

Influence of cut parameters on mesh performance of spiral bevel gear by duplex spread blade method

Longlong Geng^{1,2,*}, Shaowu Nie¹, Chuang Jiang¹, and Ruijie Xie¹

¹ School of Mechatronics Engineering, Henan University of Science and Technology, Luoyang Henan 471003, China

² Zhejiang Tongli Transmissions Technology Co., Ltd, Wenzhou Zhejiang 325000, China

Received: 24 October 2023 / Accepted: 1 December 2023

Abstract. Spiral bevel gears are key components in many mechanical transmission systems, and their production is always of great interest to industry, and hence, subjected to intensive research widely. The present machining methods for manufacturing spiral bevel gears, including the so called five-cut method and completing method, have drawbacks such as low processing efficiency, requiring complex calculations and high requirements on the machine-tool performance, respectively. To solve the above problems, the duplex spread blade method is proposed. Firstly, geometric parameters and machine setting parameters were comprehensively considered, and then a modified reference point was selected to deduce the machine setting parameters. Tooth contact analysis (TCA) model considering misalignment was established to check meshing performance, the influence of cutter parameters and misalignment on meshing performance was studied. As the research reveals that the cutter radius has an effect on the bias of contact trace, cutter number has an impact on the position of contact pattern. The experimental results are consistent with the theoretical which verified the effectiveness and feasibility of the proposed method. The results of this paper have a guiding significance and enrich the machining method for spiral bevel gear.

Keywords: Spiral bevel gear / duplex spread blade method / tooth contact analysis / cutting experiment / mesh performance

1 Introduction

Spiral bevel gears are widely used in aviation, aerospace, marine and machine tool for the advantages of smooth driving, efficient transmission and load capacity, etc. Therefore, the manufacture of spiral bevel gear has always been a research topic. Face-milling is a common method to machine spiral bevel gears which is divided into five-cut method [1–3] and completing method (also known as duplex helical method) [4–5] according to the machine of pinion. It is more efficient because two sides of pinion are manufactured simultaneously by duplex helical method while separated by five-cut method. Moreover, it is more energy-saving and environmental protection by adopt power dry cutting. So, there is a trend that the manufacture of spiral bevel gear is converting to completing method from five-cut method. Many experts and scholars have carried out deep research on it.

Duplex helical method proposed by Gleason firstly to machine spiral bevel gear while cutting principle and calculation of machine setting parameters were not fully revealed [5]. Tsay et al. [6] developed a mathematical model

that can be applied to simulate tooth surface machined by spread blade and duplex helical method. Gonzalez et al. [7] presented conversion of machine-tool setting parameters to neutral machine-tool setting parameters by duplex helical method, and parabolic profile of cutter blades was applied to adjust the contact pattern. Zhang and Yan et al. [8–10] revealed the generalized theory of duplex helical method and calculated the basic machine-tool setting parameters by defining three reference points, and later established tooth contact analysis model. Deng et al. [11] proposed a method to calculate machine-tool setting parameters for spiral bevel gears by duplex helical method that predesigned contact path. Lv et al. [12] calculated the machine setting parameters of small module hypoid gear by duplex helical method.

All the above researches, the calculation of machine setting parameters is complex, and rigorous demands to machine tool, such as helical motion, tilt and swivel structures. Duplex spread blade method is used to manufacture small module spiral bevel gear [13]. As completing method, the two sides of gear and pinion are machined simultaneously by duplex spread blade method. At the same time, the calculation of machine setting parameters is relatively simple and does not require high equipment, while its calculation principle has not revealed

* e-mail: g110379@haust.edu.cn

from existing literature. Unfortunately, it is only suitable for small module gears. So, it is significance to research duplex spread blade method which can be used to machine medium module spiral bevel gears.

Mesh performance is a key indicator of spiral bevel gear. As an effective tool tooth contact analysis (TCA) is deeply studied by many experts. Fan [14] presented a modified algorithm of tooth contact simulation with a reduced equation number of the nonlinear iterations and stabilized iteration convergence. Cao [15] proposed a new method for tooth contact analysis which was more stability when adopting a system of five nonlinear equations. Vivet [16] presented an analytical model for accurate and numerically efficient loaded tooth contact analysis applied to face-milled spiral bevel gears. Ding [17] showed numerical determination to loaded tooth contact performances considering misalignment for spiral bevel gears. Pisula [18] analyzed the effect of application of helical motion and assembly errors on meshing performance of spiral bevel gear by duplex helical method. Deng [19] introduced a helical correction motion to optimize meshing performance. Yan [20,21] compared the influence of cutter parameters on the contact characteristics of tooth surface by five-cut method and duplex helical method. But the literature on tooth contact analysis by duplex spread blade method is not found. So, it is necessary to establish corresponding tooth contact analysis model to check meshing performance.

In this paper, duplex spread blade method to machine medium module spiral bevel gear is proposed which the calculation of machine setting parameters is simple. Through inclination of root line, geometric and machine setting parameters are comprehensively designed. To guarantee mesh performance, a modified reference point is selected in which machine setting parameters are calculated. A tooth contact analysis model considering misalignment is established. Then the influence of cutter parameters on tooth contact trace, position and sensitivity to misalignment are researched. The flow chart of the research is shown in Figure 1.

2 Calculation machine setting parameters

The tooth root tilt and root taper have been studied in detail in literature [1,9,19]. A relationship is satisfied when gear and pinion are both machined by duplex spread blade method and expressed as

$$\sum \theta_D = \theta_{f1} + \theta_{f2} = \frac{s_1 + s_2}{2R \tan \alpha \cos \beta} \left(1 - \frac{R \sin \beta}{r_0} \right). \quad (1)$$

Here, θ_{f1}, θ_{f2} are dedendum angle; s_1, s_2 are tooth thickness, and $z_0(s_1 + s_2) = 2\pi R z_0$ is number of equivalent crown gear, R is mean cone distance, r is cut radius.

A hypothesis set that the sum of root angle $\sum \theta_s$ in standard taper [1] meets equation (1), and then a theoretical cut radius r_d can be calculated as

$$r_d = R \sin \beta / \left(1 - \frac{\sum \theta_s z_0 \tan \alpha \cos \beta}{180} \right). \quad (2)$$

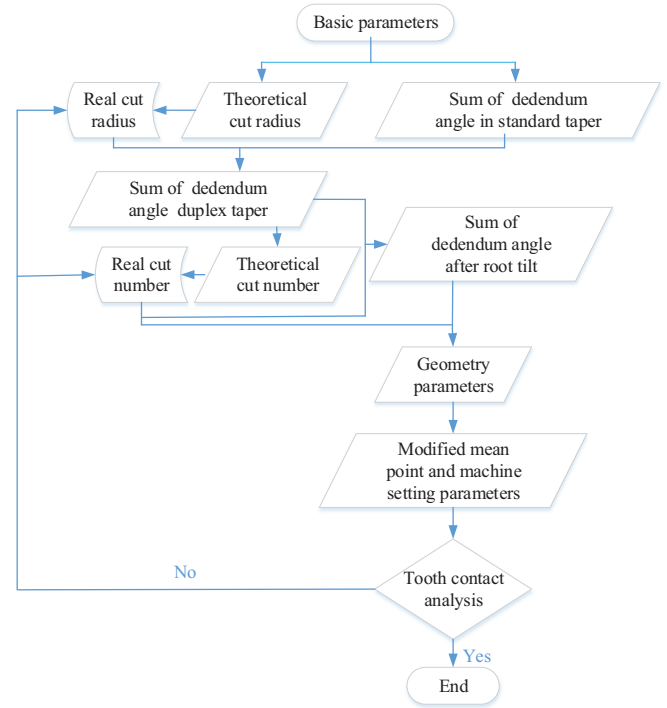


Fig. 1. Design flow by duplex spread blade method.

According to the ideal cut radius r_d , an appropriate cut radius r_0 can be selected. Then substitutes it into equation (2), a sum of root angle $\sum \theta_d$ in taper by duplex spread blade method can be obtained. The real dedendum angle of pinion and gear are distributed inversely proportional to addendum height.

At the same time, a cut number can be calculated as

$$N = \frac{\sum \theta_d}{20} \sin \beta. \quad (3)$$

The cut number calculated by equation (3) is also defined as theoretical. The cutter numbers are serialized during manufacture to reduce quantity of cutter. A real cut number can be selected and represented as N_0 . In general, there is a deviation between real and theoretical cut number. A question thus arises that the equation (2) will not establish. To solve the problem, the root line is tilted around reference point which located at mean cone distance. The change of dedendum angle $\Delta \theta_f$ and addendum height Δh showed in Figure 2 can be deduced as

$$\Delta \theta_f = \frac{10N_0}{\sin \beta} - \frac{\sum \theta_s}{2}, \quad (4)$$

$$\Delta h = \frac{b}{2} \tan(\Delta \theta_f). \quad (5)$$

According to geometric parameters of standard taper [1] and equations (4) and (5), the geometric parameters can be obtained by duplex spread blade method.

As the real cut number and geometric parameters are determined, the value will not satisfy equation (2). To solve this problem, a novel method to select modified reference

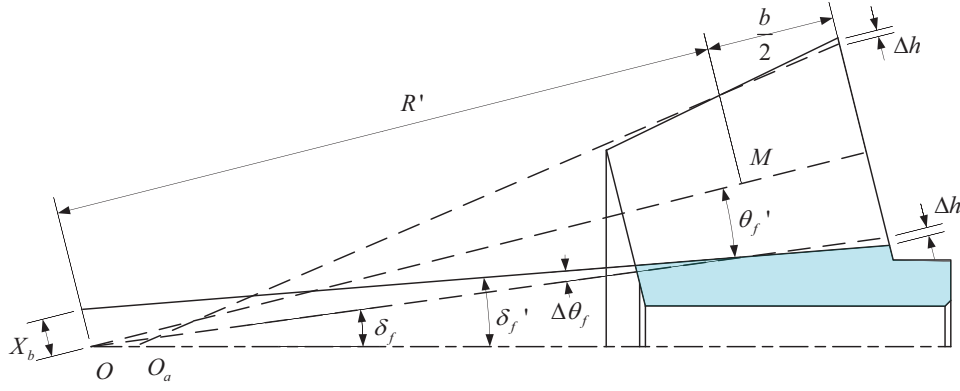


Fig. 2. Structure after root tilt.

point M as shown in Figure 2 is proposed and calculated as

$$R' = \frac{r_0}{\sin\beta} \left[1 - \frac{z_0 \tan \alpha N_0}{540 \tan \beta} \right]. \quad (6)$$

Then machine setting parameters are calculated in M as follow.

Radial setting is calculated as

$$S_r = \sqrt{r_0^2 + (R')^2 - 2r_0R'\cos\beta}. \quad (7)$$

Initial cradle angle setting is calculated as

$$q = \arctan \frac{r_0 \cos \beta}{R' - r_0 \sin \beta}. \quad (8)$$

After root tilted, the sliding base is changed as Figure 2, and the value can be determined as

$$X_b = R' \tan(\Delta\theta_f). \quad (9)$$

The other parameters are

$$\begin{aligned} E_m &= 0 \\ X_g &= 0 \\ i &= \frac{\sqrt{z_1^2 + z_2^2}}{z_i}. \end{aligned} \quad (10)$$

3 Establishment of tooth contact analysis model

The machine setting parameters can be calculated based on Section 2. It is necessary to establish tooth contact analysis (TCA) model and analyze the corresponding meshing performance. Tooth surface of pinion and gear are derived firstly, and then tooth contact analysis model considering misalignment is established. The process is as follows.

Mathematical model of machine is established as Figure 3. $S_m(x_m, y_m, z_m)$ is coordinate system of machine, $S_w(x_w, y_w, z_w)$ is coordinate system of pinion or gear, $S_t(x_t, y_t, z_t)$ is coordinate system of cutter, $S_c(x_c, y_c, z_c)$ is

coordinate system of cradle, S_d, S_e is auxiliary coordinate system. The machine-tool setting parameters, for instance, radial distance is the distance between O_c and O_t represented as S_r , center roll position is the angle formed by S_r and X_c represented as q , machine root angle γ , Blank offset E_m and machine center to back X_g , cutter radius R_{cp} , profile angle a_t are showed in Figure 3. ϕ_c represents the angle of cradle during process, ϕ_w represents corresponding angle of pinion or gear which meets with $\phi_w = R_{ap} \cdot \phi_c \cdot R_{ap}$ is roll ratio.

Tooth surface equation [19] can be expressed as

$$\begin{cases} \mathbf{r}_i = \mathbf{r}_i(s_i, \theta_i, \phi_{ci}) \\ \mathbf{n}_i = \mathbf{n}_i(s_i, \theta_i, \phi_{ci}) \end{cases}. \quad (11)$$

Here, s, θ are tooth surface parameters, $i = 1$ represent pinion and $i = 2$ represent gear.

The meshing equation during machine of pinion or gear can be expressed as

$$f(s_i, \theta_i, \phi_{ci}) = \mathbf{n}_i \cdot \frac{\partial \mathbf{r}_i}{\partial \phi_{ci}} = 0. \quad (12)$$

From equation (12) $s_i = f_i(\theta_i, \phi_{ci})$ can be derived and equation (11) can be simplified.

According to previous research [22], a model of tooth contact analysis considering misalignment is established as Figure 4. S_h is meshing coordinate system, S_1 and S_2 are the coordinate system of pinion and gear, respectively. S_a, S_b, S_c are auxiliary coordinate system. Shaft angle is the axis angle between pinion and gear which is represented as Σ , offset is distance along Y_h in meshing coordinate system and represented as E , pinion mounting distance is distance from the cone top to the mounting base of pinion and represented as p , gear mounting distance is distance from the cone top to the mounting base of gear and represented as G . $\Delta\Sigma, \Delta E, \Delta p$ and ΔG are the value of corresponding misalignment. φ_1, φ_2 , are the meshing angle of pinion and gear.

Tooth surface of pinion and gear can be represented in meshing coordinate system after coordinate transformation.

$$\begin{aligned} \mathbf{r}_h^1(\theta_1, \phi_{c1}, \varphi_1) &= \mathbf{M}_{hb}(\Delta P) \mathbf{M}_{b1}(\varphi_1) \mathbf{r}_1(\theta_1, \phi_{c1}) \\ \mathbf{n}_h^1(\theta_1, \phi_{c1}, \varphi_1) &= \mathbf{L}_{hb}(\Delta P) \mathbf{L}_{b1}(\varphi_1) \mathbf{n}_1(\theta_1, \phi_{c1}). \end{aligned} \quad (13)$$

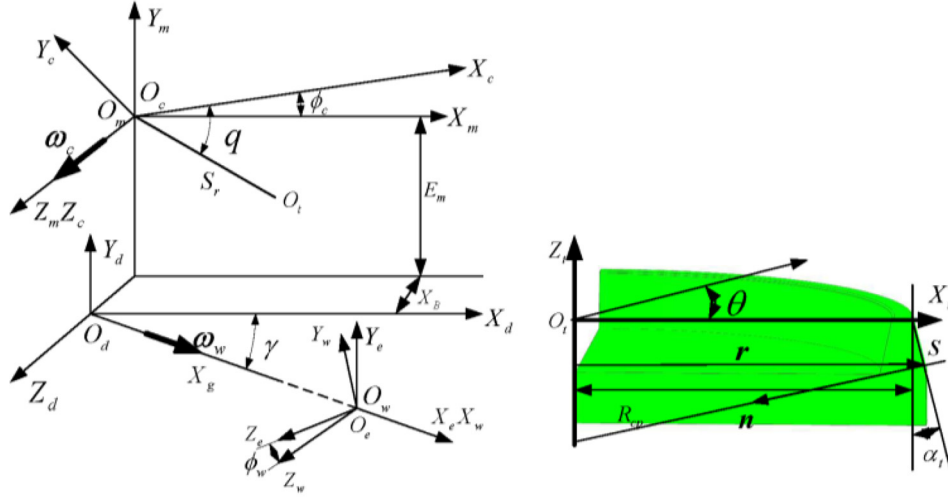


Fig. 3. Mathematical model of machine.

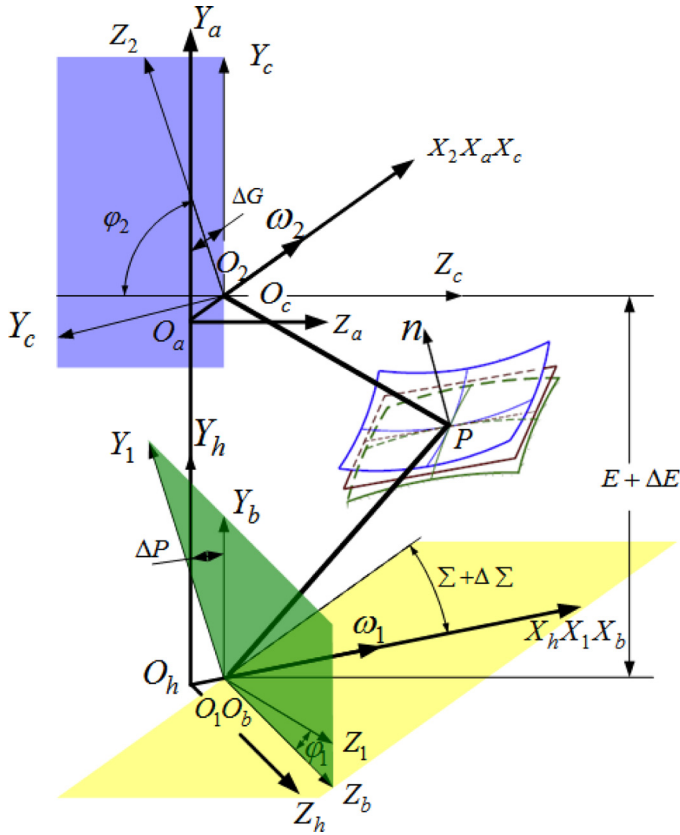


Fig. 4. Meshing coordinate system.

Here,

$$M_{b1} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos \varphi_1 & -\sin \varphi_1 & 0 \\ 0 & \sin \varphi_1 & \cos \varphi_1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} M_{hb} = \begin{bmatrix} 1 & 0 & 0 & \Delta P \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$\begin{aligned} r_h^2(\theta_2, \varphi_{c2}, \varphi_2) &= M_{ha}(\Delta E, \Delta \Delta \Sigma) M_{ac}(\Delta \Delta G) M_{c2}(\varphi_2) r_2(\theta_2, \varphi_{c2}) \\ n_h^2(\theta_2, \varphi_{c2}, \varphi_2) &= L_{ha}(\Delta E) L_{ac}(\Delta G) L_{c2}(\varphi_2) n_2(\theta_2, \varphi_{c2}), \end{aligned} \quad (14)$$

Here,

$$M_{c2} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -\cos \varphi_2 & \sin \varphi_2 & 0 \\ 0 & -\sin \varphi_2 & -\cos \varphi_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$M_{ac} = \begin{bmatrix} 1 & 0 & 0 & \Delta G \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$M_{ha} = \begin{bmatrix} \cos(\Sigma + \Delta \Sigma) & 0 & -\sin(\Sigma + \Delta \Sigma) & 0 \\ 0 & 1 & 0 & E + \Delta E \\ \sin(\Sigma + \Delta \Sigma) & 0 & \cos(\Sigma + \Delta \Sigma) & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

L is the 3X3 submatrix of M .

Meshing equation can be represented as

$$\begin{aligned} r_h^1(\theta_1, \phi_{c1}, \varphi_1) &= r_h^2(\theta_2, \phi_{c2}, \varphi_2) \\ n_h^1(\theta_1, \phi_{c1}, \varphi_1) &= n_h^2(\theta_2, \phi_{c2}, \varphi_2). \end{aligned} \quad (15)$$

Equation (15) is composed by five equations with six unknowns $(\theta_1, \phi_{c1}, \varphi_1, \theta_2, \phi_{c2}, \varphi_2)$. An assumption is made that mesh angle of the pinion φ_1 is known, and a step-size is determined to solve the above equations. The contact points within the effective boundary are obtained.

Based on solutions of equation (15), the transmission error can be expressed as

$$\delta(\varphi_1) = (\varphi_2 - \varphi_2^0) - \frac{Z_1}{Z_2} (\varphi_1 - \varphi_1^0). \quad (16)$$

Here, Z_1 , Z_2 are tooth number of pinion and gear, φ_1^0 , φ_2^0 are the initial angle of pinion and gear.

4 Influence of cut parameters on mesh performance

Cutter parameters (cut radius r , cut number N) have a great influence on the calculation of machine setting parameters by duplex spread blade method. The influence of cut parameters (cut radius r , cut number N) on meshing performance will be analyzed in this section by a number example listed in Table 1.

4.1 Influence of cut radius on mesh performance

According to equation (2) and Table 1, theoretical cut radius is $r_d = 114.427$, and a series of cut radius are selected as listed in Table 2. Then the cone distance of modified reference and machine setting parameters are calculated. The results of tooth trace in theoretical are showed in Figure 5.

As Figure 5 illustrated, (a) is contact trace of gear convex and (b) is contact trace of gear concave. Red (mark 1) represents the contact trace corresponding to $r = 95.25$; blue (mark 2) represents the contact trace corresponding to $r = 114.3$ and green (mark 3) represents the contact trace corresponding to $r = 152.4$. It is obviously detecting that smaller are the cut radius the bigger are the angle formed between contact trace and pitch line from Figure 5.

Major axis of contact ellipse of real contact points in different cut radius for concave side and convex side are listed in Table 3, and the mean and variance of major axis are calculated. The changes of major axis of contact ellipse are showed in Figure 6.

As showed in Table 3 and Figure 6, major axis of contact ellipse are bigger as cut radius becomes larger, the mean and variance of major axis of contact ellipse are basically proportional to cut radius. In other words, the major axis of contact ellipse changes more as cut radius becomes larger. For spiral bevel gears, a uniform major axis of contact ellipse is ideal that can avoid bad contact. Therefore, cutter radius can be selected according to the requirements for meshing performance during design.

4.2 Influence of cut number on mesh performance

When cut radius is selected, cut number can be obtained by equation (3). According to equation (6), the cut number is negative correlation with cone distance of modified reference which directly determines the position of contact pattern. Obviously, the correlation coefficient is related to basic parameters. Cut numbers are selected as Table 4 and the results of tooth contact analysis are showed in Figure 7.

Table 1. Basic parameters of spiral bevel gear.

	Pinion (Left hand)	Gear (Right hand)
Tooth number z	18	35
Model m	7.16	
Shaft angle Σ	90°	
Spiral angle β	35°	
Pressure angle m	20°	
Width b/mm	50	
Mean cone distance R/mm	114.3993	

Table 2. Cone distance of modified reference in different cut radius.

Cut radius r	Cut number N	Cone distance of modified reference	Mark
$r = 95.25$	$N = 8.5$	$R' = 112.5867$	1 (Red)
$r = 114.3$	$N = 11.5$	$R' = 112.4552$	2 (Blue)
$r = 152.4$	$N = 15.3$	$R' = 111.6887$	3 (Green)

As Figure 7 illustrated, (a) is the contact trace of gear convex, (b) is the contact trace of gear concave. Red (mark 1) represents the contact trace corresponding to $N = 11$; blue (mark 2) represents the contact trace corresponding to $N = 11.5$ and green (mark 3) represents the contact trace corresponding to $N = 12$. The contact trace move towards to toe as the cut number increase which is in accord with equation (6).

4.3 Influence of cut radius on sensitivity to misalignment

The machine setting parameters are calculated according to the cut parameters listed in Table 2. The effects of misalignment corresponding to different cutter radius on the contact pattern are analyzed in this section.

According to the tooth contact analysis model considering misalignment, the principle of single variable is used to analyze the impact of misalignment on contact pattern. The linear misalignment is taken as -0.3 mm , -0.2 mm , -0.1 mm , 0.1 mm , 0.2 mm , 0.3 mm , and angle misalignment is taken as -0.3 min , -0.2 min , -0.1 min , 0.1 min , 0.2 min , 0.3 min , respectively.

The offsets of contact patterns along tooth length are represented as ΔL , and the positive direction is defined as toe to heel. The corresponding offsets of various misalignments in different cutter radius are showed in Figure 8. Red (mark 1,5) represents the offsets corresponding to misalignment of gear mounting distance ΔG ; green (mark 2,6) represents the offsets corresponding to misalignment of pinion mounting distance Δp ; blue (mark 3,7) represents the offsets corresponding to misalignment of offset ΔE ;

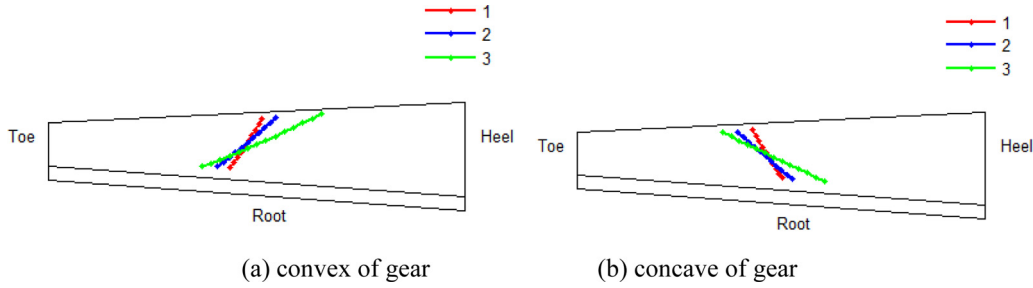


Fig. 5. Contact trace of different cut radius.

Table 3. Major axis of contact ellipse.

Major axis of contact ellipse	$r = 95.25$		$r = 114.3$		$r = 152.4$	
	Convex	Concave	Convex	Concave	Convex	Concave
1	7.481	6.0173	8.6053	6.6436	10.1345	9.8182
2	7.5136	7.5477	8.6278	8.7136	10.4932	9.8128
3	7.5078	7.5815	8.6059	8.695	10.4498	10.6126
4	7.5013	7.5767	8.5827	8.7187	10.4045	10.5691
5	7.4941	7.5713	8.5585	8.6976	10.3571	10.5237
6	7.4863	7.5652	8.5331	8.6753	10.2079	10.4762
7	7.4779	7.5585	8.5068	8.6518	10.1568	10.4269
2a	7.4945	7.3454	8.5743	8.3993	10.3148	10.3199
σ^2	0.011139	0.379473	0.035571	0.501649	0.127224	0.288245

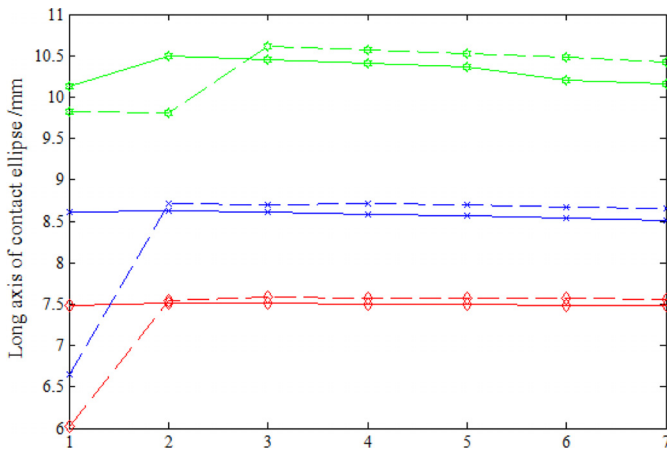


Fig. 6. Major axis of contact ellipse.

dark (mark 4,8) represents the offsets corresponding to misalignment of shaft angle $\Delta\Sigma$. The solid and dashed lines represent convex side and concave side, respectively.

As Figure 8 illustrated, (a) is offsets of contact patterns corresponding to misalignment in $r = 95.25$, (b) is offsets of contact patterns corresponding to misalignment in $r = 114.3$, (c) is offsets of contact patterns corresponding to misalignment in $r = 152.4$. For convex side, the offsets are positive correlation to the misalignment of gear mounting distance ΔG , while it is negative correlation for misalignment of pinion mounting distance ΔE and offset ΔE . But it

Table 4. Cone distance of modified reference in different cut number.

Cut radius r	Cut number N	Cone distance of modified reference	Remark
$r = 114.3$	$N = 11$	$R' = 116.23$	1 (Red)
	$N = 11.5$	$R' = 112.4552$	2 (Blue)
	$N = 12$	$R' = 108.6804$	3 (Green)

is in contrast for the concave side. Particularly, it is negative correlation between the misalignment of shaft angle $\Delta\Sigma$ for concave side and convex side. A conclusion drawn is that the correlation coefficients are not the same even the same value of various misalignments in same cut radius from Figure 8, and the sensitivity is not consistent for different type of misalignment. The rank of coefficient in order of descending is offset ΔE , pinion mounting distance ΔP , gear mounting distance ΔG , shaft angle $\Delta\Sigma$.

In order to analyze the influence of cut radius on the sensitivity of misalignment, the offsets corresponding to the same types of misalignments in different cut radius are shown in a diagram as Figure 9. Red (mark 1, 4) represents the offsets corresponding to $r = 95.25$; blue (mark 2, 5) represents the offsets corresponding to $r = 114.3$; green (mark 3, 6) represents the offsets corresponding to $r = 152.4$. Similarly, the solid and dashed lines represent convex side and concave side, respectively.

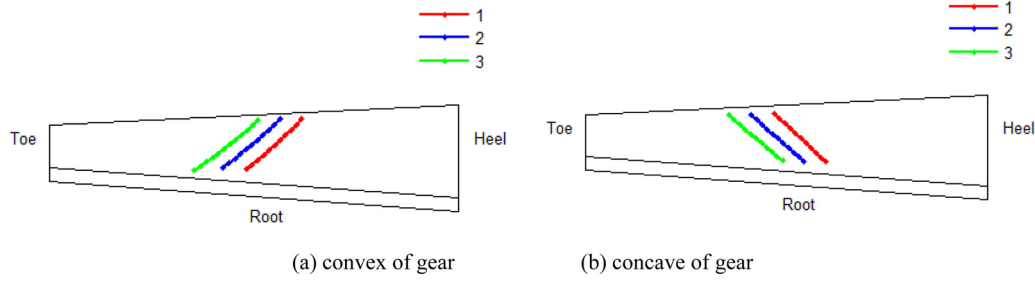


Fig. 7. Contact position of different cut number.

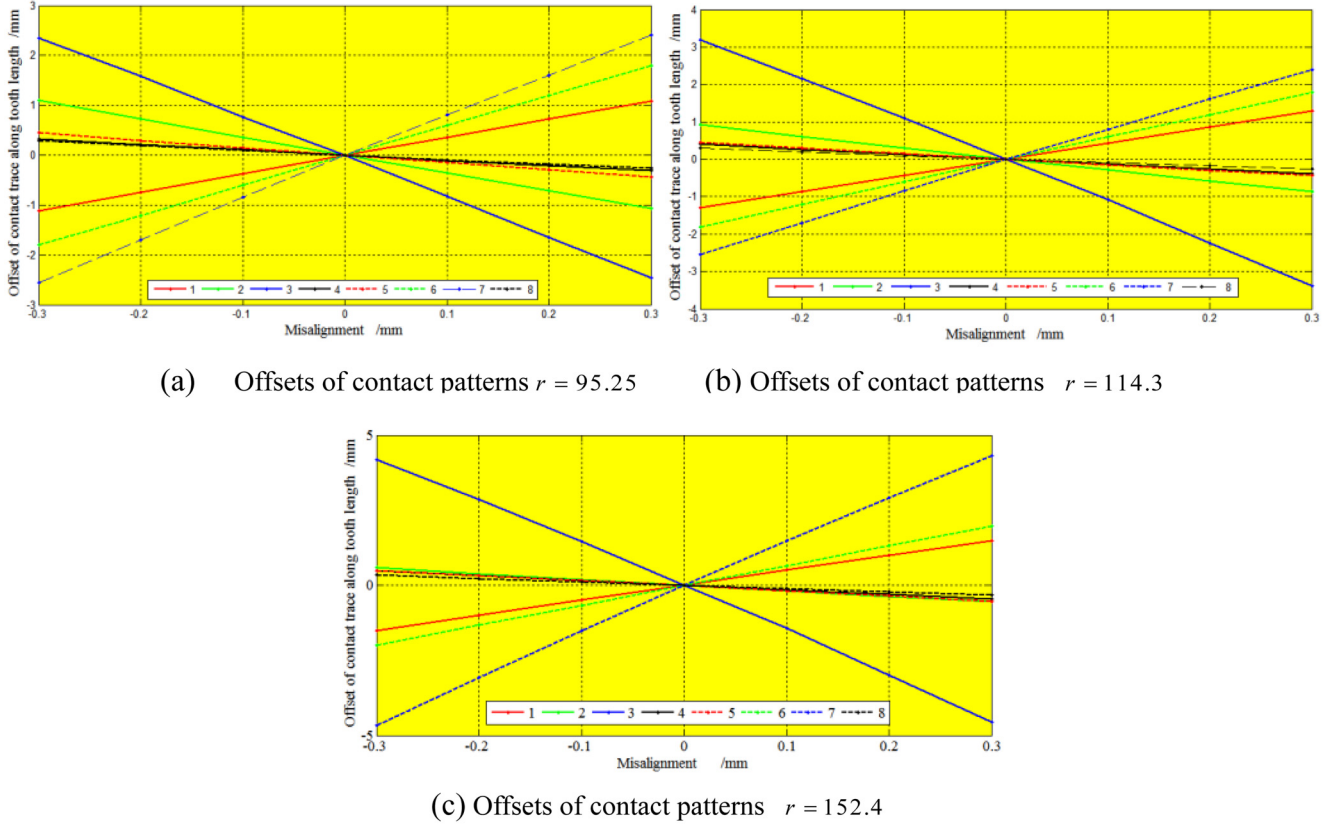


Fig. 8. Offsets of contact patterns in different cutter radius.

As Figure 9 shown, (a)–(d) are the offsets corresponding to misalignment of gear mounting distance ΔG , gear mounting distance ΔP , offset ΔE and shaft angle $\Delta \Sigma$, respectively. It is easy to find that the smaller of cutting radius the offsets are smaller. That is to say, the sensitivity is negatively correlates to the cut radius.

In this section, the influence of cut parameters on meshing performance is researched. Cut radius has an effect on the tooth trace angle formed between tooth trace and pitch line, cut number affects the position of contact pattern and a small cutter radius result in an insensitive contact pattern to misalignment. Therefore, different cutter parameters can select according to the requirements of meshing performance during design.

5 Cutting experiments

Based on the above research, cut parameters with low misalignment error sensitivity are selected, and the machine setting parameters are calculated as shown in Table 5. The tooth contact patterns and transmission errors are listed in Figure 10.

As Figure 10 illustrated, the tooth contact pattern are in the middle slightly offset to toe for both concave side and convex side. There is no edge contact. The curve of transmission error is symmetrical. Contact performance meets engineering requirements. According to parameters listed in Table 5, the pinion was machined as shown in Figure 11. The measurement is showed as Figure 12 and the result is showed in Figure 13.

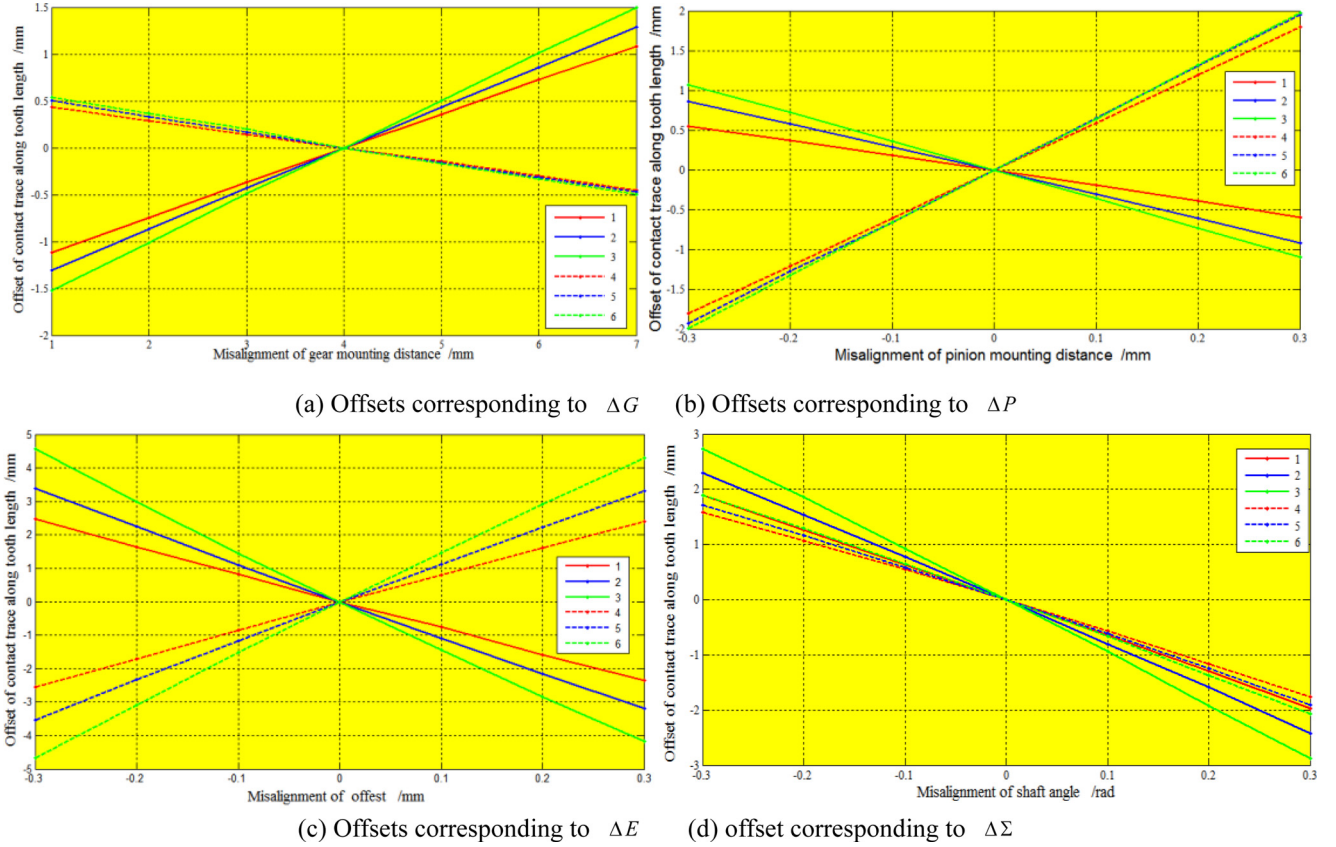


Fig. 9. Offsets of contact trace along tooth length.

As Figure 13 illustrated, tooth surface 1 is pinion concave and the biggest error is 0.0163 mm which occurs in the heel of top; tooth surface 2 is pinion convex and the biggest error is 0.0131 mm which occurs in the toe of root. The tooth surface accuracy meets the requirement which will has little impact on contact performance.

Finally, a rolling test is carried out smoothly without obvious vibration and noise. The results are shown in Figure 14.

In Figure 14, (a) is the scene of rolling test; (b) and (c) are contact pattern of gear concave and convex respectively. As Figure 14 showed, contact patterns are in the middle of tooth surface slightly offset to toe which are consistent with the TCA result showed in Figure 9. The experimental results are consistent with theoretical analysis which proves the model of machine parameter calculation and tooth contact analysis are feasible and correct.

6 Conclusion

Geometric and machine setting parameters are comprehensively calculated for spiral bevel gears by duplex spread blade method in this paper. The influences of cut parameters to meshing performance are researched. The effectiveness is proved by tooth contact analysis and cut experiment. The following conclusion may be drawn:

- cut radius has an effect on the bias of tooth contact, and the larger is the cut radius, the included angle between the contact trace and pitch line is smaller.

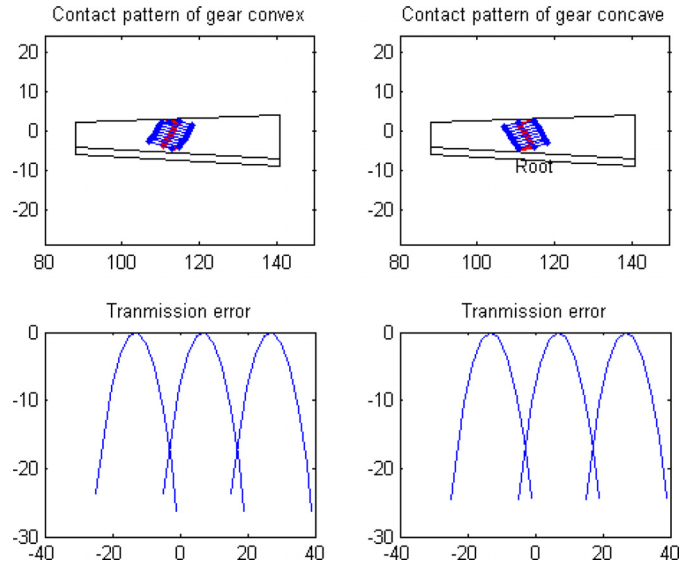
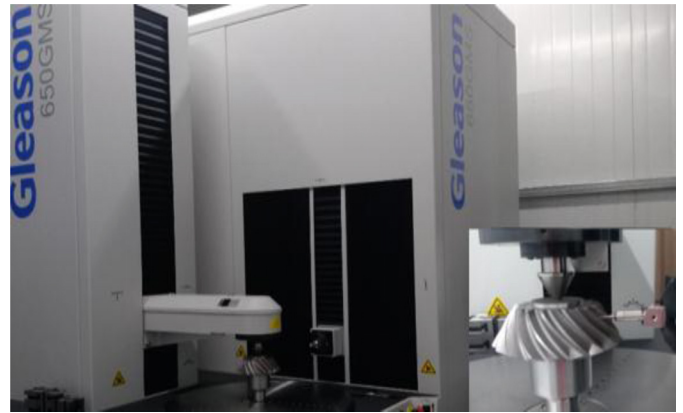
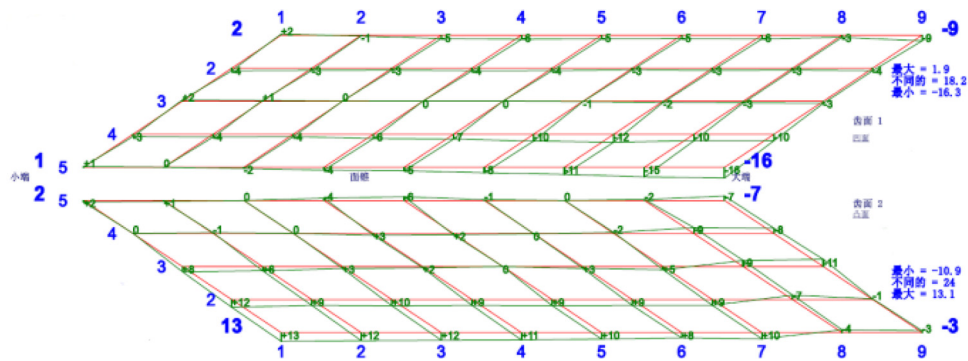


Fig. 10. Contact pattern and transmission error.

- cut number has an effect on position of contact pattern. When different cut number is selected, the contact pattern will be offset to heel or toe.
- The mesh performance of products machined by different size of cut radius have variant response to misalignment, the response is small when using little cut radius.

Table 5. Machine-tool setting parameters.

	Pinion		Gear	
	Concave	Convex	Concave	Convex
Cut radius r/mm	96.795	93.705	96.795	93.705
Cut number N	8.5		8.5	
Radial setting S_r/mm	97.3967		97.3967	
Initial cradle angle setting $q/^\circ$	-53.39637°		53.39637°	
Vertical offset E_m/mm	0		0	
Machine center to back X_g/mm	0		0	
Sliding base X_b/mm	$-.998$		$-.998$	
Machine root angle $\gamma/^\circ$	25.43598		59.62425	
Roll ratio R_a	2.186519		1.124495	

**Fig. 11.** Cutting experiment.**Fig. 12.** Measurement of pinion.**Fig. 13.** Result of measurement.

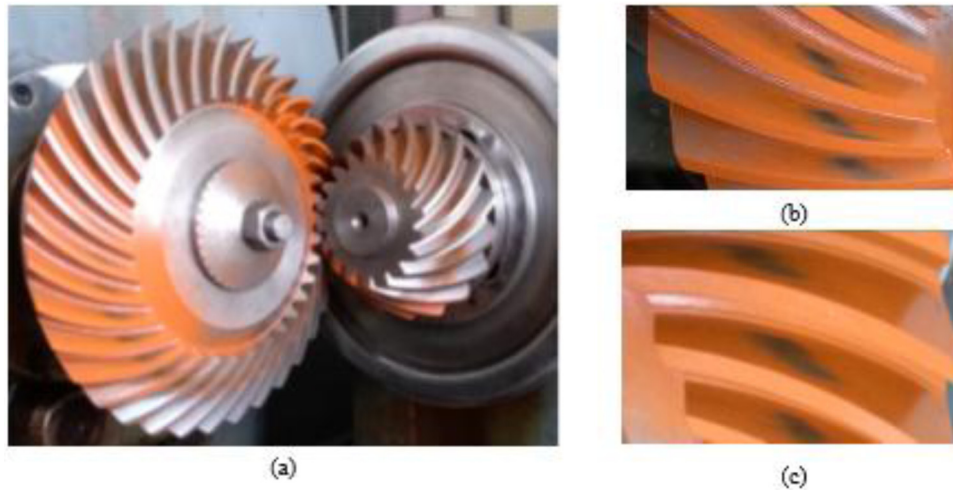


Fig. 14. Result of rolling test.

Above research provides theoretical support for the design and manufacture spiral bevel gear by duplex spread blade method.

Acknowledgment

The authors would like to thank the financial aid and support from Henan Provincial Science and Technology Research Project (No. 232102220057, 232102210167). We are grateful to the reviewers and editors for their valuable comments and suggestions.

Funding

The research is funded by Henan Provincial Science and Technology Research Project (No. 232102220057, 232102210167).

Conflict of Interest

The authors declare that they have no competing interests.

Data availability

All data generated and analyzed during this study are included in this article.

Authors contributions

Longlong Geng, Shaowu Nie, Chuang Jiang proposed the method and established model; Longlong Geng, Chuang Jiang, and Ruijie Xie contributed to the calculation, analysis, and cut experiment; Longlong Geng, Shaowu Nie and Chuang Jiang contributed to writing—original draft preparation; all the authors contributed to writing, review, and editing; Longlong Geng and Ruijie Xie acquired the funding.

References

1. T. Zeng, Design and manufacture of spiral bevel and hypoid gears, Harbin Institute of Technology, 1989. (in Chinese)
2. B.A. Shtipelman, A Wiley-Interscience Publication: Design and manufacture of hypoid gears, New York, 1978
3. F.L. Litvin, A. Fuentes, K. Hayasaka, Design, manufacture, stress analysis, and experimental tests of low-noise high endurance spiral bevel gears, *Mech. Mach. Theory*, **41** (2006) 83–118
4. Gleason Works, Calculation instructions generated hypoid gears duplex helical method, The Gleason Works, New York, 1971
5. J. Pisula, M. Płocica, Numerical model of bevel gears cutting by duplex helical method, *Key Eng. Mater.* **490** (2011) 237–246
6. C.B. Tsay, J.Y. Lin, A mathematical model for the tooth geometry of hypoid gears, *Math. Comput. Modell.* **18** (1993) 23–34
7. A. Gonzalez-Perez, Fuentes, K. Hayasaka, Computerized design and tooth contact analysis of spiral bevel gears generated by the duplex helical method, *ASME 2011 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, American Society of Mechanical Engineers, Washington DC, United states, 2011, pp. 149–158
8. Y. Zhang, H.Z. Yan, T. Zeng, Computerized design and simulation of meshing and contact of formate hypoid gears generated with a duplex helical method, *Strojniski Vestnik-J. Mech. Eng.* **61** (2015) 523–532
9. Y. Zhang, H.Z. Yan, T. Zeng, Cutting principle and tooth contact analysis of spiral bevel and hypoid gears generated by duplex helical method, *J. Mech. Eng.* **51** (2015) 15–23.
10. Y. Zhang, H.Z. Yan, New methodology for determining basic machine settings of spiral bevel and hypoid gears manufactured by duplex helical method, *Mech. Mach. Theory* **100** (2016) 283–295
11. L.L. Geng, X.Z. Deng, J. Deng, Calculation and experiment of spiral bevel gear by duplex helical method predesigned contact path, *J. Adv. Mech. Des. Syst. Manuf.* **15** (2021) 1–17

12. C.G. Lv, J.Q. Luo, H.J. Wang, Tooth cutting calculation of helical double-sided machining of small module quasi-hyperboloid bevel, *J. Mech. Transm.* **42** (2018) 92–94
13. Beijing Gear Factory. Spiral bevel gear [M], Science Press, Beijing, 1974. (in Chinese)
14. Q. Fan, Enhanced algorithms of contact simulation for hypoid gear drives produced by face-milling and face-hobbing processes, *J. Mech. Des.* **129** (2007) 1–7
15. X.M. Cao, X.Z. Deng, B.Y. Wei, A novel method for gear tooth contact analysis and experimental validation, *Mech. Mach. Theory* **126** (2018) 1–13
16. M. Vivet, D. Mundo, T. Tamarozzi, An analytical model for accurate and numerically efficient tooth contact analysis under load, applied to face-milled spiral bevel gears, *Mech. Mach. Theory* **130** (2018) 137–156
17. H.H. Ze, H. Ding, S.D. Peng, Numerical determination to loaded tooth contact performances in consideration of misalignment for the spiral bevel gears, *Int. J. Mech. Sci.* **151** (2019) 343–355
18. J. Pisula, An analysis of the effect of the application of helical motion and assembly errors on the meshing of a spiral bevel gear using duplex helical method, *Adv. Manuf. Sci. Technol.* **40** (2016) 1–14
19. L.L. Geng, X.Z. Deng, H. Zhang, Theory and experimental research on spiral bevel gear by double-side milling method, *Mech. Ind.* **22** (2021) 1–11
20. Y. Zhang, H.Z. Yan, Z.Y. Wang, The influence rules of cutter parameters on the contact characteristics of tooth surfaces by five cut processes and the duplex helical method, *Strojniški Vestnik – J. Mech. Eng.* **65** (2019) 351–365
21. S.X. Wu, H.Z. Yan, Z.Y. Wang, Tool profile modification of hypoid gear machined by duplex helical method, *Int. J. Adv. Manuf. Technol.* **119** (2021) 1–14
22. L.L. Geng, X.Z. Deng, X.M. Cao, Research on tooth contact analysis (TCA) for spiral bevel gear based on duplex spread blade [J], *Mech. Transm.* **38** (2014) 34–36.

Cite this article as: Longlong Geng, Shaowu Nie, Chuang Jiang, Ruijie Xie, Influence of cut parameters on mesh performance of spiral bevel gear by duplex spread blade method, *Manufacturing Rev.* **11**, 3 (2024)