INSERTION OF TEETH INTO ENGAGEMENT AND THEIR EFFECT THE DEFORMATION OF THE ELASTIC WHEEL IN HARMONIC GEAR.

[a]DANIELA HARACHOVÁ, [b]TEODOR TÓTH

[a]*The Technical University of Košice, Faculty of Mechanical Engineering,* Department of Machine Design, of automotive and traffic engineering*; Letná 9, 040 01 Košice;*
[b]*The Technical University of Košice, Faculty of Mechanical Engineering, Department of Machine Biomedical Engineering and Measurement; Letná 9, 04001 Košice SK email:*
email: [a]Daniela.Harachova@tuke.sk, [b]Teodor.Tóth@tuke.sk

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Abstract: Gearboxes represent the most prevalent and prominent type of transmission mechanism encountered in all spheres of mechanics. The harmonic toothed gear transmissions undoubtedly are a prospective technology. 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.

Keywords: the harmonic gearbox, deformation, the flexible wheel, the teeth curve.

1 Introduction

Harmonic drive transmissions are noted for their ability to reduce backlash in a motion control system. The principle of operation of harmonic gears is through the use of a thin-walled flexible cup with external splines on its lip, placed inside a circular thick-walled rigid ring machined with internal splines. The external flexible spline has two fewer teeth than the internal circular spline. An elliptical cam enclosed in an antifriction ball bearing assembly is mounted inside the flexible cup and forces the flexible cup splines to push deeply into the rigid ring at two opposite points while rotating. The two contact points rotate at a speed governed be the difference in the number of teeth on the two splines This method basically preloads the teeth, which reduces backlash.

2 Harmonic gearbox design

The harmonic gearbox consists of three basic components, which are necessary for a correct functioning of the harmonic gearbox mechanism (Fig.1).

Wave Generator:
The wave generator is an oval-shaped cam with a thin ball bearing placed around the outer circumference of the oval cam. The wave generator is mounted onto the motor shaft.

Flex spline:
The flex spline is a thin, cup-shaped component made of elastic metal, with teeth formed along the outer circumference of the cup's opening. The gear's output shaft is attached to the bottom of the flex spline.

Circular Spline:
The circular spline is a rigid internal gear with teeth formed along its inner circumference. These teeth are the same size as those of the flex spline, but the circular spline has two more teeth than the flex spline. The circular spline is attached to the gearbox along its outer circumference.

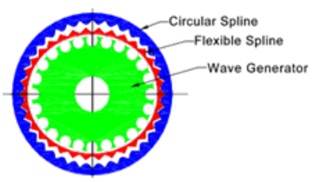


Fig. 1 Harmonic drive

The individual components (Fig.2) are mutually interconnected by the following links:

A) Rotational link between the base body and the input shaft HP, in order to drive the WG,
B) Rotational link between the base body and the output shaft, in order to drive the output element – FS,
C) Flexible link between the WG and FS,
D) Gear drive between the FS and C,
E) Solid link between the CS and the base body.

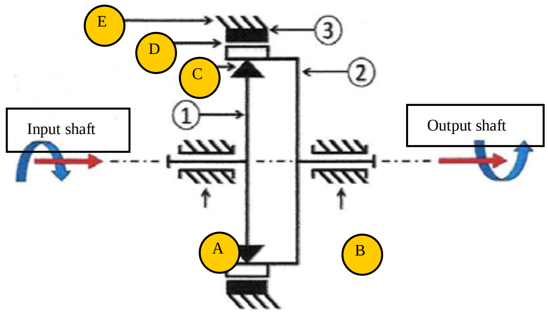


Fig. 2 Scheme of Harmonic Gearbox

A principle of the harmonic gear functioning is based on rotational-eliptical deformation of the flexible wheel. This deformation is generated by the wave generator, which is inserted into the open end of the flexible wheel. Gearing, which is situated on the external edge of the flexible wheel, is transmitting the elliptic form during rotation of the wave generator. In this way the gearing is rolling between the flexible wheel and the fixed wheel, which is firmly situated inside the gearbox.

3 The types of flexible elements of harmonic gear

Schematics basic types of elastic elements harmonic drive are given a (Fig.3). From a structural and technological point of view, the most complex hermetic elements (Fig.3 d, e, i) which are also stressed by temperature changes.

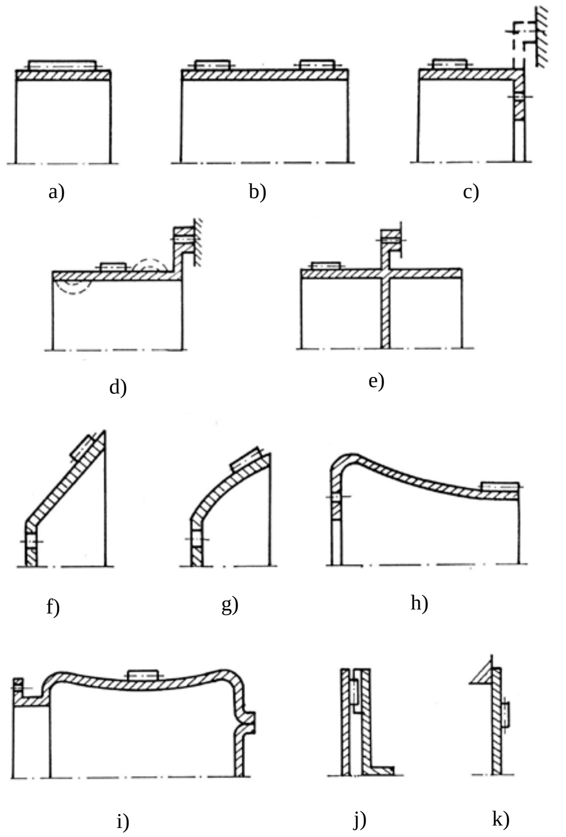


Fig. 3 Schemes types of elastic elements of harmonic gear

4 Insertion of teeth into mesh in Harmonic gear

Gearing of the harmonic gearbox belongs into the category of the internal gearings with a small difference between the numbers of teeth arranged on both wheels. This kind of gear drive is sensitive to an impact of tops of teeth during insertion of the flexible wheel tooth into the tooth space between the fixed wheel teeth (Fig. 4). Such collision can be eliminated using a suitable modification concerning active contours of tooth flanks.

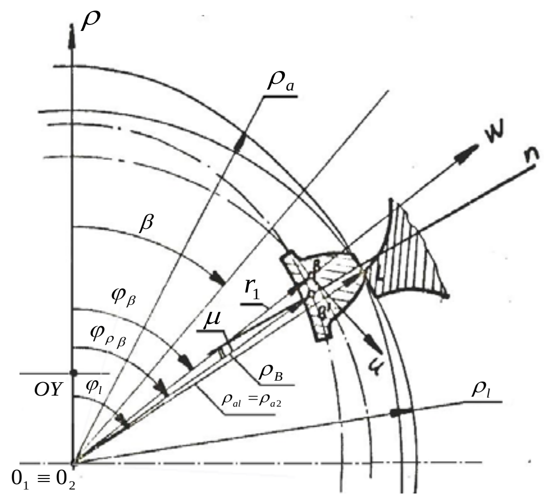


Fig. 4 Insertion of the tooth the elastic wheel into the gap between the teeth of the rigid wheel

Coordinates of the intersection point between both tops of teeth curves determine the initial moment of tooth insertion into the mesh. If the top of teeth curve in the case of the flexible wheel is an equidistant line with regard to the deformed central line, then equation of this line can be written in the form:

$$\rho_a \approx r_1 + w(\varphi) + \frac{ha}{\cos \mu(\varphi)} \qquad (1)$$

where is: ρ_a – deformed top of tooth circle,
h_a – addendum,
w – shift in direction of the coordinate axes,
$\mu(\varphi)$ – angle between the radius (vector) of the point on the deformed central line and the normal line in the same point.

Taking into consideration fact that the value of the angle $\mu(\varphi)$ is small in the case of real gears, i.e. cos $\mu(\varphi) \approx 1$, then:

$$\rho_a \approx r_1 + w(\varphi) + ha \qquad (2)$$

The intersection point between the tops of teeth curve of the flexible wheel and the top of tooth circle of the fixed wheel is determined by solution of the equation:

$$r_{a2} = r_1 + w(\varphi) + ha \qquad (3)$$

Where r_{a2} is the top of tooth circle radius with regard to the angle φ.

The relation between the line slope angle φ of the investigated point K situated on the base central line and the line slope angle φ of the corresponding point K' in the analysed cross-section of the deformed surface is given by the relation:

$$\varphi_l \approx \varphi + \frac{u(\varphi)}{r_1 + w(\varphi)} \qquad (4)$$

Where $u(\varphi)$ is a shift in direction of the coordinate axes.
The angular line slope φ_l of the intersection point for the curves of tops can be obtained by calculation of the angle φ from the relation (3) using the relation (4).

5 Flexible wheel deformation

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. 5).

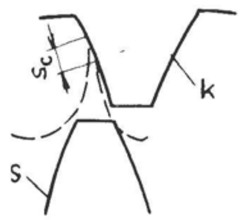
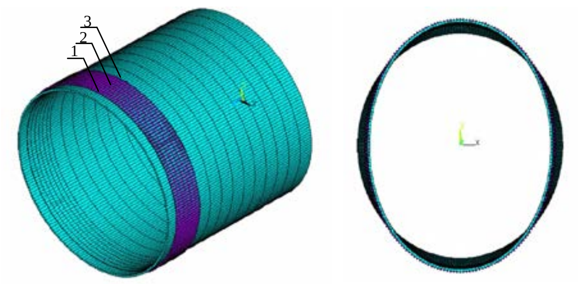


Fig. 5 Shot tooth flexible wheel and solid wheel

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. 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 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.

The deformed shape in cross-sections 1, 2 and 3 is not constant, 1. which ultimately introduces other nonlinearities into the rolling of the tooth profile (Fig. 6).



a) b)

Fig. 6 a) shell and beam model of flexspline,
b) deformation of the flexspline

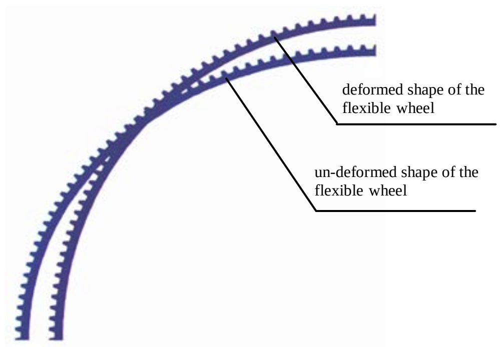


Fig.7 A comparison of the shape of the elastic wheel undeformed and deformed shape of the flexible wheel

Objective is to determine size the deformation of a flexible wheel harmonic transfer and subsequent tooth shape after deformation. 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 whee, but that is the aim of further work.

6 Conclusion

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 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. The tasks of the mechanics of deformed bodies are generally the most important results of the nodal displacements, stress and deformation. 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.

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