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MODAL ANALYSIS OF CYCLOIDAL SPEED REDUCER

Abstract: *Cycloidal speed reducer is an extremely compact and stiff device. In laboratory conditions, it is known as a mechanism that produces very low noise and vibrations. However, due to elastic deformations of cycloidal speed reducer, errors because of inadequate production and installation, and due to nonuniform load distribution, there are internal dynamic forces that increase the level of noise and vibrations. It is therefore very important to define natural frequencies and proper modes of oscillations to avoid the occurrence of resonance.*
In this paper are defined natural frequencies of cycloidal speed reducer housing as well as proper modes of oscillations, using the software Autodesk Inventor.
Keywords: *Cycloidal Speed Reducer, Natural Frequencies, Modes of Oscillations, Resonance*

1. INTRODUCTION

Cycloidal speed reducers, (Figure 1) belong to new generation of reducers. They are widely used (robot industry, satellite technology, elevators, tool machines, ...). Their characteristics are: compact design, very high efficiency, high ratio, long and reliable work life, reliable fuctioning in dynamical load condition,... [1].

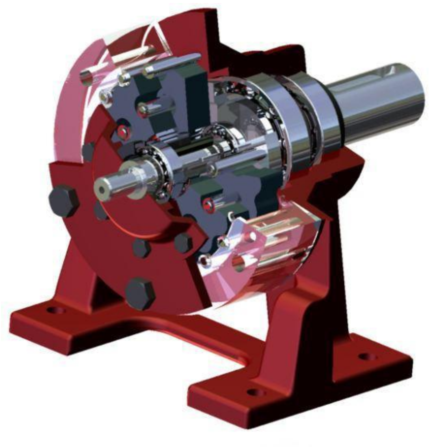


Figure 1 *- Model of cycloidal speed reducer*

Cycloidal speed reducer working principle is as follows: on the input shaft is mounted eccentric with needle roller bearings, on which cycloid gears are mounted. Due to rotation of the input shaft, there is complex movement of cycloid gear, which is in contact with fixed central gear rollers and output mechanism rollers, which are bonded to the output shaft. If the number of teeth of cycloid gear is n then number of central gear rollers is $n+1$. Therefore, when input shaft rotates n times, the output shaft rotates once (Figure 2).

Prof. *Malhotra* defined load distribution in cycloidal speed reducer, [1]. In the papers [2, 3] dynamic behavior of cycloidal speed reducer is described, while in papers [4, 5 and 6] most attention was given to efficiency of cycloidal speed reducer. However, problems about vibrations and oscillations are mostly ignored.

Modal analysis of cycloidal speed reducer housing was performed and natural frequencies and modes of oscillations were determined in this paper. The results of analysis are presented, too.

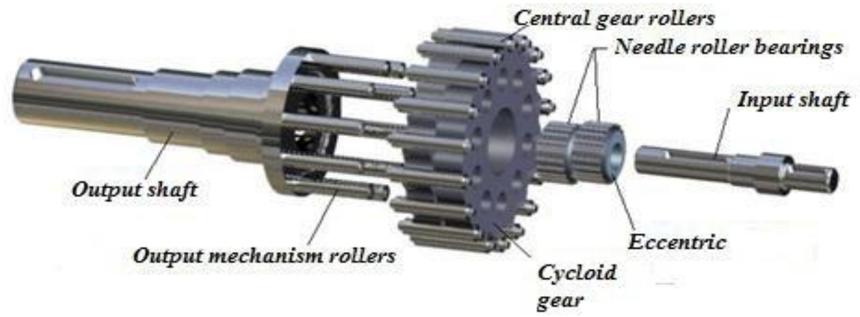


***Figure 2** - Rotation elements in cyloidal speed reducer*

2. DYNAMIC BEHAVIOR OF CYCLOIDAL SPEED REDUCER

Cycloidal reducer is very complex mechanical system. Different factors influence on its dynamic behavior, [7]:

- cycloid gear profile production errors,
- other elements procution and mouting errors,
- nonuniform torque distribution on the cycloid gears,
- nonuniform load distribution on central gear rollers,
- nonuniform load distribution on output mechanism rollers,
- elastic deformations of central gear, output mechanism, housing and so on.

The most complex and important element of cycloidal speed reducer is cycloid gear. It is very sensitive to production errors, which can have major consequeces. These errors can cause nonuniform load distribution on every other vital cycloidal speed reducer element. It is important to say that, compared to ordinary involute tooth gears, in cycloidal speed reducers value of relation between width and diameter is lover, which can cause gear beveling and nonuniform load distribution. This can happen under the influence of, [7]:

- unachieved axis match of cycloid gear openings and corresponding surfaces of other elements, which are in contact with cycloid gear,
- deviations of central gear and output mechanism,
- angular deviations caused by temperature deformations of central gear and output mechanism,
- influence of centrifugal forces,
- angular deviations caused by beveling of central gear rollers and output mechanism.

In order to balance centrifugal forces and reduce load on cycloid gear tooth, two cycloid gears mutually rotated by 180° are mostly used in single - stage cycloidal speed reducers. There are cycloidal speed reducers which even contain three cycloid gears.

3. DETERMINATION OF NATURAL FREQUENCIES AND MODES OF OSCILLATIONS OF CYCLOIDAL SPEED REDUCER HOUSING

Performed modal analysis and obtained natural frequencies and oscillation modes of single - stage cycloidal speed reducer housing are presented in this chapter. Basic paremeters of this cycloidal speed reducer are given in Table 1.

***Table 1.** Cycloidal speed reducer parameters*

Unit	Value
Central gear pitch radius, r [mm]	55
Cycloid gear number of teeth, z_1	17
Number of rollers in central gear, z_2	18
Speed ratio, u_{cr}	17
Eccentricity, e [mm]	1.986

3D modeling of cucloidal speed reducer housing and modal analysis were performed in software Autodesk Inventor.

Wireframe view of housing is shown in Figure 3, while generated finite elements mesh can be seen in Figure 4.

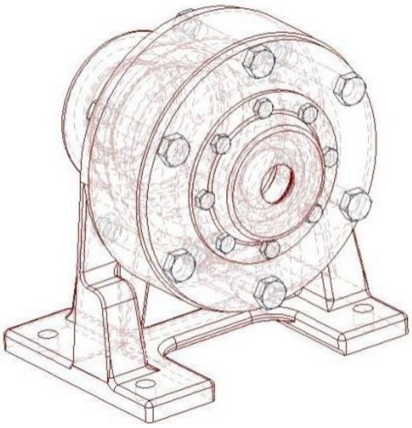


Figure 3 *- Wireframe view of cycloidal speed reducer 3D model*

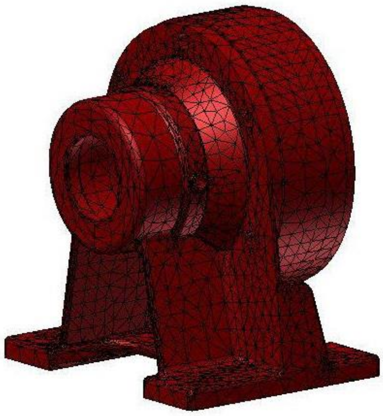


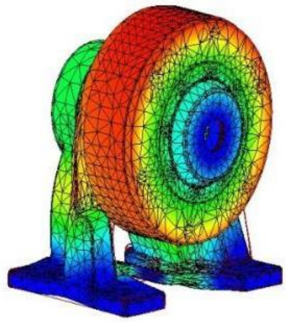
Figure 4 *- Generated mesh on cycloidal speed reducer housing*

Cast steel was chosen as a housing material. Characteristics of this material are presented in Table 2.

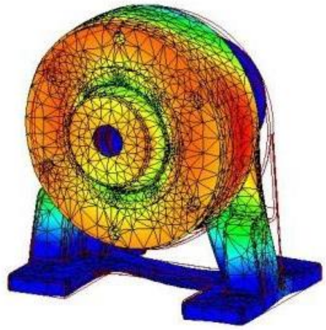
Table 2. *Housing material characteristics (cast steel)*

Unit	Value
Elastic modulus, $\boldsymbol{E}$ [MPa]	$2{,}1 \cdot 10^5$
Poisson's coefficient, $\boldsymbol{\mu}$	0,3
Density, $\boldsymbol{\rho}$ [kg/m^3]	7850
Yield stress, $\boldsymbol{R_{eH}}$ [MPa]	250
Tensile strength, $\boldsymbol{R_m}$ [MPa]	300

Natural frequencies were calculated numerically, using the Finite elements method. Finite elements method is based on discretization of physical model. By reducing elements' dimension, their number is increasing and more accurate results are obtained. Discretizated cycloidal speed reducer housing model in this paper contains 39375 tetrahedron finite elemens, 71 002 nodes and 213006 degrees of freedom. Number of natural frequencies, obtained as a result of modal analysis, is directly related to number of oscillation modes. Each obtained natural frequency corresponds exactly to one mode of oscillation. Three characteristic oscillation modes, which correspond to natural frequencies of 1882,17 Hz, 5410,22 Hz and 6835,90 Hz, are shown in Figure 5.



a)



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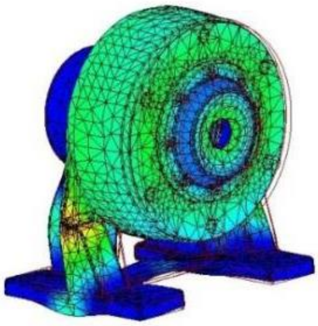

c)

Figure 5 *- Characteristic modes of oscillations*

(a–1882,17 Hz; b–5410,22 Hz; c–6835,90 Hz)

Modal analysis determined 10 natural frequencies and the same number of oscillations modes. *Fig 6* shows a diagram of oscillation modes depending on the value of natural frequencies.

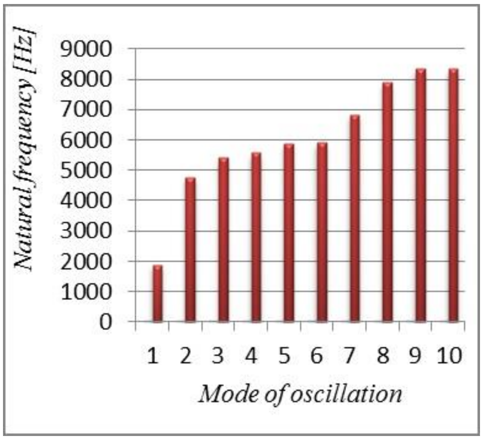

Figure 6 *- Natural frequencies of reducer housing for all modes of oscillatiopns*

The exact values of natural frequencies for each oscillation mode are presented in Table 3.

Table 3. *Numeric values of natural frequencies*

Oscillation mode	Frequency [Hz]
1	1882,17
2	4766,45
3	5410,22
4	5579,12
5	5878,15
6	5898,88
7	6835,90
8	7892,55
9	8345,81
10	8347,72

4. CONCLUSION

Using the finite elements method, modal analysis of cycloidal speed reducer housing was performed. Ten important modes of oscillations were identified as well as proper natural frequencies. The first several oscillations modes are crucial, and they have the biggest influence on cycloidal speed reducer housing dynamic behavior.

Following researches should contain modal analysis of other parts of cycloidal speed reducer, as well as analysis of whole reducer as an assembly, in order to reach more results.

REFERENCES:

[1] Malhotra, S. K., & Parameswaran, M. A. (1983). Analysis of a Cycloid Speed Reducer. *Mechanism and Machine theory*, *18*(6), 491-499.

[2] Thube, V.S., & Bobak, R.B. (2013). Dynamic Analysis of a Cycloidal Gearbox Using Finite Element Method. *GearSolutions*, 35-44.

[3] Thube, V. S., & Bobak, R. B. (2011). The Dynamic Simulation and Analysis of a Cycloidal Speed Reducer. *11th ASME International Power Transmission and Gearing Conference*, Washington, DC, USA.

[4] Mačkić, T., Babić, Ž., Kostić, N., & Blagojević, M. (2013). Cyclo Drive Efficiency. *13th International Conference on Tribology*, Kragujevac, Srbija, 230-233.

[5] Blagojević M., Kočić M., Marjanović N., Stojanović B., Đorđević Z., Ivanović L., & Marjanović V. (2012). Influence of the Friction on the Cycloidal Speed Reducer Efficiency. *Journal of the Balkan Tribological Association*, *18* (2), 217-227.

[6] Mačkić T., Blagojević M., Babić Ž., & Kostić N. (2013). Influence of Design Parameters on Cyclo Drive Efficiency. *Journal of the Balkan Tribological Association*, *19*(4), 497-507.

[7] Blagojević, M. (2008). *Stress and Strain State of Cyclo Speed Reducer's Elements under Dynamic Loads* (in Serbian, Doctoral dissertation). Faculty of Mechanical Engineering, Kragujevac, Serbia.