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Involute helical-bevel gearing

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Abstract

This paper describes helical-bevel gearing (HBG). The helical-bevel gearing commonly includes a cylindrical and a bevel gear. The tooth profiles can be either spur or helical. The involute HBG provides an opportunity to design a broad variety of gear trains, unobtainable by the use of conventional types of gears. The article defines methods of their generation, a contact shape and points out advantages of various arrangements of gears, diagrams of an external helical-bevel gearing skew axis, hypoid gearing, intersecting axes, parallel axes. The expediency of the use of such gear in a machine drive is justified.

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Keywords: helical-bevel gearing; involute bevel gear; TCA; synthesis of gears.

1. Introduction

In the design of modern mechanical drives, successful solutions can be obtained by using non-conventional gearing, which includes helical-bevel gearing [1, 2]. The helical-bevel gearing (HBG) commonly includes a cylindrical and a bevel gears. The tooth profiles can be either spur or helical. The helical-bevel gearing can transfer torque between the shafts at an arbitrary disposition (Fig. 1) [3, 4].

The generation of the HBG by a rack-cutter produces involute flanks of the bevel gear teeth due to the fact that the axis of the machining engagement L is parallel to the gear axis (Fig. 2). That type of the gears is called an involute-bevel gear. It is characterized by the linearly changing displacement of the rack-cutter [5]. I this case, the HBG is involute. The generation of the HBG by a hob is impossible due to the difference of the machining kinematics and the actual meshing of the gears in the HBG. The generation of the non-involute internal and external HBG by a hob shown in [4, 6, 7, 8].

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2. Methods of teeth profile generation and contact shape

Depending on the type of the generating tools and the kinematic arrangements of the manufacturing process, the profile of the teeth of the bevel gear of the helical-bevel gearing can be involute or non-involute.

3. Advantages of involute helical-bevel gearing

The involute HBG provides an opportunity to design a broad verity of gear trains, unobtainable by the use of conventional types of gears. The explanation of main arrangements as follows.

3.1 Skew axes HBG

The gearing shown at Fig. 1 (a) can only exist if:

$$\cos\Sigma = \cos\left(\beta_1 + \beta_2\right)\cos\delta \tag{1}$$

The center distance:

$$a_w = \left(\frac{mz_1}{\cos\beta_1\cos\delta} + \frac{mz_2}{\cos\beta_2}\right)\frac{\sin\left(\beta_1+\beta_2\right)\cos\delta}{\sin\Sigma}; \tag{2}$$

where δ is a taper angle of the HBG, m is a module, z1 and z2 are numbers of teeth of the gears, β1 and β2 are base helix angles.

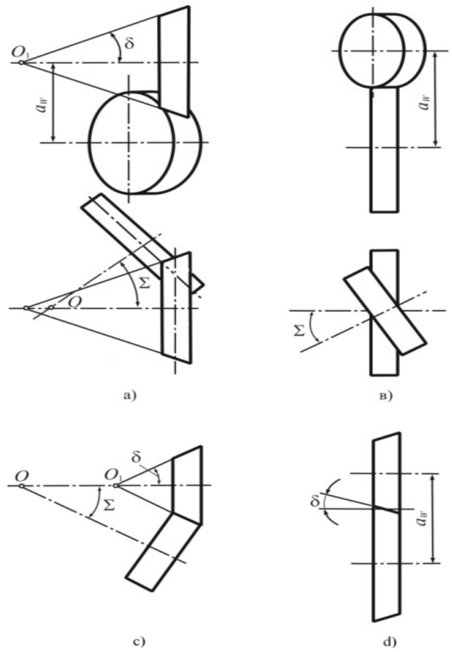

Fig. 1. Diagrams of an external helical-bevel gearing:
a) skew axis (Σ is the angle between axes); b) hypoid gearing (special case when bevel gear becomes cilindrical); c) intersecting axes; d) parallel axes (special case when Σ=0).

Advantages:

1. This type of gearing allows reducing dimensions of the transmission due to an ability to position the gears arbitrarily with a respect to the line of shortest distance between the centers for the given cross-angle. As it can be seen in Fig. 3, the axial dimensions of the conventional transmission A are greater than the dimensions of the HBG transmission A_1.

2. The skew axes HBG gives an opportunity to set the contact area dimensions and shape on each side of the tooth by assigning appropriate helix angles. The contact can be designed as a linear one-sided meshing by evaluating helix angles as follows [4]:

HBG is involute. The generation of the HBG by a hob is impossible due to the difference of the machining kinematics and the actual meshing of the gears in the HBG. The generation of the non-involute internal and external HBG by a hob shown in [4, 6, 7, 8].

$$\mathrm{tg}\alpha \cdot \sin(\beta_1 + \beta_2) = \mathrm{tg}\delta \cdot \cos\beta_1, \quad (3)$$

where α is a profile angle.

For δ and β_1 as above:

$$\cos\beta_2 = \frac{\mathrm{tg}\alpha}{\sin\delta}\sqrt{(\cos^2\delta - \cos^2\Sigma)} \quad (4)$$

where $\Sigma > \delta > \arcsin(\sin\Sigma \cdot \sin\alpha)$.

3. It possible to set an appropriate meshing backlash by axial translation of the bevel gear, which is very important to adjust a kinematic precision.

The linear contact HBG is irreversible, because contact only occurs on the one side of the tooth profile.

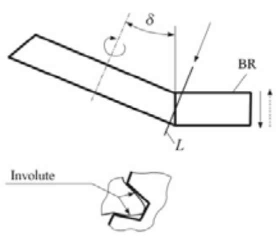

Fig. 2. HBG generation by a rack-cutter (BR).

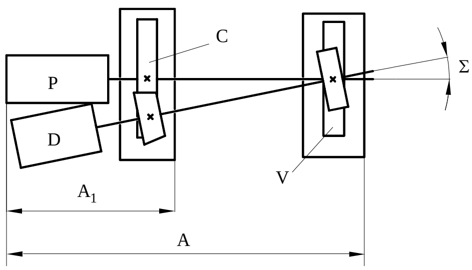

Fig. 3 Arrangement advantages of the HBG:
D – electric motor; P – receiver; V – hypoid gearing; C – HBG.

3.2 Intersecting axes HBG

If the skew axes helical-bevel gear ensured a mutual arrangement of the initial surfaces when they are produced in the initial transfer plane coincide with each other, they become a bevel gearing (see. Fig. 1, c). An obvious condition for the formation of such is:

$$\beta_1 = -\beta_2; \delta = \Sigma. \quad (5)$$

There are some options:

a) transmission, composed of involute helical-bevel and helical gears $\beta_1 = -\beta_2$; $\delta \neq 0$;
b) transmission composed of spur and bevel gears $\beta_1 = \beta_2 = 0$; $\delta_1 \neq 0$.

Advantages of the transmission.

1. When using helical-bevel gear with intersecting axes can be obtained bevel gear with an arbitrarily small interaxal angle Σ, which is implemented is not possible for conventional bevel gears due to lack of technological equipment for the production of gears with a large cone distance.
2. As for the transmission with skewed axes, a backlash in an engagement can be adjusted by axial displacement of the bevel gear.
3. Due to a highly localized contacts, the transmission is not very sensitive to any errors in an assembling and a manufacturing.

In the transmission with intersecting axes of the working surfaces the degree of localization increases with the increase of the axial angle Σ. Therefore, the power drive is advisable to desing only at small interaxal angles ($\Sigma < 15°$).

3.3 Parallel axes HGB

If both gears are involute bevel the parallel axes transmission can be designed (see. Fig. 1, d) [10].

This gears shall have equal taper angles $\delta 1 = \delta 2 = \delta$, set by the codirectional cones and by the angles of inclination of the tooth line $\beta 1 = -\beta 2$, which are equal by magnitude but in the opposite directions.

In this case, the teeth flanks are involute helicoids, equal by magnitude and antitropic with a respect to the helical lines on the main cylinder.

Advantages of the transmission:

Due to the linearity of the contact, the load capacity of the transmission is very high.

Due to the curvilinear boundaries of the field of engagement and the overlap factor of 1.2 ... 1.5 times higher (even for spur gears) than for conventional cylindrical gears, the smoothness of the transmission is increased.

By the axial displacement of the gears it is possible to change the center distance of the transmission, or to reduce or even eliminate backlash between the teeth if the center distance is fixed, which is important to increase the kinematical precision.

By an appropriate selection of angles δ and β, a zero axial force can be obtained. In this case, one of the teeth profiles is an involute helicoid and another one is a linearly extruded involute. Therefore, $\sin\beta = \mathrm{tg}\,\alpha\ \mathrm{tg}\,\delta$.

If the tooth angles on a pitch cylinders are of the same sign for both sides of the teeth, it is possible to obtain a one-way transmission, which have an option of a free running. The transmission is legit for the condition ($\sin\beta > \mathrm{tg}\,\alpha \cdot \mathrm{tg}\,\delta$) [10].

Summary

Involute helical-bevel gears can be designed for any position of the shaft axes (skew, intersecting or parallel axis). In that HBG have a number of layout, operational and technical advantages relative to transmissions made up of conventional spur and bevel gears.

The most efficient use of HBG is at small interaxal angles ($\Sigma<20°$) and taper angles of the bevel gear ($\delta <15°$), the width of which is limited to values of the coefficients of the displacement of its faces.

One of the significant advantages of involute HBG is that the gears can be made by the same mechanical units and with the same precision as the conventional spur gears. Therefore, the HBG can be used in any precise heavy loaded transmissions.

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