COMETa 2018
4th INTERNATIONAL SCIENTIFIC CONFERENCE
27th - 30th November 2018
Jahorina, Republic of Srpska, B&H
University of East Sarajevo
Faculty of Mechanical Engineering
Conference on Mechanical Engineering Technologies and Applications

FEM ANALYSIS OF GEROTOR MACHINES IMPELLER WITH PLANETARY MOTION

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Abstract: This paper presents the finite element method analysis in a gerotor machine impeller. The analysis was carried out for the impeller of a gerotor machine with planetary motion. So far, a lot of has been conducted on the topic of the gerotor machines with the fixed position of the axis of the impeller element, while in the case of planetary motion of the impeller there are much less researchings. This case requires a more complicated force analysis, which is necessary for setting constraints and loads in finite element analysis. The mathematical model of the gerotor impeller force analysis with planetary motion is taken from the literature. The paper analyzes for cases with several combinations of teeth numbers with variation of materials. At the end of the paper, the results obtained by this analysis with conclusions and given further directions of research on this topic were presented.

Key words: Gerotor imppeler, Epicyclic movement, Finite element method, Load analyses

1 INTRODUCTION

Trochoid gearing belongs to the newest types of gearings. Trochoid gearing is most commonly encountered in gerotor pumps and orbital gerotor hydromotors. The usage of this type of gearing is greatly caused by the improvement of functional characteristics such as increasing the efficiency and working life, reducing the overall dimensions (since this type of toothed profile has a higher loading capacity), and so on. Its use as a consequence of the reduction of the overall dimensions reduces the consumption of materials, both for trochoid pairs and for the cases in which these pairs are installed, which further leads to significant savings in the production of devices using trochoid pairs as a working element. The increased loading capacity of this gearing type is achieved by the fact that unlike the conventional gearing (involute toothed) in the case of using a trochoidal gearing, the simultaneous coupling of a significantly larger number of teeth occurs. For example, if in the involute gearing in contact of one to two teeth in trochoid gearing, they are always in contact with more than half of the teeth of the gearing. Due to these advantages, there is a great interest in both mechanical engineers

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and researchers for the application of these gears in places where there are present significant space limits. As has been said before, this type of gearing is applicable to gerotor pumps and orbital gerotor hydro motors, but also to other rotary machines such as: compressors, blowers, etc.

One of the most important aspects of analyzing gerotor pumps is the analysis of the dynamic behavior of pump elements in operation. C. F. Heish [1] obtained such an analysis of useful data that can be further applied in the gerotors manufacturing. An important aspect of the analysis of the forces and pressures that occur on the gears with the external toothed gerotor, [2]. A very important aspect is the gerotor kinematic analysis [3], as well as the determination of the pump flow [4]. By observing and reviewing all these aspects, it is concluded that the research of the gerotor has accelerated greatly if there was an adaptive parametric CAD model, which could later be used both for the analysis of the stress conditions of the gerotor elements and for determining the contact pressures in the meshing of the trochoid gears. Some groups of authors have partly succeeded in introducing such a model into the research of gerotors [5-7]. In order for such a model to be used for practical research and experiments, it is very important to implement technological gaps in this model, [8-11].

In modern industrial applications, there are increasingly stringent demands in terms of pump performance. In addition, the environmental protection standards prescribe the development of hydraulic systems without any noise and without fluid leakage. Taking into account the quality of the gerotor pumps and the challenges they face in modern applications, as well as the requirements of the standards, the authors have developed a new concept of the gerotor pump whose prototype has been presented in the reference. [12] New topics related to gerotor pumps and cycloid gearing are generally numerical approaches supported by experimental work [13-14].

This paper is an extension of the group of author's research on the topic of automation and testing of the obtained results of parameterization of the gerotor of orbital motors. The paper presents orbital motors with planetary movement of the inner trochoid gear and determination of the pressure values that occur in the contact when the inner and outer gears are meshing. The theoretical model of determining this pressure is taken from the literature [16-17], while the result value is determined by the FEM method set up based on the theoretical model in the software package ***Autodesk Inventor*.**

2 THEORETICAL MODEL OF DETERMINING PRESSURE CONTACT IN TROCHOIDAL GEAR PAIR MESHING WITH PLANETARY MOVEMENT OF INNER GEAR

In the gerotor machines with internal trochoidal gearing, the profile of one of the gears is generated by a trochoid (curve from the family of cycloids), while the coupled profile is an appropriate inner or outer envelope. Thanks to specific geometry, the entire profile can be applied for meshing. Equivalent modification provides a profile with better functional characteristics. These advantages are used in the orbital motors design, which are presented in this paper.

In this paper, the contact pressures are considered which occur due to the meshing of the trochoid rotary machine with the planetary movement of the inner gear, for which the drive shaft is attached, while the outer gear is fixed. The main objective of this analysis is to have a closer look at the contact pressures values, which would further enable the definition of conditions for reducing the same, and thus reducing the wear, and prolonging the life of the gerotor machine. The problem of determining contact pressures is complex since the load is transmitted simultaneously at several points of contact. This means the contact (normal) force acts at each touch point, and the directions of all normal forces goes through the current pole of rotation C. Since the number of contact points and, therefore, the number of unknown forces is equal to the teeth number of the external gear z, it is clear that it is a static indeterminate system of forces. In order to determine the size of the contact pressures, it is necessary to determine the intensity of the resulting force of the fluid pressure, which, as a concentrated force, acts in point C. In trochoid machines with planetary motion of the working elements, the shaft torque [16] balances the total moment of the fluid pressure force. The model for determining contact forces is shown in Figure 1.

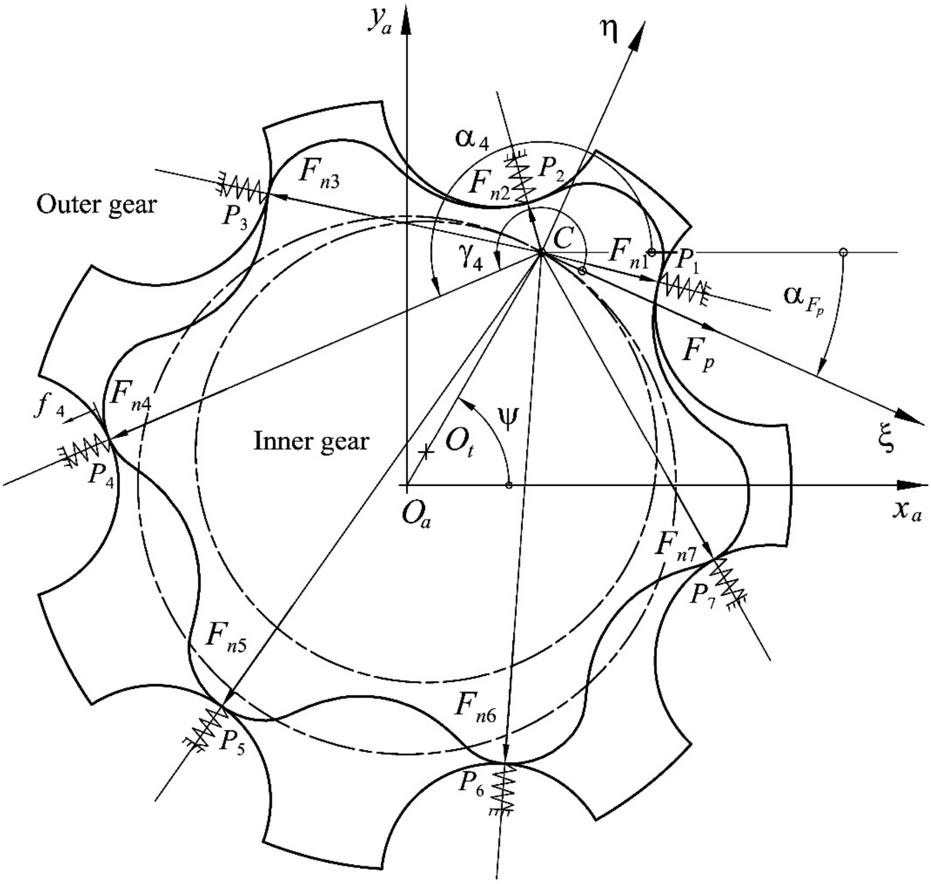


Figure 1. A model of contact forces acting on an external gear at an arbitrary point

Each contact point is modeled with a cylindrical spring, whose axis coincides with the normal direction to the surface at the touch point. Under the influence of the contact force, the F_{ni} spring is elastically deformed, and this deformation is a deflection or a shortening of the spring f_i. A well-known relationship between deformation and normal force can be written by expression:

$$F_{ni} = cf_i \,, \tag{1}$$

where is c spring constant stiffens. The numeric value of stiffens is c=1x10^6 N/mm.

3 SELECTION OF GEOMETRIC VALUES OF TROCHOID GEAR PAIRS AND FEM BOUNDARY CONDITIONS

In order to achieve as realistic results as possible for this investigation, the real values of the size of the three trochoidal gear pairs are taken from the catalog [18-20]. The catalog includes both geometric values and input torque values. In the variation of geometric measures, the overall dimensions of the gerotor pair have not been changed. In order to detect the differences in the use of trochoidal gears, in all cases (with 4.5 and 6 teeth) three different materials were used. The geometric characteristics of the selected trochoidal gear pairs are shown in Table 1.

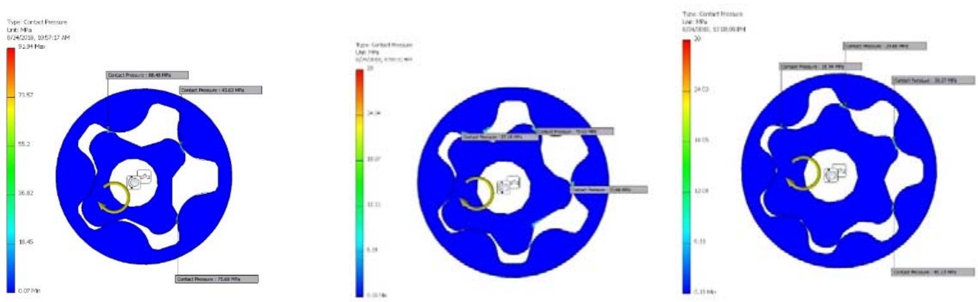
Table 1. *Geometric characteristics of selected trochoidal gear pairs*

No.	z_1	λ	e	r_c
1.	4	1,3	4,95 mm	12,375 mm
2.	5	1,3	4 mm	10 mm
3.	6	1,3	3,5 mm	8,75 mm

The FEM analysis used: steel E235, aluminum 6061 AHC and HDPE plastics for all variations in the number of teeth. A torque, 32 Nm was selected in the catalog, while the location of their action was determined in accordance with Figure 1. The outer gear in all iterations was constrained in all six degrees of freedom of movement, while inner gear was constrained by so-called *pin-constraint*.

4 FEM ANALYSIS RESULTS

As previously mentioned, FEM analysis was performed for combining all selected material variations and all previously selected teeth numbers. The results of the analysis are shown graphically and tabular for easier comparison.
Figure 2 shows the analysis for all selected teeth numbers when the steel E235 is taken into account.



a) b) c)

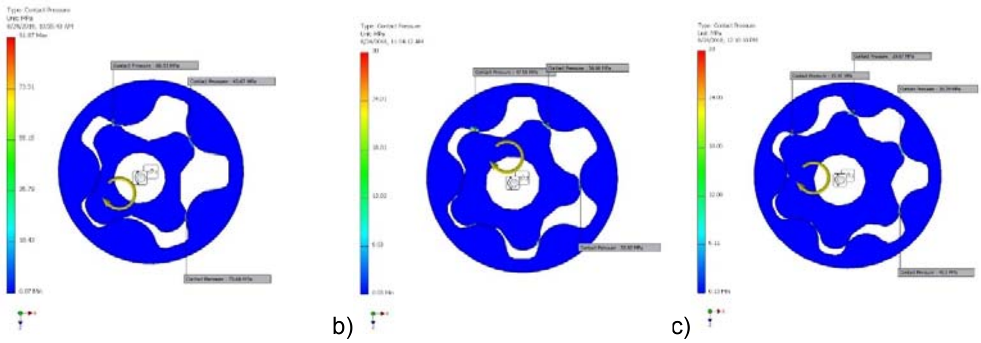
Figure 2. *The FEM analysis results in the case when the steel E235 is taken into consideration: a) trochoidal gear with 4 teeth; b) trochoidal gear with 5 teeth and c) trochoidal gear with 6 teeth*

Figure 2 also illustrates the constraints and input torque entry point. Table 2 shows the number of contact stresses between the individual teeth.

Table 2. *Meshing tooth contact pressure, MPa*

No.	*1. tooth meshing*	*2. tooth meshing*	*3. tooth meshing*	*4. tooth meshing*
1.	88,48	43,63	75,68	-
2.	27,18	70,03	33,64	-
3.	15,94	29,66	30,27	45,13

Figure 3 shows the analysis for all selected teeth numbers when the aluminum 6061 AHC is taken into account.



a) b) c)

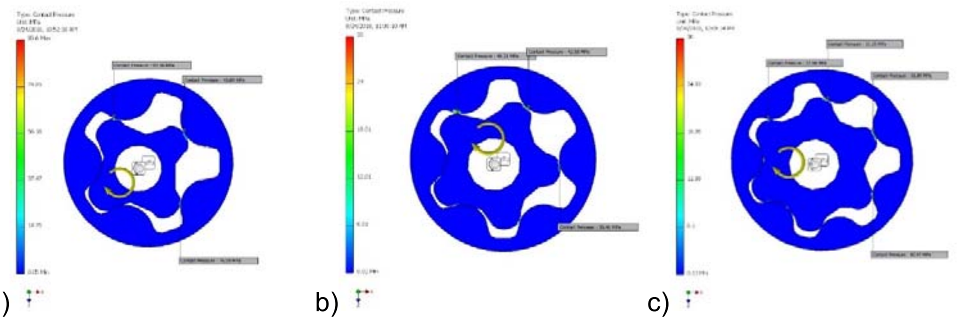
Figure 3. *The FEM analysis results in the case when the aluminum is taken into consideration: a) trochoidal gear with 4 teeth; b) trochoidal gear with 5 teeth and c) trochoidal gear with 6 teeth*

For ease of analysis results in Table 3 shows the numerical values of contact stress between the individual teeth.

Table 3. *Meshing tooth contact pressure, MPa*

No.	*1. tooth meshing*	*2. tooth meshing*	*3. tooth meshing*	*4. tooth meshing*
1.	88,53	43,67	75,68	-
2.	47,55	36,68	33,63	-
3.	15,95	29,67	30,29	45,10

Figure 4 shows the analysis for all selected teeth numbers when HDPE plastic is taken into account.



a) b) c)

Figure 4. *The FEM analysis results in the case when the HDPE is taken into consideration: a) trochoidal gear with 4 teeth; b) trochoidal gear with 5 teeth and c) trochoidal gear with 6 teeth*

Table 4 shows the number of contact stress contacts between meshing teeth.

Table 4. *Meshing tooth contact pressure, MPa*

No.	*1. tooth meshing*	*2. tooth meshing*	*3. tooth meshing*	*4. tooth meshing*
1.	93,56	48,09	76,09	-
2.	48,31	42,58	36,41	-
3.	17,68	31,25	31,89	42,47

The presented simulations were performed by replacing the action of the working fluid with concentrated pressure forces modeled on the models shown in the works [15-16].

5 CONCLUSION

In the presented paper, a multiple FEM analysis of the orbital motor trochoidal gear pairs for three different materials was conducted: steel E235, aluminum 6061 AHC and HDPE plastics and three different number of teeth of internal triode gears (z1 = 4.5 and 6). The analysis was conducted out for all combinations of different materials and teeth numbers. The results of the authors presented in the references [17] were used for the baseline analysis model. As this model is adaptive, these analyzes can be said to be universal and can be applied to any parameters of trocohidal gearing, which are physically feasible.

If, as a benchmark of these analyzes, steel is used as the material used for all combinations of teeth numbers, it can be concluded that in aluminum, there are slightly higher contact stresses compared to steel. If we consider comparative plastics and steel, considerably higher contact stresses occur in plastics. Distribution of contact stresses is very similar for all three types of materials. As expected, the greatest contact stresses occur with the smallest number of teeth for all materials, while as the number of teeth increases. The size of the contact stresses depends directly on the contact force location.

The presented research was conducted assuming that there is no working fluid in the gerotor pair, but the effect of its pressure force is taken into account through the resulting force F_p. This is the first step towards determining the critical points of the trochoidal gears. Further research will also include the simulation of the working fluid flow in the determination of the contact pressures, as well as the study of the stress-deformation state of the trochoidal gear pair. When the simulations are completed authors plans to conduct an experimental research.

ACKNOWLEDGMENT

This paper is a result of two investigations: (1) project TR33015 of Technological Development of Republic of Serbia, and (2) project TR35033 of Republic of Serbia. We would like to thank to the Ministry of Education, Science and Technological Development of Republic of Serbia for their financial support during these investigations.

NOMENCLATURE

Variables:

e eccentricity, mm

F_{ni} normal force on gear tooth, N

F_p resultatnt of normal forces, N

r_c geometric characteristics of trochoidal profile, mm

z_1 tooth number of inner gear

Greek symbols

α angle between the starting and current position of the point of contact of the basic and rolling curve relevant to the center of the base curve, rad γ angle between resultant force and component forces F_{pi}, rad

λ trochoid coefficient

Subscripts and superscripts

i number of chamber

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