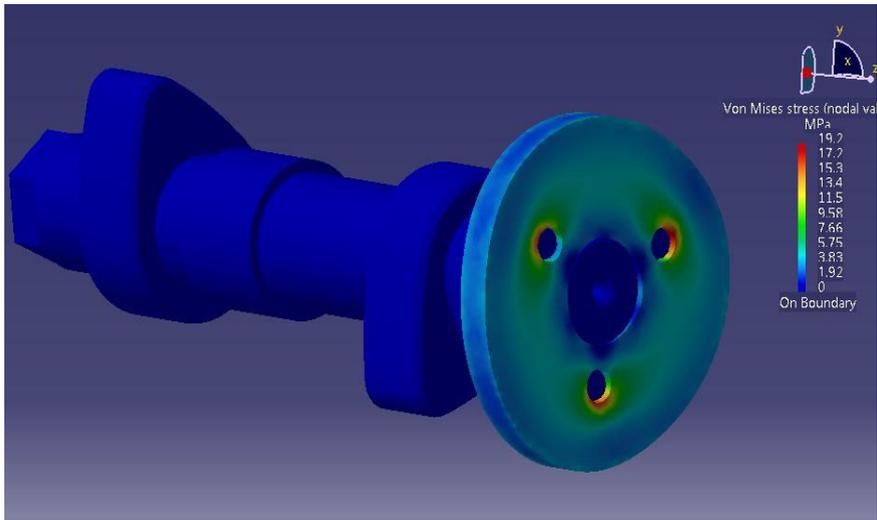
**Fig. 8.** The map of stress in the second variant



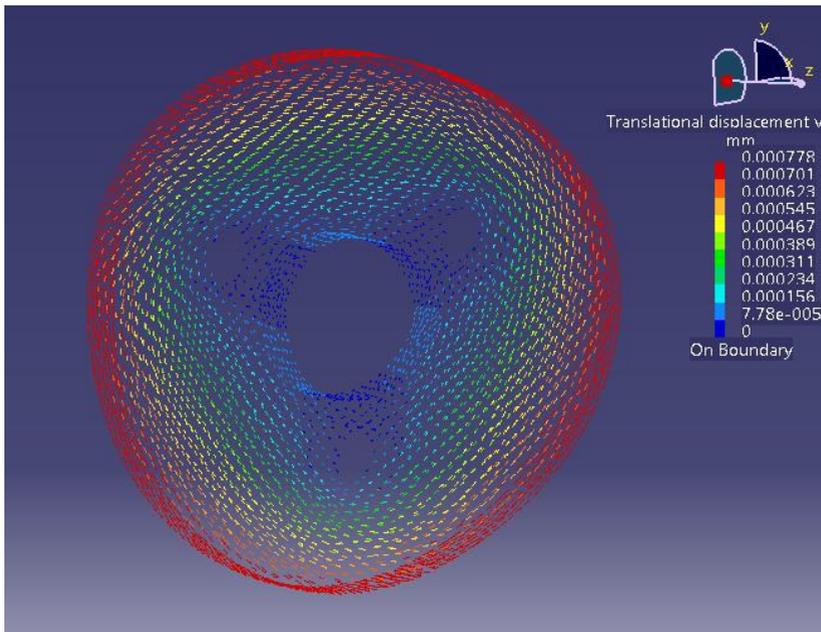
**Fig. 9.** The map of the displacements in the second variant

### 3.3 Variant III (3-screw orientation and fixing)

The latest analysis is that of fixing the wheel with 3 screws. The main demand is the shearing of the screws. The maps of strains and stresses are shown in Figures 10 and 11, respectively. One can see that the highest stress ( $\sigma_{ecv} = 19.2$  Mpa) is considerably lower than in the other cases.



**Fig. 10.** The map of stress in variant III



**Fig. 11.** The map of the displacements in variant III

## 4 CONCLUSIONS

In order to obtain efficient gears, the chain wheels, the chain and the whole assembly in which they operate must be thoroughly analysed.

Following the analysis was found that the best solution is Variant III (orientation and fixing with three screws). The underlying arguments are:

- ✓ smaller Von Mises stress ( $\sigma_{cv} = 19.2$  Mpa vs. 80.6 Mpa of the I version (one-point orientation) or 46.9 of the II variant (two feathering));

- ✓ lower displacements in the material (0.00077 mm), the previous versions having higher values;
- ✓ smaller runout;
- ✓ better processability;
- ✓ lower price;
- ✓ easier assembling/removal (easier maintenance);

Another argument is that for the variant III, the number of types of markers that come into the gear structure is smaller. The axial displacements of the wheel on the shaft are also taken over by the guide-fastening bolts, while in the other two cases, there were other washers, caps or bolts needed.

In a later research, the ensemble should be studied dynamically. System vibrations may be greater for bolt assemblies. This could make it advisable to replace bolts with screws in many companies from the automotive industry.

## References

1. G. van Zyl, A. Al-Sahli, *Finite Elem Anal Des* **1**, 144 (2013)
2. A. Gebresilassie, Design and an analysis of Composite Drive Shaft for Rear - Wheel Drive Engine, *Int J Sci Res*, **3**, Issue 5 (2012)
3. D. Schwartz, G. Porter, Making the Right Shaft Connections <https://www.machinedesign.com/motion-control/making-right-shaft-connections>
4. S. Kr Mandal\*, P. Kr Maji, S. Karmakar, *Adv Automob Eng.* **4**, 114 (2015)
5. P.Gierlak, D. Szybicki, K. Kurc, A. Burghardt, D. Wydrzyński, R. Sitek, M. Goczał, *J Vibroeng* **20**, 1129 (2018)
6. D. Rangababu, K. Depti, B. Ramana, *Journal of technological advances and scientific research* **1**, 353 (2015)
7. D. Zaharica, Structural analysis of a key coupling, *ModTech International Conference Modern Technologies, Quality and Innovation - New face of TMCR* **2**, 1077 (2012)
8. D. Zaharica, Structural analysis of a conical shrink fitting, *ModTech International Conference Modern Technologies, Quality and Innovation - New face of TMCR*, **2**, 1073 (2012)