# Solution and modification in the profile the harmonic drive

#### Daniela Harachová<sup>1</sup>

<sup>1</sup> Technická univerzita v Košiciach, Strojnícka Fakulta, KKDaL; Letná 9, 040 01 Košice; email: Daniela.Harachova@tuke.sk

Grant:. VEGA 1/0515/13 Name of the Grant: Draft design layout and architecture of intelligent implants Subject: JR - Other machinery industry

© GRANT Journal, MAGNANIMITAS Assn.

**Abstract** The harmonic gearing unquestionably include among a prospective technology. A harmonic gear is basically a differential gear with a train of spur gears where the mesh is achieved by the flexible deformation of one of the meshing wheels. The extent of the flexible wheel deformation is coherent to the character and the mesh quality. The difference lies in the fact that more cogs/teeth participate in meshing and thus also in transmission at the same time. The existence of the flexible wheel within the harmonic gear which undergoes deformation during the process of usage requires a specific approach in the mesh examination of this gear. During recent years the issue of the tooth deformation has been solved with modern methods of calculation including also one of the widely used numeric ones, the finite element method (FEM).

**Key words** Harmonic drive, elastic gear, finite element methods (FEM), model, deformation analysis.

## 1. DESCRIPTION HARMONIC DRIVE

Fig.1 shows the complete set of harmonic gear, ie flexible toothed wheel, solid sprocket and wave generator.

3

1- wave generator

- 2 solid sprocket
- 3 flexible wheel



Fig. 1 Harmonic drive

The meshing of a harmonic gear is achieved with the deformation of a flexible wheel (w) under the application of a wave generator (g). There is a very small relative movement between the teeth in the toothed mesh. In reality this relative movement of meshing teeth happens in zones where their loading capacity is small, i.e. on their entrance into the mesh and on their leaving it. This deformation influences the shape of the active walls of the teeth of the flexible wheel. And as a result they do not mesh correctly. When properly selected parameters of gearing between the teeth of the flexible wheel - (a) a rigid wheel - (k), there is a relative movement along such a path, which provides a small slip of teeth – (sc ) (Fig. 2).



Fig. 2 Shot tooth flexible wheel and solid wheel

This deformation influences the shape of the active walls of the teeth of the flexible wheel. And as a result they do not mesh correctly.

As a consequence of the meshing of the flexible wheel with the hard wheel the impact and interference (and also contact ratio) are created. These occurrences result in quick wear and the increase of the general damage which consequently decrease the longevity of the harmonic gears.

### 2. THE ELASTIC WHEEL DEFORMATION ESTIMATE USING FEM

Within the harmonic gear, the existence of the flexible wheel being deformed while being used requires an individual approach to the mesh examination for this gear. Primarily it is important to define the effect of the flexible wheel deformation on the tooth shape. The problem of the tooth deformation has been researched by many authors. The older works emerged from the classic theory of elasticity and treated a tooth as a fixed beam. So the flexible wheel is the limiting part of the harmonic gear's bearing power in direct coherence of an adverse wear. In the experiment conditions the tooth deformation loaded with a constant power or it is determined with the measurement of the divergence during a slow rotation. Currently the finite element method (FEM) is one of the

most prevalent numeric methods. Modern program systems FEM utilising the ever-growing facilities of the computer equipment enables to solve even very complicated tasks. The user of the program is able to work very effectively as the data feeding, calculation itself and the result analysis are fully automated.

# 3. CREATING A TREE-DIMENSIONAL GEOMETRIC MODEL

In standard cases a 3-dimentional geometric model can be created via volume calculations. In more complicated cases it is necessary to model it with the help of more complex geometric forms in the program Cosmos/M. In this case we use the command for the volume operations VLEXTR which creates the volume by shifting the generating plane (or a group of planes) in the direction of a given axis of the active coordinate system. After the design of the 3-dimentional geometric shape we frame its grid. This was done by the command for the parametric griding M\_VL which grids volume to create a 3-dimentional model of the object.



Fig. 3 Element of Solid type

Next step is to find out 3-dimensional geometric model.

Entering the material constants Limit conditions geometric limit conditions force limit conditions

In case solutions deformation tooth the elastic wheel the harmonic gear using FEM, we select all the displacement and rotation in place solid and the inflexiblelink zero bond. Saving bond is shown in (Fig. 3). As regards the prescription of surface forces, we proposed the of force in the place where the action arises from the wave generator (Fig.4).



### 4. TREATMENT OF RESULTS

Processing of computed results is important, the final part of the calculation by finite element method. The tasks of the mechanics of deformed bodies are generally the most important results of the nodal displacements, stress and deformation.

To detect displacement, stress and deformation will the use animation. Animation is an easy way representation of the deformed shape of the structure. Animation is a useful tool to better understand the behavior of the proposed model. For animation mostly just when a command ANIMATE confirm the proposed parameters (Fig.5).



Fig. 5 Deformed shape of the flexible wheel to move the field



Fig. 6 Comparison of shape

Fig.6 is a comparison of the shape of the elastic wheel undeformed and deformed shape of the flexible wheel

In (Fig. 7) are illustrated teeth and nodes in which indicated values of displacement along the axis X, Y, Z.



Fig. 7 Teeth with marked nodes

Measured figures are used in ascertaining whether the movement is greater if the force in respective directions is on the middle of the teeth.

Arithmetic mean of the displacement in the X - $\Delta$  X

i - the number of nodes in which they were subtract displacement

$$\Delta X = \frac{\left|\sum UX\right|}{i} = \frac{5,280587.10^{-3}}{12} = 4,400489.10^{-4} mm$$

Arithmetic mean of the displacement in the Y -  $\Delta$ Y

$$\Delta Y = \frac{\left|\sum UY\right|}{i} = \frac{3,763.10^{-2}}{12} = 3,135833.10^{-3} mm$$

Arithmetic mean of the displacement in the Z -  $\Delta Z$ 

$$\Delta Z = \frac{\left|\sum UZ\right|}{i} = \frac{4,3228.10^{-7}}{12} = 3,60233.10^{-8} mm$$

#### 5. CONSTRUCTING PROFILE AS ENVELOPES CIRCLES – PONCELET'S METHOD

As mentioned objective is to determine size the deformation of a flexible wheel harmonic transfer and subsequent tooth shape after deformation using FEM. After determining the shape of the deformed tooth it is necessary to design an appropriate shape of the opposite profile so when meshing the flexible wheel with the rigid wheel of the harmonic gear it would not cause interference. Tooth flanks solid wheel must be enveloping curves of the tooth flanks of the flexible wheel.

The internal gear is when the outer and the inner teeth mesh together. The harmonic gear is such a case where the outer teeth are provided by the flexible wheel and the inner by the rigid wheel. During meshing the associated teeth profiles are in point contact at all times. The most used direct construction is to design a profile like envelope circles (Poncelet's method).

Poncelet's method is very graphic and is based on the envelope principle: following the movement of both profiles in the axis system connected to one wheel (example 2) (Fig. 8), the sought  $p_1$ 

profile is the envelope of the  $p_1$  profile connected to the wheel 1 which spins off the rigid wheel 2 during this relative movement.



Fig. 8 Principle Poncelet's method

The mentioned method is used in discovering the opposite profile to the deformed tooth profile of the flexible wheel. The program "AUTOCAD" will be used for the design of the opposite profile. On (Fig 9) is the active panel of the deformed tooth of the flexible wheel and the opposite profile designed to it.



Fig. 9 Create opposite profile wheel using Poncelet's method

To design the opposite profile by the Poncelet's method is time consuming as the sides of the flexible wheel teeth must create the pitch circle of the rigid wheel teeth. It would be necessary to design the envelope of the active panel for each tooth separately because the teeth have individual shape as a consequence of the flexible wheel deformation. Also method is not very accurate, and especially in this case where the elastic wheel dimensions are very small.

For this reason, it is preferable to set up a calculation of the mathematical model to determine the contra profiles to the flexible wheel, but that is the aim of further work.

#### 6. CONCLUSION

The harmonic toothed gear transmissions undoubtedly are a prospective technology. Its uniqueness is in using a higher number of teeth in mesh and consequently also in conveyance. Within the harmonic gear, the existence of the flexible wheel being deformed while being used requires an individual approach to the mesh examination for this gear. Primarily it is important to define the effect of the flexible wheel deformation on the tooth shape. The shape of the active side of the tooth elastic deformation of the wheel, we found using the finite element method. Processing of computed results is an important part of the final calculation by finite element method. To detect displacement, voltage and deformation to used the animation. As mentioned objective is to determine size the deformation of a flexible wheel harmonic transfer and subsequent tooth shape after deformation using FEM. After determining the shape of the deformed tooth it is necessary to design an appropriate shape of the opposite profile so when meshing the flexible wheel with the rigid wheel of the harmonic gear it would not cause interference. Tooth flanks solid wheel must be enveloping curves of the tooth flanks of the flexible wheel. The internal gear is when the outer and the inner teeth mesh together. The harmonic gear is such a case where the outer teeth are provided by the flexible wheel and the inner by the rigid wheel. During meshing the associated teeth profiles are in point contact at all times. The most used direct construction is to design a profile like envelope circles

(Poncelet's method). To design the opposite profile by the Poncelet's method is time consuming as the sides of the flexible wheel teeth must create the pitch circle of the rigid wheel teeth. It would be necessary to design the envelope of the active panel for each tooth separately because the teeth have individual shape as a consequence of the flexible wheel deformation. Also method is not very accurate, and especially in this case where the elastic wheel dimensions are very small.

For this reason, it is preferable to set up a calculation of the mathematical model to determine the contra profiles to the flexible wheel, but that is the aim of further work.

#### Reference

- IVANČOI, V., KUBÍN, K., KOTOLNÝ, K. (2000): Program COSMOS/M. Elfa, Košice.
- IVANČO, V., KUBÍN, K., KOSTOLNÝ, K.: Program Cosmos/M.Elfa, Košice 2000.
- HAĽKO, J., VOJTKO, I., (2008): Diferenciálny Harmonický prevod a jeho simulácia, In: Mechanica Slovaca. Roč. 12, č. 3-C, s. 165-172. – 1SSN 1335 – 2393.
- HAĽKO, J., SEDLÁKOVÁ, J. (2009): Integrovaný harmnicko diferenčný prevod s možnosťou obojstranného vstupu. IN: 50. Medzinárodná vedecká konferencia katedier časti a mechanizmov strojov – Žilina: ŽU – S. 1-7. –ISDN 9788055400815.
- Harachová, D., Tóth T. (2013): Deformation analysis and modification in the profile the harmonic drive In: Technológ. Roč. 5, č. 4 (2013), s. 63-66. - ISSN 1337-8996