STUDY OF THE ELASTIC DEFORMATION OF A SHORT FLEXIBLE TOOTHED WHEEL UNDER THE ACTION OF A TWO - ROLLERS WAVE GENERATOR

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ABSTRACT: This paper presents the results of a study on determining the deformation state in the body of a flexible toothed wheel from a double harmonic transmission, for the case of its deformation by a two-rollers wave generator. The research of the elastic behavior of a short flexible toothed wheel, which has the shape of a circular tube with thin wall, open at both ends and provided at each end with teeth (at one end with outer teeth and at the other end with inner teeth), consisted in calculating the deformations in the wall of the flexible wheel, both in static and dynamic regime. In determining the deformation state of the flexible wheel, an analytical calculation method based on an elliptical deformation law of the wheel was used, as well as the finite element method within the SolidWorks Simulation program. The numerical simulations performed on the flexible wheel confirmed the results obtained by applying the analytical calculation method and highlighted the importance of knowing the law of deformation of the flexible wheel when choosing the main geometric parameters of the teeth of the three wheels of a double harmonic transmission.

KEY WORDS: Deformation state, simulation, rollers wave generator, flexible wheel, double harmonic transmission.

1. INTRODUCTION

Toothed harmonic transmissions are mainly used for automation equipment that requires, at small dimensions and masses, high kinematic orientation accuracies and high and very high transmission ratios. Thus, these transmissions are frequently found in the construction of space exploration devices, manipulators and industrial robots, because they allow precise positioning of objects, as a result of the simultaneous engagement of a large number of teeth (about 25-40% of the total number of teeth of the conjugated wheels) [1, 2, 3, 4].

The main disadvantage of toothed harmonic transmissions is the limited operating time, which is given by the durability of the flexible wheel. This is the element from the transmission with the heaviest load. Because of this, in a large number of specialized works, a series of results were presented, regarding the research of the state of deformation and tension of the flexible wheel. Thus, in works [5, 6, 7], the dynamic behavior of long flexible wheel cup-type, with external teeth, under the action of a cam wave generator, was studied. In work [8], the case of a short flexible wheel with external teeth, under the action of a wave generator with eccentric discs, was analyzed.

This paper seeks to answer some aspects regarding the elastic deformation of short flexible wheel with combined teeth (outer, respectively inner) from a double harmonic transmission, under the action of a 2-rollers wave generator.

The constructive particularities of the double harmonic transmission are presented in figure 1. Basic elements of the double harmonic transmission are: 1 - the wave generator with 2 rollers, as driving element, 2 - flexible wheel, as intermediate element, 3 - fixed rigid wheel, 4 - mobile rigid wheel, as driven element. The transmission of the rotational movement is achieved by propagating an elastic deformation on the periphery of the flexible wheel, with a certain frequency.

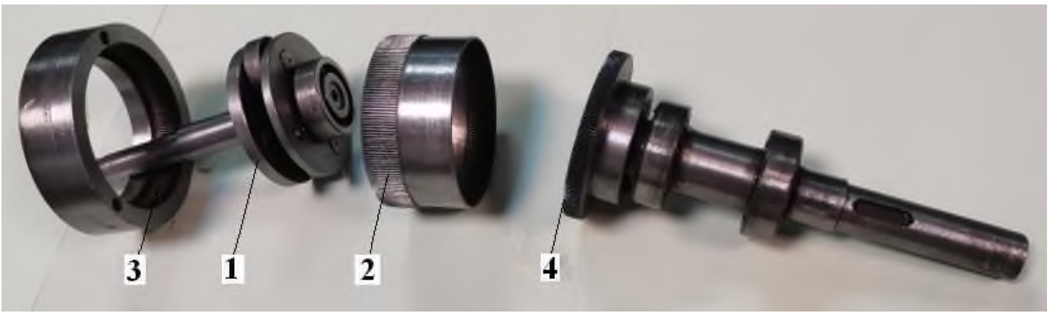

Figure 1. Construction of the double harmonic transmission

The flexible wheel has the shape of a short circular tube with a thin wall, which is provided at each end with teeth (at one end - outer teeth and at the other end - inner teeth).
In case of the double harmonic transmission, the flexible wheel has four equidistant harmonic engagement zones: two with fixed rigid wheel (3 - with internal teeth) and another two with mobile rigid wheel (4 - with external teeth). Between the two pairs of opposite harmonic engagement areas there is an angle of 90° [9].

2. DEFORMATION STATE OF THE FLEXIBLE WHEEL

The functional performances of the double harmonic transmission depend on the type and geometry of the active part of the wave generator, and on the geometry and precision of the execution of the toothed wheels.
In order to investigate the state of deformation of the short flexible wheel, it was assimilated with a thin cylindrical tube, with a constant wall thickness, which has an inextensible median surface. Thus, the medium fiber in any cross section of the deformed flexible wheel will have a constant length, and the elastic displacements of the points on the same generatrix of the median surface will have different values [10].
It was also considered that the law of elliptical deformation of the median surface of the short flexible wheel was achieved with the help of a 2-rollers wave generator, which operates inside the flexible wheel on a length corresponding to the width of the outer teeth (figure 2).

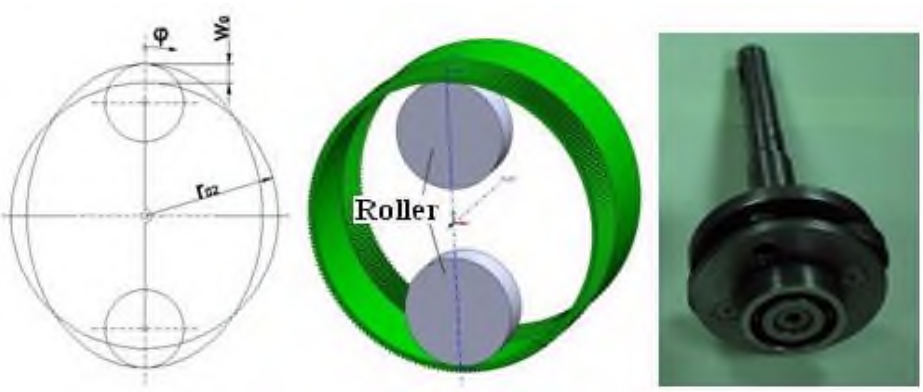

Figure 2. Construction of the 2 - rollers wave generator

For the analytical determination of the deformation state of the short flexible wheel in static regime, in its two frontal sections, the calculation model specific to thin-walled coatings was adopted, which allowed the determination of the elastic displacements of the points located on the medium fibers in the respective sections.
Calculation relations adopted for the radial displacement (w; w'), the tangential

displacement (v; v') and the rotation angle of the normal (θ; θ′) of the points located on the middle fibers of the two front sections of the flexible wheel, in case of its deformation by a wave generator with 2 rollers, they are [11]:

$$w = A\left[\sin\varphi + \left(\frac{\pi}{2} - \varphi\right)\cos\varphi - \frac{4}{\pi}\right] \qquad \textbf{(1)}$$

$$v = -A\left[\left(\frac{\pi}{2} - \varphi\right)\sin\varphi - B\right] \qquad \textbf{(2)}$$

$$\theta = \frac{A \cdot B}{r_{02}} \qquad \textbf{(3)}$$

$$A = \frac{w_0}{\pi/2 - 4/\pi}; B = 2\cos\varphi + \frac{4}{\pi}\varphi - 2 \qquad \textbf{(4)}$$

where: w_0 - the maximum radial deformation; r_{02} - the radius of the medium fiber of the undeformed flexible wheel; φ - the angular parameter of the 2- roller wave generator.

In the researched case, the short flexible wheel model is defined by the following parameters: the radius of the medium fiber, r_{02} = 29.3 mm; the maximum radial deformation in the frontal section of action of the wave generator, w_0 = 0.3 mm, respectively the maximum radial deformation in the other frontal section (where the wave generator does not act), w_0' = 0.27 mm.

Figure 3 shows the variation curves of the radial displacements (w; w'), tangential displacements (v; v') and of the rotation angle of the normal (θ; θ') depending on the rotation angle φ of the wave generator with 2 rollers, for the points on the medium fibers in the two front sections of the flexible wheel.

Figure 4 shows the variation curves of the radial displacements (w, respectively w') depending on the tangential displacements (v, respectively v'), for the case of deformation of the short flexible toothed wheel in static regime by a wave generator with 2 rollers.

From the study of the two curves of variation of the radial displacement according to the tangential one, valid for the frontal sections of the flexible wheel, it can be observed that they keep their elliptical shape in both sections. The trajectories of any two points on the middle fibers in the two front sections of the flexible wheel, which are on the same generatrix of the wheel, are closed elliptical curves. It is also observed that the maximum radial deformation of the points on the same generatrix of the flexible wheel decreases with the increase of their positioning distance

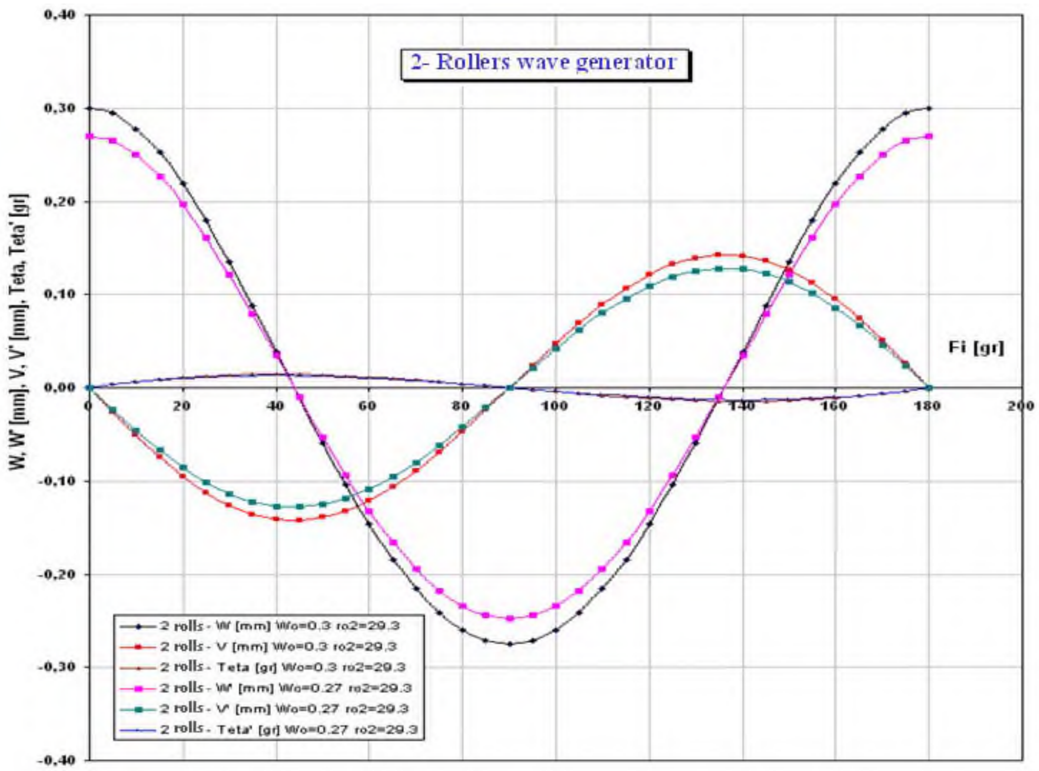

Figure 3. The elastic deformations of the short flexible wheel

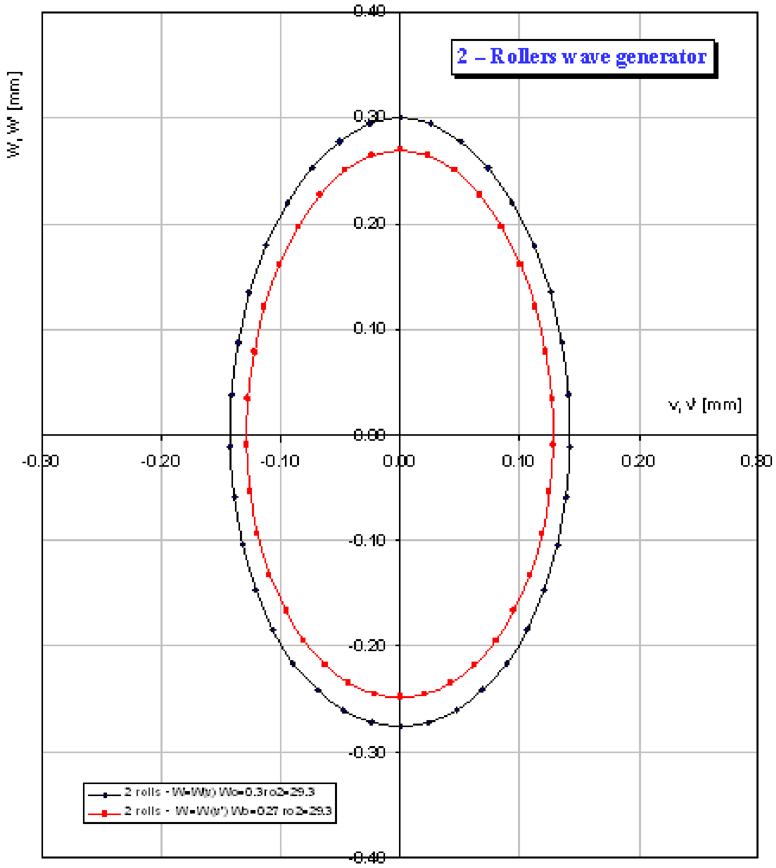

Figure 4. Deformation of the flexible wheel in the front sections

on the length of the generatrix.

Thus, in the front section where the 2-rollers wave generator operates, the maximum radial deformation will be: w_0 = 0.3 mm, and in the other front section of the wheel it will have a diminished value: w_0'= 0.27 mm.

3. DYNAMIC SIMULATION OF THE SHORT FLEXIBLE WHEEL

In order to study the deformation state of the short flexible wheel in dynamic regime, numerical simulations of the wheel were performed, for the case of its deformation by a 2-rollers wave generator, using the finite element method within the SolidWorks Simulation module.

The short flexible wheel was modeled by a cylindrical tube open at both ends, characterized by: radius of medium fiber, r_{02} = 29.3 mm; wheel length, l = 30 mm; wall thickness, s = 0.6 mm and the length of the teeth (outer with z_2 = 200 teeth, respectively inner with z_2' = 192 teeth), b = 12 mm.

The numerical simulations of the short flexible wheel aimed at studying the state of deformation and von Mises stresses from the wheel body, depending on certain torque of the driven element of the transmission.

Figure 5 shows, in the form of color maps, the distribution of the von Mises tensions ($\sigma_{von\ Mises}$) and the resulting displacement (Δ) in the flexible wheel body, for a torque at the driven element, M_{t4} = 100 Nm.

From the analysis of the numerical simulations of the flexible wheel, performed for the different torques M_{t4}, it was found that the von Mises tensions depend on the torque from the driven element of the transmission.

The von Mises tensions increase as the transmission load increases, and the maximum tension appears in the contact area of the flexible wheel with the two rollers of the wave generator, i.e. in the direction of the large axis of the ellipse.

Figure 6 shows, in the form of color maps, both the elastic deformations in the flexible wheel body and the values of the resulting displacements Δ of some characteristic points, which coincide even with the nodes of the finite elements, for the case of a torque M_{t4} = 100 Nm. Characteristic points are positioned on the generatrix of the deformed flexible wheel, corresponding to the area of action of the 2- rollers wave generator.

Figure 7 shows the variation curve of the resulting displacement Δ of the characteristic points depending on their position (given by the z dimension) on the active generator of the flexible wheel, for a torque at the driven element, M_{t4} = 100 Nm.

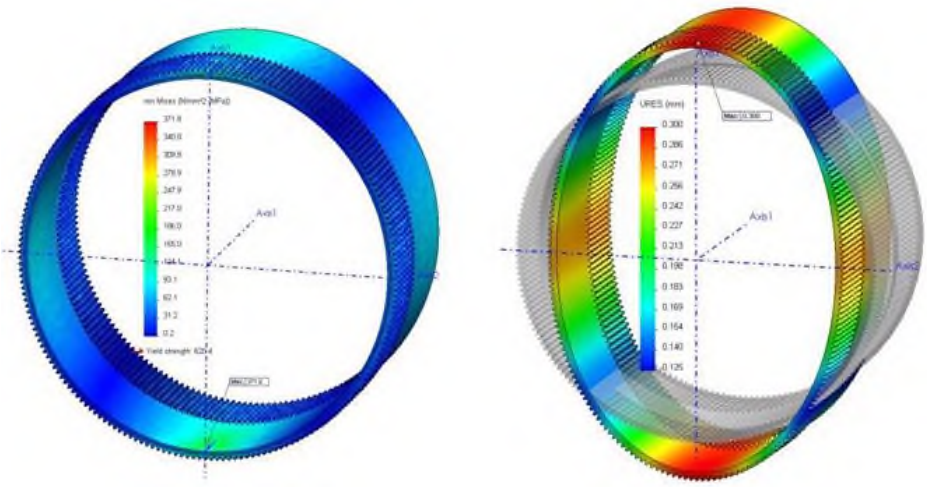

Figure 5. Distribution of $\sigma_{von\ Mises}$ tension and resulting displacement Δ

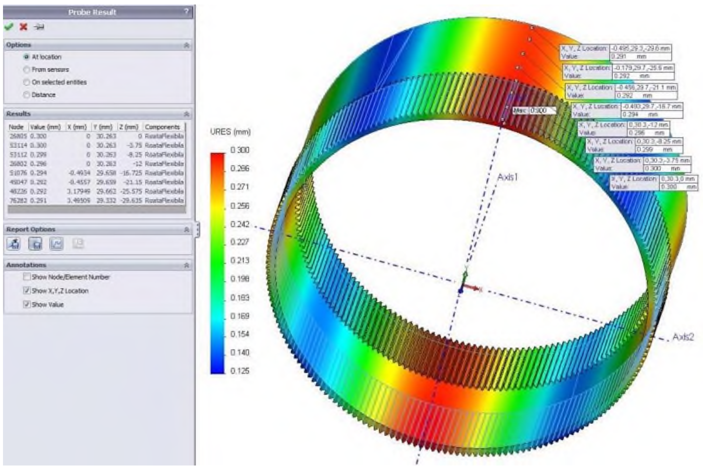

Figure 6. Distribution of the resulting displacement Δ

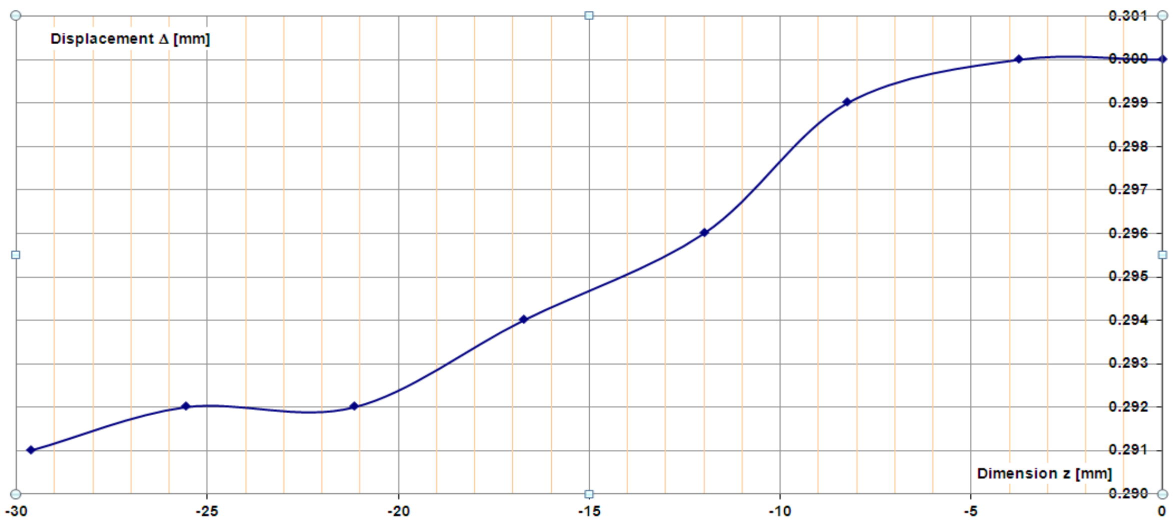

Figure 7. Variation of displacement Δ along the generatrix

From the analysis of the resulting displacement graph Δ = Δ (z), it is observed that in the front section of the flexible wheel where the 2-rollers wave generator operates, corresponding to the dimension z = 0 on the generatrix of the wheel, the maximum value for radial deformation is obtained: Δ (0) = w_0 = 0.3mm.
It has also been found that the resulting displacement Δ of the characteristic points has a slightly decreasing character with the increase of the z dimension of positioning these points in relation to the front section of the flexible wheel in which the 2-rollers wave generator operates.

4. CONCLUSION

Knowledge of the way of accomplishing the law of deformation of the short flexible wheel, as well as of its elastic behavior, presents a special importance in the correct appreciation of the conditions of harmonic engagement within the double harmonic transmission. Usually, the wheels modulus is chosen equal to the value of the maximum radial deformation (m = w_0).
This paper had as objective the investigation of the deformation state of a short flexible toothed wheel from a double harmonic transmission, in case of its deformation by a 2-rollers wave generator.
The results obtained by applying the proposed method of analytical calculation of elastic deformations, for an adopted model of flexible wheel, were verified and confirmed by using the finite element method, based on numerical simulations performed on short flexible wheel, at different transmission loads. From the analysis of the presented results, it was found that the von Mises tensions in the flexible wheel wall rise with the increase of the transmission load, and the maximum tension appears in the contact areas of the flexible wheel with the rollers of the wave generator. The resulting displacement of the points located on the same generatrix of the flexible wheel decreases with the increase of the distance from the wheel section in which the wave generator operates.

REFERENCES

[1]Ghinzburg, G. Volnovîe zubciatîe peredaci, Izd. Maşinostroenie, Leningrad, 1977
[2]Ianici, D. Contributions to the constructive -functional improvement of the double gear harmonic transmission. Ph.D. thesis, „Eftimie Murgu" University, Reşiţa, 2012
[3]Ianici, S., Ianici, D. Elemente de inginerie mecanică. Universitatea Eftimie Murgu, Reşiţa, 2015
[4]Ivanov, M. N. Volnovîe zubciatîe peredaci. Izd. Vîsşaia Şkola, Moskva,1981
[5]Dong, H., Zhu, Z., Zhou, W., Chen, Z. Dynamic simulation of harmonic gear drives considering tooth profile parameters optimization, Journal of Computers, 7(6), 2012, pp. 1429-1436
[6]Sahoo, V., Maiti, R. State of stress in strain wave gear flexspline cup on insertion of drive cam - experiment and analysis. Proceedings of the World Congress on Engineering 2016, Vol. II, WCE 2016, London, U.K.
[7]Zoo, C., Tao, T., Jiang, G., Mei, X. Deformation and stress analysis of short flexspline in the harmonic drive system with load, Proceedings of 2013 IEEE, International Conference on Mechatronics and Automation, 2013, Takamatsu, Japan, pp. 676-680
[8]Folega, P., Analysis of stress state of toothed ring of flexspline by means the BEM, Archives of Materiald Science and Engineering, 59(1), 2013, pp. 40-45
[9]Ianici, S., Miltenovic, V., Ianici, D. Numerical simulation of stress and strain state of the flexible wheel of the double harmonic transmission. The 8th International Symposium KOD 2014, Balatonfured, Hungary, pp. 135-138
[10]Ianici, S. Contributions au calcul des deformations et tensions dans l'element flexible de la transmission harmonique hermetique. Eighth IFToMM International Symposion SIROM 2001, Bucharest, pp. 175-180
[11]Ianici, D., Ianici, S. Dynamic research of the flexible wheel of a double harmonic gear transmission, Analele U.E.M., 22(1), Reşiţa, 2015, pp.223-230