

Sensitivity Analysis of Face Gear Installation Error

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Abstract—The face gear is the core component used in the helicopter transmission system. Compared with other gear transmissions, the face gear transmission has large coincidence degree, stable transmission, low noise, no axial force, small space occupied by the transmission device, and torque splitting effect. It is a good advantage, so it is generally used in the aerospace field. In this paper, in the face gear transmission process, the contact lens sensitivity caused by the surface gear installation error, using the combination of theoretical analysis and computer simulation, the application of differential geometry and gear meshing transmission theory, combined with the surface topology design technology, The face tooth surface design method with low sensitivity of meshing impression error and stable meshing quality is used, and Gauss curvature is used as the installation sensitivity coefficient to analyze the sensitivity of surface gear mounting error.

Keywords—Face Gear; Installation Error; Contact Path; Gauss Curvature; TCA

I. INTRODUCTION

The face gear is a circular angle transmission gear that meshes with the spur gear in the non-parallel shaft configuration. It has high angular accuracy, large single-stage transmission ratio, free choice of shaft angle, and free floating of the active cylindrical gear. It has broad application prospects. Many scholars at home and abroad have conducted a lot of research on the face gear transmission. The research data shows that the face gear is sensitive to the installation error. In practical applications, it is easy to deviate from the ideal contact area and cause edge contact and eccentric load. Wu Xuncheng, Mao Shimin[1] et al. studied the sensitivity of the mounting error of the point contact tooth surface, and gave the formula for calculating the sensitivity of the contact point position of the contact tooth surface to the mounting error; Zhou Kaihong [2] proposed a sensitivity method to quantitatively evaluate the tooth surface meshing characteristic to gear installation position error by using the condition number of linear equation group coefficient matrix.; Su Jinzhan[3-4] et al.

using the area, direction and position of the tooth surface impression as the sensitivity coefficient of the mounting error of the spiral bevel gear, and optimizing the stability of the gear impression with the minimum of the sensitivity coefficient as the objective function; In this paper, the sensitivity of the face gear to the installation error is modified by the opposite gear in the direction of the tooth profile and the direction of the tooth. A low-mounting error sensitive topological tooth surface design method suitable for face gear transmission is studied. The Gauss curvature is used as the evaluation index of the installation sensitivity, and the sensitivity of the face gear before and after the modification is analyzed.

II. FACE GEAR THEORETICAL TOOTH SURFACE

The flank surface of the spur gear is formed by an involute spur gear cutter, which is equivalent to the meshing of the spur gear and the face gear during the development process. According to the principle of face gear shaping, when the angle between the tool axis and the face gear axis is 90°, the coordinate system of the spur gear tool is shown in Figure 1. S_m is a fixed coordinate system of the tool fixed to the tool holder, S_p is a fixed coordinate system of the face gear fixed to the face gear bracket; S_s and S_2 are two moving coordinate systems respectively rotating together with the tool and the face gear, the tool and the face gear are The corners in the machining process are represented by φ_s and φ_2 , respectively, and the relationship between the two is satisfied:

$$\varphi_2 = N_s \times \frac{\varphi_s}{N_2} \quad (1)$$

In the formula: N_s , N_2 are the number of teeth of the tool and the face gear.

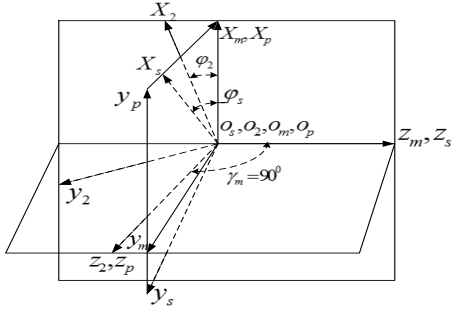


Figure 1. Face Gear Machining Coordinate System

If the tooth surface parameter of the tool tooth surface Σ_s is (u_s, θ_s) , the tooth surface vector of the tool tooth surface equation can be expressed as $r_s(u_s, \theta_s)$, and the face gear tooth surface equation is:

$$r_2(u_s, \theta_s, \phi_s) = M_{2s} \cdot r_s(u_s, \theta_s) \quad (2)$$

In the formula, M_{2s} is a transformation matrix of the tool coordinate system S_s to the surface gear coordinate system S_2 . According to the principle of gear meshing, The geometry of the face gear is completely defined by the pinion cutter, so the spur gear that meshes with the face gear is actually exactly the same as the geometry of the pinion cutter. Therefore, the tooth surface equation of the spur gear can be obtained by replacing the subscript “s” of the tool tooth surface equation with “1”.

III. FACE GEAR TOPOLOGY MODIFICATION

In the meshing drive, the spur gear we use is exactly the same as the tool gear, so the small wheel (cylindrical gear) and the large wheel (face gear) are in line contact at each moment during the transmission. However, due to installation errors and manufacturing manufacturing errors, problems such as eccentric load and meshing interference may occur during the actual meshing process. Therefore, it is necessary to modify the shape of the tooth flank of the gear so that the surface gear pair becomes point contact when it is engaged by the line contact. In this paper, the tooth surface of the opposite gear is modified in two directions, so that the spur gear is in point contact with the surface gear when meshing with the surface gear, and the sensitivity of the contact spot to the error is reduced, and the desired parabolic transmission error is obtained to avoid edge contact happened.

As shown in Fig.2, the face gear tooth surface modification is to establish a parabolic shape modification function δ_h along the tooth surface contact path direction L_2 on its projection plane, and a parabolic shape modification function δ_v along the contact line direction

L_1 , and then offset. Face gear bidirectional shaping function δ is

$$\delta = \delta_h + \delta_v \quad (3)$$

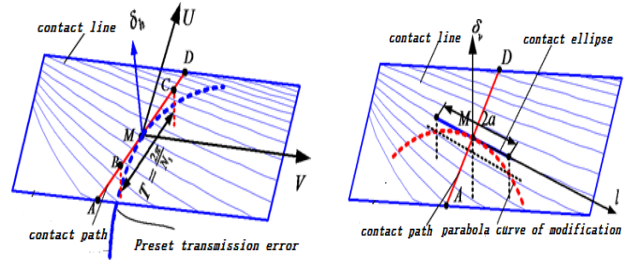


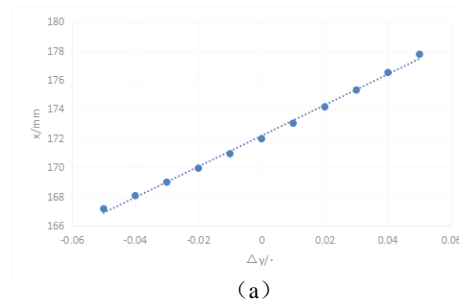
Figure 2. Face gear tooth surface modification

The function δ is superimposed on the original standard face gear tooth surface Σ_2 along the normal of the tooth surface, and the tooth surface Σ_2' of the bidirectional drum topology is recorded as

$$r_2'(u_s, \theta_s, \phi_s) = r_2(u_s, \theta_s, \phi_s) + n_2(u_s, \theta_s, \phi_s) \cdot \delta \quad (4)$$

IV. INSTALLATION ERROR SENSITIVITY ANALYSIS

Surface gear mounting error sensitivity refers to the degree of influence of the mounting error on the contact marks and transmission errors in the face gear transmission process. Through analysis, it can be seen that in all installation errors, the axial angle error has the greatest influence on the contact marks of the tooth surface. Therefore, the installation error analyzed in this paper is mainly for the shaft angle error. Figure 3 shows the influence of the mounting error of a certain gear on the parameters of the tooth surface. Where x is the horizontal position of the meshing reference point; y is the vertical position of the meshing reference point; K is the Gauss curvature of the bite and the reference point; $\Delta\gamma$ is the axis angle error.



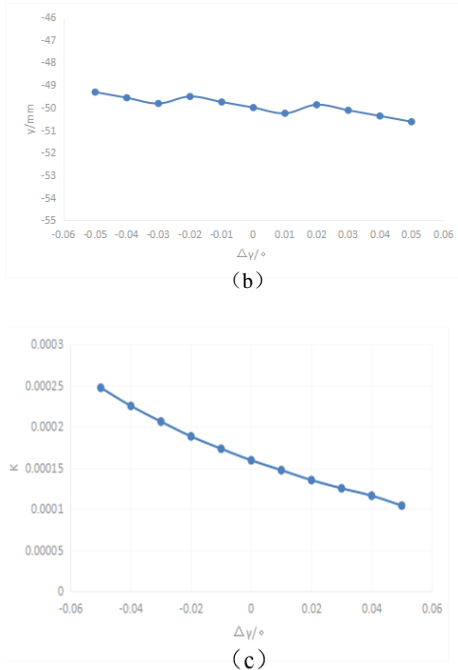


Figure 3. Installation error affects the parameters of the tooth surface:(a)horizontal position(b)vertical position(c)Gauss curvature

Fig. 3(a) shows the influence of the angle error of the shaft on the horizontal position of the meshing reference point. It can be seen from the figure that when the angle error of the shaft is negative, the biting and the reference point are offset toward the small end; For timing, the bite and reference point are offset toward the big end. It can be seen from Fig. 3(b) that the axial angle error has little effect on the vertical position of the bite and the reference point. Fig. 3(c) analyzes the influence of the axial angle error on the Gauss curvature of the reference meshing point. The Gauss curvature at the meshing point tends to decrease as the axial angle error changes from negative to positive. In combination with (a) and (c), the Gaussian curvature decreases when the reference meshing point moves toward the large end, and the Gauss curvature increases as it moves toward the small end. The purpose of the two-way shape modification of the opposite gear is to reduce the sensitivity of the surface gear mounting error and stabilize the contact mark in an ideal position. That is, as the angle of the shaft angle changes, the position of the reference meshing point does not change or changes little. And because the curvature of the Gauss is the essence of the curvature of the curved surface near the point on the tooth surface of the gear. Therefore, according to the above theory and analysis, the Gauss curvature at the reference point of the surface gear is defined as the installation error sensitivity evaluation index. When the Gauss curvature at the joint and the reference point changes with the error of the angle of the shaft, the value is constant or the fluctuation range is very

small, which indicates that the face gear has low installation error sensitivity.

V. EXAMPLE ANALYSIS

Taking the design parameters of the face gear given in Table 1 as an example, the simulation analysis and the Gauss curvature calculation of the spur gear gear pair before and after the modification with installation error are carried out, and the results are analyzed.

TABLE1 FACE GEAR DESIGN PARAMETERS

Design Parameters	value
Number of pinion teeth N1	25
Number of face gear teeth N2	86
Number of shaper teeth Ns	25
Normal module m	4
Normal pressure angle α (°)	25
Axis angle Δγ (°)	90
Face gear inner distance L1 (mm)	160
Face gear outer distance L2 (mm)	193

Since the meshing of the large wheel and the small wheel is a line contact, the line contact condition cannot be realized in practice due to various errors. Therefore, in this paper, the small gears with 3 teeth less than the number of teeth of the tool are used for simulation analysis in the gear pair transmission before the modification.

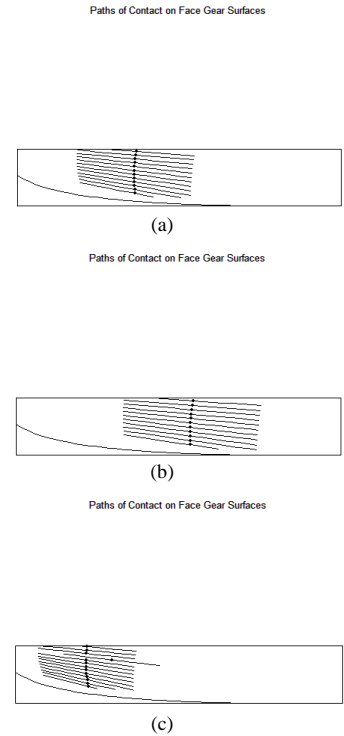


Figure 4. Face gear drive contact impression(a)Δγ=0(b)Δγ=+0.05(c)Δγ=-0.05

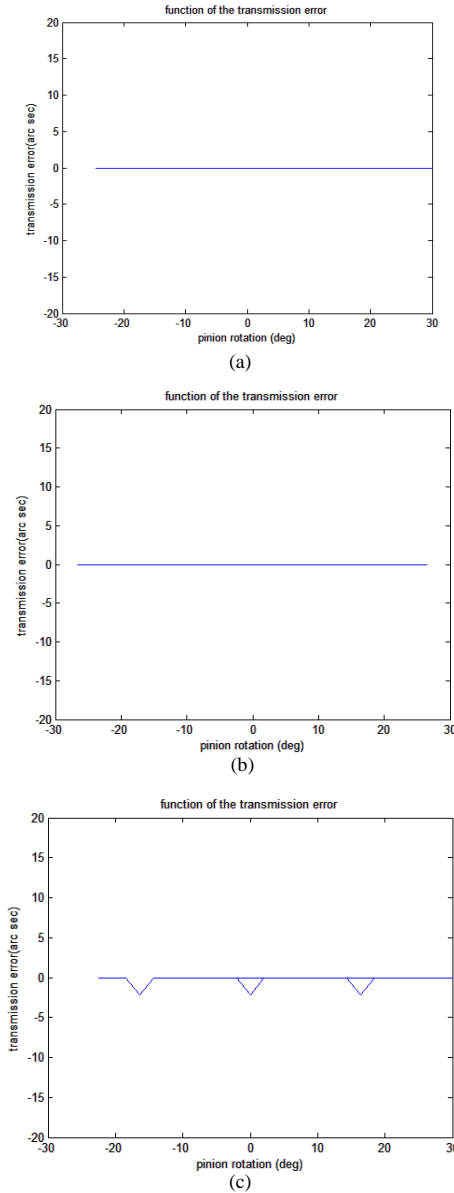


Figure 5. Face gear transmission error(a) $\Delta \gamma = 0$ (b) $\Delta \gamma = +0.050$ (c) $\Delta \gamma = -0.050$

It can be seen from Fig. 4 and Fig. 5 that although the small wheel which is three teeth less than the number of teeth of the tool is engaged with the large wheel in the gear pair transmission, the original line contact between the two teeth of the small wheel and the large wheel becomes Point contact, but under different axial errors, the contact marks on the surface of the face gear are still not stable, resulting in a large offset, and the transmission error curve is relatively fluctuating.

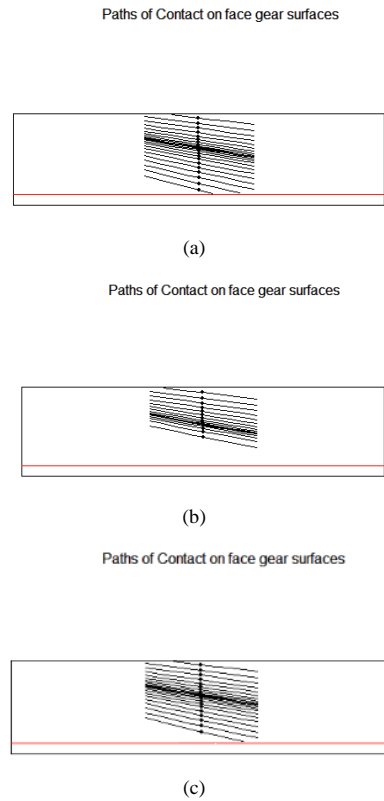


Figure 6. Modified face gear drive contact impression(a) $\Delta \gamma = 0$ (b) $\Delta \gamma = +0.050$ (c) $\Delta \gamma = -0.050$

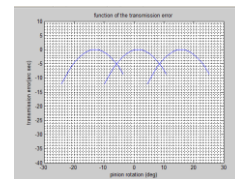


Figure 7. Modified face gear transmission error

It can be seen from Fig. 6 and Fig. 7 that the modified large wheel has a small offset between the contact mark of the tooth surface and the ideal contact mark when the installation error is included, and the modified shape is large. The wheel transmission error curve is in the form of a quadratic parabola. This form of transmission error can absorb the linear error caused by the installation error and keep the shape of the error curve unchanged.

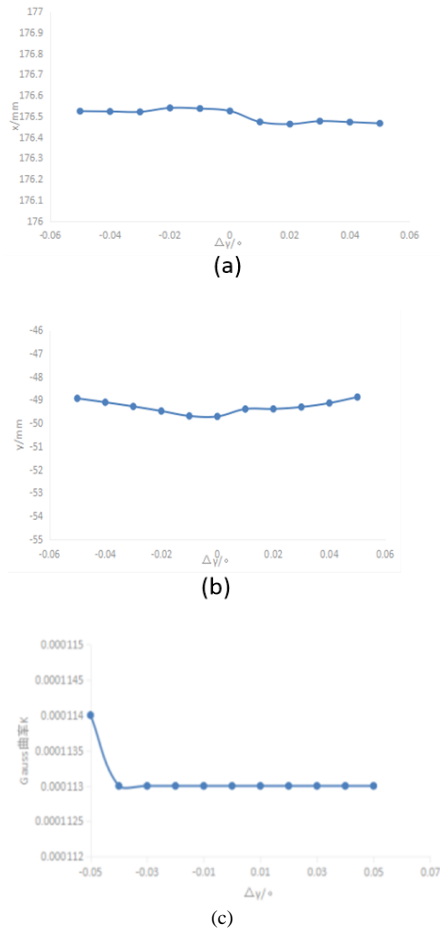


Figure 8. Installation error affects the parameters of modified face gear tooth surface:(a)horizontal position(b)vertical position(c)Gauss curvature

As can be seen in conjunction with Figures 4 and 6, The contact trajectory of the face gear is a straight line distributed approximately along the tooth height direction, and the Gauss curvature fluctuation amplitude at the meshing point on the same contact trajectory is small, so the position of the meshing point on the contact trajectory can be expressed by the magnitude of the Gauss curvature. Further analysis of the Gauss curvature at the reference point of the meshing gear tooth surface after trimming can be obtained

Comparing Fig. 3 and Fig. 8, it can be seen that the face gear with the mounting error sensitivity after trimming has a small fluctuation range of Gaussian curvature at the biting and reference point in the case where the axial angle error is constantly changing. And the position of the bite and the reference point changes little.

VI. CONCLUSION

The results of the performed research allow the following conclusions to be drawn:

- The opposite gear has been modified in both directions, and the top tooth profile geometry of the face gear with meshing information is constructed.
- The TCA simulation of the face gear pair drive before and after the trimming was carried out, which verified that the gear behind the shape modification has stability in contact with the print mark in the case of installation error.
- The Gauss curvature is used as the evaluation index of the surface gear installation error sensitivity. The face gears before and after the modification are analyzed. The results show that the face gear with low error sensitivity has a small fluctuation range of Gauss curvature at the biting and reference point, and vice versa.

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REFERENCES

- [1] Wu Xuncheng, Mao Shimin, Wu Shutang. Effect of Second-order parameter on design for point contact tooth surface by control error sensitivity [J]. Journal of Xi'an Jiaotong University, 1999, 33 (11): 86
- [2] Zhou Kaihong, Li Shu. Quantitative analysis on integrated of gear mounting errors to point-contact tooth surface meshing characteristics [J]. Coal mine machinery, 2009, 30 (07): 37-40
- [3] Su Jinzhan, Fang Zongde. optimization design of the error sensitivity for spiral bevel gears[J]. Journal of Aerospace Power, 2012, 27 (01): 183.
- [4] Su Jinzhan, Fang Zongde. optimization design and test of stability of patterns of spiral bevel gears[J]. Journal of Aerospace Power, 2012, 27 (12): 2622-2628(in chinese).
- [5] Fu Xuezhong , Fang Zongde. Assembly errors tolerance and sensitivity of offset face gears[J] Journal of Harbin Engineering University, 2018, 39 (07) :1227-1232.
- [6] Walker H. Gear tooth deflection and profile modification[J].the engineer, 1990, 166(4318):409-412
- [7] Lin H H, Oswald F B, Townsend D P. Dynamic loading of spur gear with linear or parabolic tooth profile modification [J]. Mechanism and Machine Theory, 1994, 29(8): 1115 — 1129.
- [8] Claudio Z, Jose L P. Application of modified geometry of face gear drive[J]. Computer Methods in Applied Mechanics and Engineering, 2005, 194:3047-3066.
- [9] Litvin F L, Fuentes A, Matt H. design, generation, and TCA of new type of asymmetric face-gear drive with modified geometry[J]. Computer Methods in Applied Mechanics and Engineering, 2001, 190:5837-5865
- [10] Sigg N. Tooth profile modification of high speed duty gear[C]. In: Proceedings of International Conference on Gearing. New York: McGraw-Hill Co, 1958, 313-316