The development of gears technology used in rotary tables

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Abstract. The paper presents technology of forming of a face gear cooperating with cylindrical worm in spiroid gear drive application for rotation table. The method is based on application of a disc tool instead application of a hob. The solution is possible after application the CNC milling machine with five axis numeric system control. The method of forming face gear proposed in this article is based on application of the disc tool with a single blade edge and CNC milling machine. The method of forming the face gear cooperation with cylindrical worm on CNC milling machine with continuous divide and the scheme of the process kinematics have been presented in the paper.

1. Introduction

Invention of face worm gear drives with conical worm by Saari [1] was a substantial contribution. Face gear cooperating with cylindrical worm in spiroid gear drive can be cut with conical or cylindrical hob cutter [1,2,3,4]. Litvin and coworkers [5] had proposed a tilted head-cuter for forming of face gear with cylindrical worm. Grajdek [6] developed a new technique of cutting a face gear on a CNC machine. He used the 4-axis vertical CNC milling machining incorporate a rotary table and a NC spindle. The generations are performed by a tilted tool edge with straight line profiles of blades.

The authors of the paper [5] point out to big problems with sharpening hobbing cutters with small radius blades used for forming face gear and hob scale error that are transferred onto the gear. There is also a possibility of cutting the face gear with the use of a disc tool with a single blade tool [7,8,9]. For generation face gear used the 5-axis vertical CNC milling machine incorporate a rotary table and a NC spindle. The generations are performed by a tilted tool edge with straight line profiles of blades. Due to addition two rotational axes in 5-axis machining enables forming face gear and taken high surface quality. For numerically controlled milling machine a face gear can be shaped with different front lines of teeth [7]. While notching the teeth, workgroups of machine performs movements at a constant speed, the tracks are rectilinear or rotary (NC rotary table, spindle tool).

Face gear cooperating with cylindrical worm in spiroid gear drive may have different type of involute teeth line used (elongated, shortened) with a modification of the teeth line and profile, in order to avoid edge contacts. All those involute teeth lines in face gear variations can be cut with the use of a disc tool on CNC machine tools.

The Company Tool Works in Illinois – USA manufacture different types of spiroid gears. Figure 1 illustrates the idea of construction of a spiroid gear drive type duplex with two face gears cooperation with cylindrical worm application for rotation table.
2. Technology of forming face gear cooperation with cylindrical worm

Figure 2 illustrates schematically the generation of the face gear. The tool is mounted at the spindle of the CNC milling machine and performs rotation about the axis tool. The face gear mounted at the rotation table and performs rotation about the axis face gear.

The main chipping movement is realized by the disc-tool (rotation around its own axis as well as the tangential feed to the generating line of face gear). Due to the tangential feed to a generating line of face gear a compensations of the circular movement of work piece must be performed in order to realize of a geometrical parameter of a face gear. The tangential movement of disc-tool lasts until the calibrating teeth of the disc-tool cover the teethed surface. Exemplary orientation of the disc tool on the space of machine tool in relation to the face gear installed on the rotation table were presented in Figure 2 [8,9].

![Figure 2](image2.png)

Figure 2. Tool orientation during forming face gear with: left teeth line inclination (left) and right teeth line inclination (right).

The formation of the other cooperating face gear with the spiroid gear drive type duplex is executed by cutting the teeth line that is a mirror reflection of the face gear it will work with. Figure 2 shows the ways of cutting face gears with a left (Figure 2a) and right (Figure 2b) direction of teeth line. During formation, the machine tool's control system couples the spindle rotations with the table's rotations with face gear in order to ensure continuous index. The roll movement (forming of the teeth line) is implemented through connecting the SN rotation table movement with the movement of the tool along the axis of face gear in a rotated coordinate system by an angle $\gamma_m$ in the plane of the face gear.

The tool and its movement should be selected in such a way, as to achieve the required teeth line modification, allowing to avoid edge contact in spiroid gear drive. The general principle of modified line teeth of face gear is to set the conformity of the track described by the edges of blade's curve radius and the teeth line of face gear in the spiroid gear drive point and with rolling from a ring with a smaller diameter (Figure 3) [8].
When forming the face gear with the use of a disc tool, it is possible to select: tool movement track, inclination direction of the teeth line and the tool axis twist in the system connected with the machined rim on the tooth tip plane. Possible ways of cutting the involute line in face gear were listed in figure 4 [9].

The technology model with tool advance parallel on the axis of the face gear and next tool advance perpendicular on the axis of the face gear illustrated on Figure 5.

The blade of the tool is a straight line and profile angle $\alpha_1$ is determined from the conditions that the straight line is a tangent to the cross-section of the face gear at point $P$ (Figure 5). Figure 5 explains the next positions between tool and work piece as well as the necessary movements in order to realize the cutting tooth line of face gear.
To simplify the calculations parameters used in reassertion of face gears a computer program has been developed. A method of calculations of parameters of face gear of spiroid gear drive can be found in references [8]. The results of the calculations spiroid gear drive with cylindrical worm are presented in Figure 6.

Figure 7 illustrates the control algorithm CNC milling machine during of forming a face gear. The control algorithm. The dependencies presented in Figure 2, 3 and 5 were used to develop this algorithm of machine tool control.
Figure 7. The control algorithm of forming a face gear on CNC milling machine.

3. Manufacturing of face gear

Theoretical principles of a teeth forming, which are presented in this paper has been confirmed by experimental researches. Figure 8 presented view of face gear during cutting on CNC milling machine. Attempts to shape face gear were conducted on the milling machine FYN – 50Nd type.
Figure 8. View: (a) the investigations stand during forming a face gear (view next position of tool and face gear) and (b) of the face gears and investigations stand during research of trace of meshing.

Table 1. Design parameters of face gear

| Parameter                                           | Value   |
|-----------------------------------------------------|---------|
| Inner radius of the theoretical face gear           | \( R_i \) 78.5 mm |
| Outer radius of the theoretical face gear            | \( R_e \) 57.5 mm |
| Number of teeth of the conical face gear             | \( z \) 60 |
| Tooth height (groove depth)                          | \( h \) 4.32 mm |
| Twist angle of the spindle                           | \( \gamma_m \) 2.979° |
| Concave profiles angle of the conical face gear      | \( \alpha_1 \) 3° |
| Convex profiles angle of the conical face gear       | \( \alpha_2 \) 32° |
| Distance from the axis of the tool axis of conical face gear | \( a_w \) ±45 mm |

LEGEND OF SYMBOLS

- \( R_i \) – inner radius of the face gear
- \( R_e \) – outer radius of the face gear
- \( R_o \) – theoretical rolling radius
- \( R_w \) – radius of generation a involute tooth line of face gear
- \( a_w \) – distance from the axis of the tool axis and of the axis of face gear
- \( h \) – tooth height (groove depth)
- \( P \) – point of contact on surface of tooth line and grinding tool trace gear
- \( z \) – number of teeth of the face gear
- \( \alpha_1 \) – concave profiles angle of the face gear
- \( \alpha_2 \) – convex profiles angle of the face gear
- \( \varphi \) – angle of rotation of the grinding tool
- \( \psi \) – angle of rotation of the face gear in the process of generation
\( \Delta l_z \) – additional move motion of the grinding tool during face gear rotational motion
\( \gamma_m \) – twist angle of the spindle
\( \omega_k \) – rotational speed of face gear
\( \omega_n \) – rotational speed of tools
\( \kappa \) – inclination angle of the spindle to face gear
X,Y,Z – coordinate system connected to machine tool
x,y,z – coordinate system rigidly connected to face gear

Conclusions
The performed investigations presented main directions of improving the reductions of costs of cutting the face gear cooperating with cylindrical worm in spiroid gear drive application for rotation table.

Discussed methods of forming face gear teeth are based on contemporary machining offered by modern CNC machine tools. The presented CNC milling control algorithm allows you to create any number of teeth in the teeth (18 - 720 teeth) using only one tool.

The presented control algorithm of the machine tool for cutting the teeth of the face gear enables the formation of an involute tooth line with right teeth line inclination or left teeth line inclination.

The presented method of forming teeth in face gear is used in Poland to produce spiroid gear drive type duplex with two face gears cooperation with cylindrical worm application for rotation table.

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