Geometry insertion of teeth into engagement in a harmonic transmission

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Abstract Basically, the Harmonic Drive®-developed to take advantage of the elastic dynamics of metal- is typically made up of only three components: a wave generator, a flexspline and a circular spline (Depending on its shape, the Harmonic Drive® is sometimes made up of four components; but even this four-component Harmonic Drive is based on the same principle of motion). One can grasp the Harmonic Drive's® unique mechanisms from the way its teeth mate with one another. Harmonic gears are lighter and smaller in comparison to regular toothed gears. It is characterized by a high kinematic accuracy, less noisy and has up to 5 times higher damping capacity than current transfers. A harmonic toothed gear is basically a differential gear with frontal gearing where the meshing is achieved by a flexible deformation of one of the wheels.

Keywords Harmonic gearbox systems, flexible wheel, deformation, insertion the teeth.

1. THE HARMONIC GEARBOX

The harmonic gearing 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 the 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 (Figure 1.).

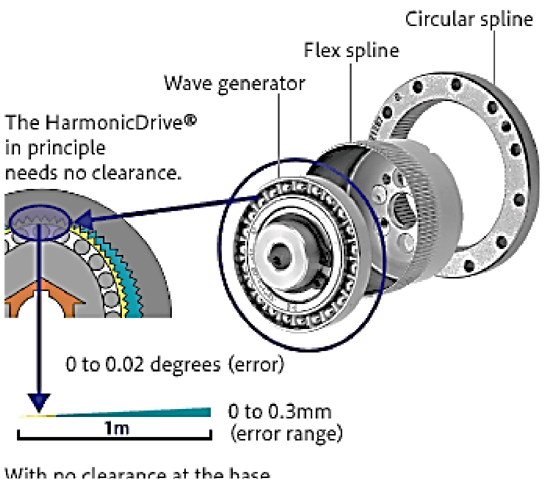

Figure 1. Harmonic gearbox.

1.1 Flexspline

The Flexspline is a thin-walled steel cup with gear teeth machined into the outer surface near the open end of the cup. The bottom of the Flexspline (cup bottom) is called the diaphragm. The diaphragm is usually fitted to the output shaft.

The Flexspline is slightly smaller in diameter and has two fewer teeth than the Circular Spline. The elliptical shape of the Wave Generator causes the teeth of the Flexspline to engage the Circular Spline at two opposite regions across the major axis of the ellipse. For every 180 degree clockwise rotation of the Wave Generator the Flexspline teeth are advanced counterclockwise by one tooth in relation to the Circular Spline. Each complete clockwise rotation of the Wave Generator results in the Flexspline moving counter-clockwise by two teeth from its original position relative to the Circular Spline [8]. Because the gear teeth are always fully engaged in a region along the major axis, Harmonic Drive gearheads have Zero Backlash (Figure 2.).

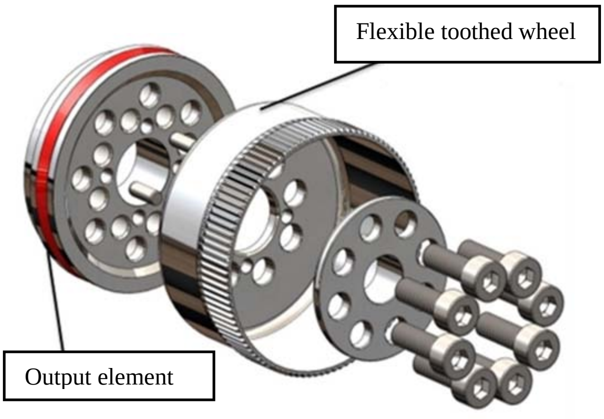

Figure 2. Flexible gear assembly

1.2 Circular spline

The circular spline is a rigid ring with internal teeth. It angages the teeth of teh flexspline along and major axis of the Wave Generator ellipse. The circular spline has twu moore teeth than the Flexspline and is generally fixed (no rotating) and mounted within a gear housing (Figure 3).

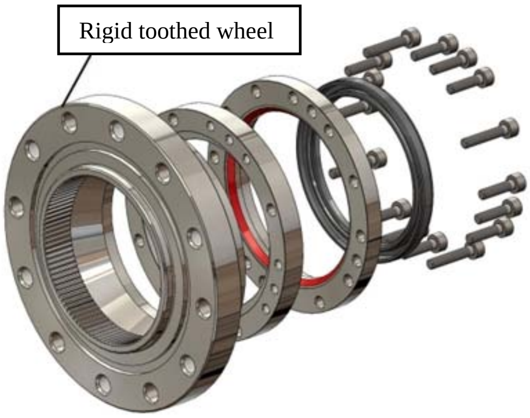

Figure 3. Rigid gear assembly

2. CONSTRUCTION OF FLEXIBLE WHEELS

The decisive factor for the load capacity of harmonic gears is the flexible wheel. It deforms during operation, with the deformation circulating around the entire circumference. This results in difficult working conditions for the flexible wheel. The flexible wheel is usually made in the form of a thin-walled tube or a thin-walled container with a bottom. Some is in practice often use the which are shapes shown in (Figure 4.).

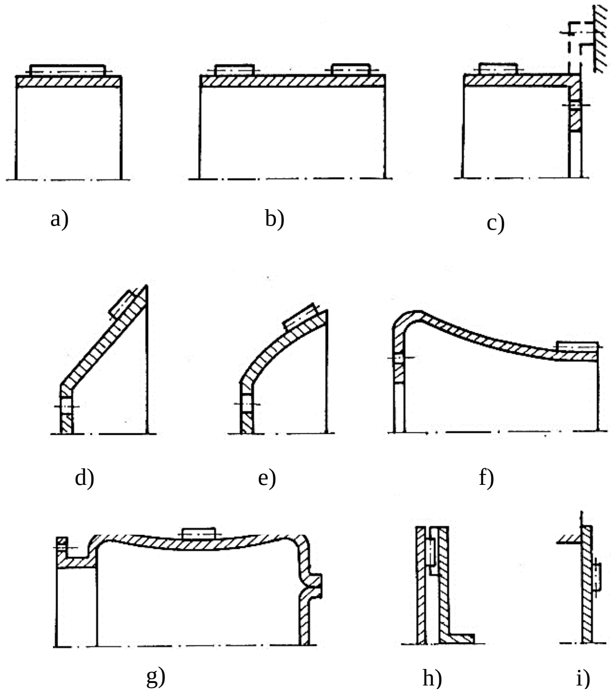

Figure 4. Schemes types of elastic elements of harmonic gear.

3. ISERTION OF TEETH TEETH INTO MESH IN HARMONIC GEARBOX

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 (Figure 5.). Such collision can be eliminated using a suitable modification concerning active contours of tooth flanks.

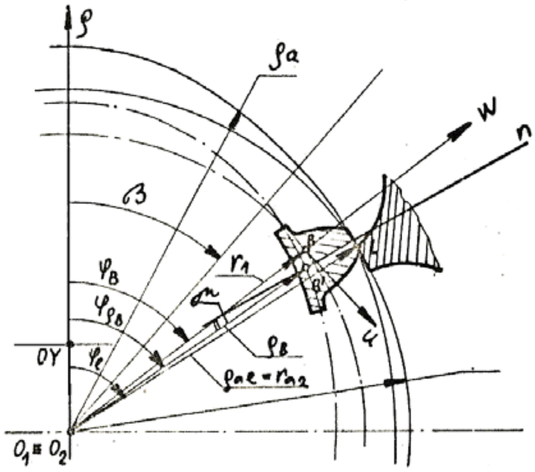

Figure 5. Insertion of the tooth the elastic wheel into the gap between the teeth of the rigid wheel.

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:

$$\varphi_1 \approx \varphi + \frac{u(\varphi)}{r_1 + w(\varphi)} \qquad (4)$$

Where $u(\varphi)$ is a shift in direction of the coordinate axes.
The angular line slope φ_I 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).

Examination the harmonic gearbox with fixed harmonic generator (Figure 6.). When the gear teeth pass from position I, corresponding to the moment on the larger axis of the harmonic generator when the axle of the elastic wheel is identical to the axis of the toothed gap of the solid wheel to position II, when the point F of the rigid wheel coincides with the point L, the shaft of the rigid wheel is rotated by the angle φ_2, and the shaft of the flexible wheel by the angle φ_1. The gear- ratio of the spring wheel shaft to the rigid wheel shaft with the harmonic deformation generator fixed is determined by the relationship:

$$\frac{\omega_1}{\omega_2} = \frac{z_2}{z_1} = \frac{\varphi_1}{\varphi_2} \qquad (5)$$

$$\varphi_1 = \frac{z_2}{z_1}\varphi_2 \qquad (6)$$

The radius - the vector of the point F is rotated by the angle φ_2 and assumes the position with the angular direction φ_1, where:

$$\varphi_1 = \varphi_2 + \frac{p_{a2} - s_{a2}}{2\,r_{a2}} \qquad (7)$$

Where: ρ_{a2} - tooth pitch on the head circle
s_{a2} - tooth thickness on the head circle
r_{a2} - radius of the head circle

The radius - the vector of point D is rotated by the angle $\varphi_{\rho 1}$, corresponding to the rotation of the shaft of the elastic wheel by the angle φ_1, its position will be given by the angular directive $\varphi_{\rho d}$ (Figure 7).

$$\varphi_{\rho 1} \approx \varphi_1 + \frac{u(\varphi_1)}{r_1 + w(\varphi_1)} + \frac{h_a \,.\sin\mu(\varphi_1)}{r_1 + w(\varphi_1) + h_a} \qquad (8)$$

because the angle $\mu(\varphi_1)$ is small, we adjust the relation (8) to form:

$$\varphi_{\rho 1} \approx \varphi_1 + \frac{u(\varphi_1)}{r_1 + w(\varphi_1)} + \frac{h_a \,.\mu(\varphi_1)}{r_1 + w(\varphi_1) + h_a} \qquad (9)$$

$$\varphi_{\rho d} \approx \varphi_{\rho 1} + \frac{0{,}5.\,s_{a1}}{r_1 + w(\varphi_1) + h_a} \qquad (10)$$

By substituting the relation (9) into the relation (10) we get:

$$\varphi_{\rho d} \approx \varphi_1 + \frac{u(\varphi_1)}{r_1 + w(\varphi_1)} + \frac{h_a \,.\mu(\varphi_1) + 0{,}5 s_{a1}}{r_1 + w(\varphi_1) + h_a} \qquad (11)$$

Condition that at gear wheel engagement there was no impact of the teeth heads is expressed by:

$$\varphi_{\rho d} < \varphi_1 \qquad (12)$$

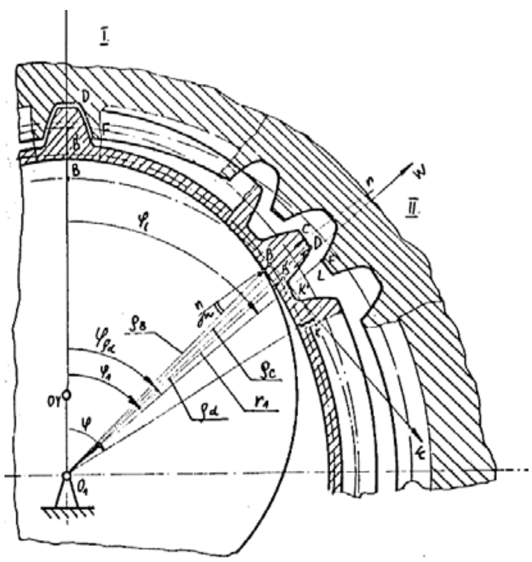

Figure 7. Harmonic gear with fixed harmonic distortion generator.

The peculiarity of the harmonic transmission is that, due to the changed shape of the flexible wheel from the load or due to the chosen cam shape of the generator, there is a very small relative movement between the teeth in the gear. Basically, the relative movement of the meshing teeth occurs in zones where their load is small.

4. CONCLISION

The meshing of a harmonic gear is achieved with the deformation of a flexible wheel under the application of a wave generator.

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.

The teeth of the gear wheels are deformed under load, causing a number of negative consequences. Therefore, the knowledge of the deformation properties of the toothing is very important.

As 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 wheel.

Properly taking up profiles must meet all the requirements of the gear design. It follows from the essence of this law that if the centers of rotation O1, O2 of both meshing wheels and the shape of a single profile are given eg. p1 is known, then the shape of the second profile p2 is thus clearly determined. The aim of further work is to construct a profile as a circle envelope.

Sources

1. GREGA, R., KRAJŇÁK, J., MORAVIČ, M.: Experimental verification of the impact of a technical gas-using pneumatic coupling on torsional oscillation. Scientific Journal of Silesian UniversDity of Technology = Zeszyty Naukowe Politechniki Śląskiej: Series Transport: Seria Transport., č. 99, pp. 55-63 (2018).
2. GHORBEL H., GANDHI, P. S., ALPERER, F., “On the Kinematic Error in Harmonic Drive Gears”, J. Mech. Des., pp. 90–97, 2001.
3. HARACHOVÁ, D.: Decomposition of driving systems specified for rehabilitation machines, In: Ad Alta: Journal of Interdisciplinary Research. Vol. 7, no. 2 (2017), p. 271-273. - ISSN 1804-7890.
4. IANICI, S., IANICI, D.: Contributions to determining the trajectory of a point on the average fiber of the flexible wheel of a double harmonic transmission. In: Analele Universitatii 'Eftimie Murgu' Vol. 26, no. 1 (2019), p. 99-106 ISSN: 1453-7397.
5. JANOTA D., CZECH R., CHECH P.:. Analiza zanieczyszczenia powietrza atmosferycznego tlenkami azotu na przykładzie wybranych śląskich miast. Logistyka, Vol. 4/2015, str. 3795-3812. ISSN: 1231-5478.
6. JEZNÝ,J.: Kinematic model of nonholonomic mobile robots In: Applied Mechanics and Materials Vol. 611 (2014), p. 107-114 ISSN: 1660-9336
7. KRAJŇÁK,J., MALÁKOVÁ,S.: Behaviour of change relating to the polytropic coefficient in thermodynamic processes within gaseous medium insidethe shaft coupling In: Projektowanie, badania i eksploatacja P. 211-218 ISBN: 978-83-66249-24-0
9. MALCZEWSKI B., ŁAZARZ B., CHECH P., WITASZEK K., WITASZEK M., : Drgania ogólne odczuwalne przez kierowcę samochodu osobowego podczas przejazdu przez progi zwalniające – cz. 2. Technika Transportu Szynowego, Vol. 12/2015, 1026-1031. ISSN: 1232-3829.
10. MANTIČ, M. a kol.: Autonomous online system for evaluating steel structure durability Diagnostyka. Vol. 17, no. 3 pp. 15-20. - ISSN 1641-6414 (2016).
11. PUŠKÁR, M., KOPAS, M., PUŠKÁR, D.: Development of Fuel Maps in Hexadecimal Format for Reduction of NOX Emissions and Application in Real HCCI Engine, In: Acta Mechanica Slovaca : journal published by Faculty of Mechanical Engineering, the Technical University in Košice. - Košice (Slovensko) : Strojnícka fakulta Roč. 22, č. 2 (2018), s. 38-46 [print]. - ISSN1335-23 (2018).
12. XIAOXIA CH., SHUZHONG L., JINGZHONG X.,: “The investigation ofelongation of the neutral line in harmonic drive”, v 2010 International conference on computer desigh and appliations, 2010, roč. 4, s. V4-383-V4-386.