DEFORMATION ANALYSIS OF FLEXIBLE WHEEL IN THE HARMONIC DRIVE

*DANIELA HARACHOVÁ, †TEODOR TÓTH

The Technical University of Košice, Faculty of Mechanical Engineering, Department of Machine Design, of automotive and traffic engineering; Letná 9, 040 01 Košice; email: *Daniela.Harachova@tuke.sk, †Teodor.Toth@tuke.sk.

VEGA 1/0515/13, Draft design layout and architecture of intelligent implants. KEGA 021TUKE-4/2015, Development of cognitive activities focused in innovative educational programs in the engineering, construction or modernization of specialized laboratories designated in logistics and inter-operational transfer.

Abstract: The harmonic gearing unquestionably include among a prospective technology. It is about spur gearing where the meshing is achieved by the flexible deformation of one of the wheels. As a result of this deformation the shape of the flexible wheel changes from its original state resulting in incorrect meshing with the teeth of the opposite profile wheel. The deformation of the shape of the flexible wheel is the result of collision and interference, as well as the contact rate, occurring during the meshing of the flexible wheel with the rigid one. This转让 reaches some excellent properties such as great transference number in one stage, a sufficiently large effectiveness of a great kinematic accuracy and wide application. The disadvantage of a harmonic gear is that they are be sensitive to the torsion oscillations, design complexity and reduced service life of the elastic wheel.

Keywords: Harmonic drive, elastic gear, finite element methods (FEM), model, deformation analysis

1. The Harmonic gear

The harmonic gearing (Fig.1) 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. Flexible wheel 1 has outer gearing, solid wheel 2 has internal teeth. Both wheels have the same module and pitch. Flexible wheel has less teeth than a solid wheel.

The first speciality rests in the fact that in gear and thus and the transmission at the same time a greater number of teeth involved. The greater the of load be will transmit flexible member team will grow and its deformation and therefore a greater number of teeth will huddle in toothed.

The second peculiarity the harmonic gearing rests in that, due to changes in shape of the elastic wheel from the load, or due to the choices an shape of the wave generator there is a change a very small the relative movement between the teeth, the contained the with in toothed engagement. The third particularity is also conditional on the design of the flexible wheel rests reduce of angles of pressure of kinematic pair of wave generator - of the flexible wheel, as reflected by the reduce friction - of sides this pair in compared catch cam - satellite in the planet gear. The principle of harmonic gear (Fig. 1).

Fig. 1 Harmonic drive 1 - flexible Wheel, 2 - solid sprocket, 3 - wave generator

2. Types of generator

Types of the wave generator:

a) Four-cylinder generator - every deformation - wave - of the flexible wheel is created by two cylinders.

b) The multiple-cylinder generator – enables the assurance of the required shape of the flexible wheel deformation in all its circumference, while the load of individual cylinders will differ according to the deformation zone of the respective cylinder.

c) A disc generator – creates waves with a greater curve radius.

d) A cylinder generator - a kinematic bond between a cylinder generator and a flexible member can happen via frictional or rolling kinematic pairs. The cam of the generator can be in the shape of a circle, ellipse, logarithmical spiral, evolvent or other curved line.

Fig. 2 a) four-cylinder generator, b) the multiple-cylinder generator c) a disc generator, d) a cylinder generator

3. Elastic deformation of the wheel and its impact on gearing

The existence of a flexible wheel in harmonic gear box of that are deforms at work, need a special approach to the investigation in the mesh in this gear. Above all, it is necessary to show the influence of the deformation flexible of the wheel on the shape of teeth. Flexible the wheel is to during operation straining very negative.

The following are the main stresses:

- Deformity Stress induced by the generator
- Stress induced/generated by the transmitted load
- The elastic deformation of the harmonic wheel may be twofold.

As a result of the adverse stress the flexible wheel is the limiting part of the load-bearing capacity of the harmonic gears. The elastic deformation of the harmonic wheel may be:

a) Free form deformation, is where the harmonic wheel is deformed by the cylinders of a smaller cross-section. A harmonic wheel deforms into an approximately elliptical shape.

b) The forced deformation, where the shape of a harmonic wheel is given by the shape of the generator of harmonic deformations.

A second case is preferable, because the harmonic wheel can be deformed into any shape. If we want to use involute gearing must have the pitch curve harmonic wheel after deformation in the area of a mesh the shape circle line.
The deformed shape of the flexible wheel can vary providing two conditions:

- the roller curve of the deformed wheel has to be of the same length as its roller circle before the deformation so that the pitch would remain unchanged,
- the extent of the deformation must not exceed the breaking limit of the flexible wheel under the influence of stress.

The size of deformation of the flexible wheel has a significant impact on the character and quality of the mesh. In case of radial deformation the flexible wheel cogs mesh with the profile wheel cogs in its full height. If the pitch circles do not touch (Fig.3b)) and side clearance is created. When side clearance is great, the cogs of the flexible wheel can move within the gaps of the profile wheel without transmitting movement. The stated short-comings are removed by the negative shifting of the tool for working the profile wheel cogs (Fig.3c)). If the pitch circles cut interfere (Fig.3d)), the interference is removed by the positive shifting of the tool for working the cogs of the profile wheel.

![Fig. 3 Variants gearing](image)

**Fig. 3 Variants gearing**

\[ w_o = m \]

\[ w_o (m) \]

**a)**

\[ x_3 = 0 \]

**b)**

\[ d_2 \text{ – diameter flexible wheel, } d_3 \text{ – diameter of solid wheel, } x_3 \text{ – shifting tool during operation teeth the solid wheel.} \]

**4. Determination deformation flexible wheel using FEM**

Flexible cog-wheel is during operation stressed very negative. The stress from the generator deformation, the load bearing stress and local stress from the cog bending in the cog gaps are present in it. As mentioned before, the deformation alters the cogs’ shape and they do not fulfil the correct meshing conditions any more.

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. In the experiment conditions the tooth deformation is mostly determined by a static measurement of 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.

Size of the deformation of the elastic wheel is detected in two cases, namely:

Alternative 1 – if the force emergent from the wave generator is applied in the center of the tooth (Fig. 4).

![Fig. 4 The applied force in the center of the tooth](image)

Alternate 2 - if the force emergent from the wave generator will operate in the middle tooth gap (Fig. 5).

![Fig.5 The applied force in the middle tooth gap](image)

**5. A creating the geometric calculation model**

The gradual processing of individual steps by the Cosmos/M programme created a geometric model of a flexible wheel cog (Fig. 6) – generated using the generating commands to represent the surveyed model which is a \( \frac{1}{4} \) of the flexible wheel with the cog number \( z = 172 \).

![Fig.6 The final form of the tooth before generation](image)

To be able to proceed in solving the static deformation analysis using FEM gearing is necessary, appropriate proposals boundary conditions.

In mechanics flexible bodies can distinguish two types of boundary conditions:

1. Geometric limit conditions
2. 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 inflexible link zero bond. Bonds were placed on the left side of the model in the direction of the \( y \) axis on the frontal part of the wheel of the \( z \) axis and then on the active part of the wheel in the direction of the \( x \) axis (Fig. 7). Regarding the prescribing of surface forces, has proposed the imposition of force in the place where the action arises from acting time wave generator.
Other bonds I proposed the active tooth face which is at the moment engaged. The bonds are disposed on both opposite sides of the elastic wheel (Fig. 8) over the full length of the relevant nodes.

Action of force boundary conditions prescribed surface forces. In this alternative I proposed the force in places where there is the arises action of waves and the generator is stored in the center of the tooth that is engaged (Fig. 9). Burdensome strength for flexible wheel the unit. Because my computing model is ¼ of the flexible wheel, the extent of the input force will be as follows:

\[ F = \frac{1}{4} \cdot \text{unit force for whole the flexible wheel} \]

\[ F = 0.25 \cdot \text{onto ¼ the wheel:} \]

\[ F = \frac{1}{4} = 0.25 \cdot N \]

as shown in (Fig. 9) the total force divided into 5 and the value of one will be:

\[ F = \frac{0.25}{5} = 0.05 \cdot N \Rightarrow \text{magnitude of the force I specify at insert forces.} \]

6. Treatment of results

Processing of calculated results is important, the final part of the finish calculated finite element method. In tasks of mechanics of deformed bodies are generally the most important results of the nodal displacement, 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.
Fig. 11 Deformed shape of the flexible wheel

Tab. 1 Size deformation which with creates from the deformation of elastic wheel

<table>
<thead>
<tr>
<th>Color resolution</th>
<th>Displacement values when force is applied at the center of the tooth [mm]</th>
<th>Displacement values when force is applied in a notched gap [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.082126</td>
<td>0.0800237</td>
</tr>
<tr>
<td></td>
<td>0.07552</td>
<td>0.073788</td>
</tr>
<tr>
<td></td>
<td>0.068914</td>
<td>0.067338</td>
</tr>
<tr>
<td></td>
<td>0.062308</td>
<td>0.060888</td>
</tr>
<tr>
<td></td>
<td>0.055702</td>
<td>0.054438</td>
</tr>
<tr>
<td></td>
<td>0.049096</td>
<td>0.047989</td>
</tr>
<tr>
<td></td>
<td>0.042490</td>
<td>0.041539</td>
</tr>
<tr>
<td></td>
<td>0.035885</td>
<td>0.035089</td>
</tr>
<tr>
<td></td>
<td>0.029279</td>
<td>0.028640</td>
</tr>
</tbody>
</table>

If we compare the values of the resulting shifts from the coloured area, we discover that smaller values occur when the power generated by the wave generator acts in the middle of the cog gap (Alternative No.2). As mentioned before, the deformation alters the cog’s shape and they do not fulfill the correct meshing conditions any more. Because the cog’s shape after the deformation can be determined using MKP, it is consequently necessary to create a profile that mirrors the profile of the flexible wheel cog after the deformation. This would minimise interference and contact impact.

7. Conclusion

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. Processing of computed results is an important part of the final calculation by finite element method. Processing calculated 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.

Literature:


Primary Paper Section: J

Secondary Paper Section: JR