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A Novel Gear Honing Machine Parameter Design and Finite Element Analysis Based on the Principle of Dislocation Axis Line Contact

Lijuan Yu [1], Xinxu Guo[1], Xuecheng Zhang [1], Xin Wang [1*], Xiaoming Ji [2]and Hongguo Wang [2]

[1] School of Mechanical and Aerospace Engineering, Jilin University, Changchun, China, 130025;

[2] Jilin Yuxing machinery manufacturing co., LTD, Jilin Yitong, China, 136000

Corresponding author and e-mail: Xin Wang, wxin@jlu.edu.cn

Abstract. The characteristics of the dislocation axis line contact gear space transmission was analyzed in order to study the new precision gear honing machine prototype which could be clamped and formed at one time, and a pair of dislocation axis involute helical gears in space was designed from the most basic principle of involute gear meshing. The vertical dislocation axis line contact the worm and worm gear (helical gear) transmission mechanism were formed, when two gears had equalent normal base diameter and the sum of their base-circle spiral angles was equal to 90°. According to worm drive relationship of the vertical dislocation axis line contact, the helical gear tooth surface was honed through the worm could be used as a grinding wheel of the honing machine. Grinding wheels with different parameters could be used to machine bevel gears with different modulus, different numbers of teeth and different tooth widths. The finite element analysis and optimization showed that the prototype of the machine tool was reasonable, and the first-order natural frequency is 341.8Hz, which was much higher than the working frequency of 30Hz to avoid resonance.

1. Introduction

The dislocation axis line contact gear transmission was a special case of the spatial dislocation axis gear transmission, whose main feature was that the line contact form of the gear tooth surface meshing ,with the advantages of smooth transmission, large carry capacity and high transmission efficiency. In this paper, the gear honing machine tool prototype with a novel dislocation axis line contact was designed. The worm was made into a honing machine tool to honing the tooth surface of the helical gear by using the vertical dislocation axis line contact worm drive relationship. Compared with the traditional machine tool, the new honing machine tool reduced the axial feed motion of the workpiece, and the grinding wheel and the workpiece had a large honing area, and the honing process was completed once, which significantly improves the gear processing efficiency and precision[1~4].

2. The Transmission Principle of Novel Precision Gear Honing Machine Tool

The dislocation axis gear transmission mechanism could realize the transmission mode in which any two helical gear transmissions or worm gears was arranged in a dislocation axis, and the axes of the two gears was neither parallel nor intersect. As shown in Fig. 1, the oblique line B-B became the spiral line B-B on the unfolding cylinder surface. Assuming that the occurrence surface (Q) fits snugly on the unfolding cylinder surface and performs pure rolling along the spiral direction, then the motion path of the oblique line B-B (occurrence line)would form an involute helix plane (Σ) composed of coutless straight lines.

On the plane (Q), the angle λb between the occurrence line B-B and the plane xoy was called the helix angle, and the remainder angle of the helix angle λb was called the base-circle helix angle, which is represented by βb. The M was any point on the spiral B-B, and $\vec{\mathbf{n}}, \vec{\mathbf{n_1}}, \vec{\boldsymbol{\tau}}$ were the principal normal vector, the secondary normal vector, and the tangent vector of the M point basic triangular[5] respectively, in the coordinate system oxyz, MN was an occurrence line on the involute surface, the vector of the N point is:

$$\overrightarrow{ON} = \overrightarrow{OK} + \overrightarrow{KM} + \overrightarrow{MN} \tag{1}$$

$\overrightarrow{MN}$ means the distance between the MN of the involute spiral surface of the cylinder as μ; $\overrightarrow{OK}$ means the radius of the unfolding cylinder as R_b; $\overrightarrow{KM}$ means the axial displacement of the spiral at the rotation angle θ, KM=pθ, p was the spiral parameter.

Vector equation of any point N on a cylindrical involute helicoids:

$$\overrightarrow{ON} = (R_b \cos\theta + \mu\cos\lambda_b \sin\theta)\vec{i} + (R_b \sin\theta - \mu\cos\lambda_b \cos\theta)\vec{j} + (p\theta - \mu\sin\lambda_b)k \tag{2}$$

The intersection of the plane perpendicular to the z-axis and the involute helicoid becomes an involute, the radius of the base circle of the involute is , and the involute equation was:

$$\begin{cases} x = R_b \cos\theta + \mu\cos\lambda_b \sin\theta \\ y = R_b \sin\theta - \mu\cos\lambda_b \cos\theta \end{cases} \tag{3}$$

According to the basic theorem of involute gear meshing, the involute gears must ensure equal normal tooth distance to properly mesh. As shown in Fig. 2, the base circle radius of the right-handed involute helicoid Σ_1 was R_{b1} ,and the base circle radius of the left-handed involute helicoid Σ_2 was R_{b2} , and t two base circles had a common plane (Q).

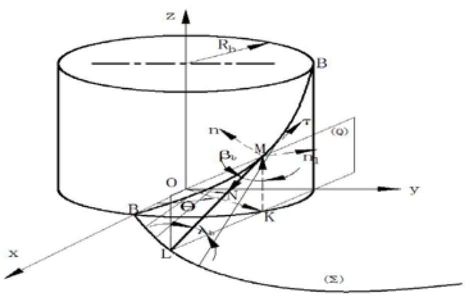

Figure 1. Involute surface principle

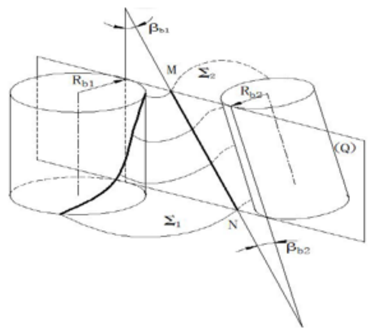

Figure 2. The dislocation axis line contact gear transmission principle

The base circle helix angle of the right-handed involute helicoid was β_{b1} , and the base circle helix angle of the left-handed involute helicoid was β_{b2} ($\beta_{b1} \neq \beta_{b2}$), and the sum of two base circles helix angles were equal to the axis intersection angle ψ of the dislocation axis, that is $\psi = \beta_{b1} + \beta_{b2}$ (in the case of internal meshing, $\psi = \beta_{b1} - \beta_{b2}$) At this time, the occurrence line of the surface Σ_1 and Σ_2 was coincides with the straight line MN. If the contact transmission state still conformed to the basic meshing theorem, two tooth faces could remain properly engaged. In addition, the center distance A of two the dislocation axis was: . $A = R_{b1} + R_{b2}$.

The transmission of the dislocation axis line contact worm gear had unique advantages - the tooth surface was line contact and the shaft angle was 90°, which could be applied to precision gear honing machines. The involute bevel gear replaces the worm gear (in the same principle), and the worm could be the grinding wheel of the machine tool. The two grinding wheels had the same tooth shape, and were symmetrically mounted on both sides of the bevel gear, respectively honing the tooth flanks on both sides of the bevel gear.

As shown in Fig. 3, the worm and the bevel gear with the same tooth shape were in the space of the vertical dislocation axis line contact worm gear transmission [6~8]. The left worm base circle helix angle β_{b1} was close to 90°, and the base circle radius was R_{b1}. The right worm base circle helix angle was $\beta'_{b1} = \beta_{b1}$, and the base circle radius was $R'_{b1} = R_{b1}$. The base circle helix angle of the bevel gear was β_{b2} , and the base circle radius was R_{b2}. Take the left worm as an example, the center distance between the worm and the helical gear was A:

$$A = R_{b1} + R_{b2} \tag{4}$$

The sum of the base circle helix angle of the left worm β_{b1} and the bevel gear β_{b2} were equal to 90°. In the common cylindrical section Q of the left worm and the bevel gear, the contact type between the worm tooth surface and the bevel gear tooth surface was line contact, that is, the straight line MN. The right worm and the bevel gear mesh in the same state, no longer repeat. When the left and right worms maintain the equal angular velocity (ω_1, ω'_1) and opposite directions, the two worms could maintained the vertical dislocation axis line contact.

3. Overall Design of New Precision Gear Honing Machine

The novel precision gear honing machine could achieve the honing of common helical gears. According to the dislocation axis line contact worm drive relationship, the worm was used as a grinding wheel of the honing machine to honing the helical gear tooth surface. The grinding wheel material was made of hardened steel, and was electroplated CBN, which saved cost [9] [10]. The gear material could be made of engineering plastic or common steel.

Figure 4 shows the transmission principle and prototype of the novel precision gear honing machine. Two servo motors drives the left and right grinding wheels through the spindle system to perform high-speed rotary motion. The left and right grinding wheels were simultaneously in contact with the two tooth surface lines of the machined workpiece (bevel gear), and then the two grinding wheels perform the synchronous counter-rotation movement to complete the honing processing of the machined workpiece.

The rotary motion of the machine tool spindle was simultaneously used as the feed motion of the honing gear, and the feed amount of the grinding wheel in the tooth thickness direction of the bevel gear was controlled by changing the phase between the left and right grinding wheels. In addition, the movement of the machine tool also included the workpiece adjustment mechanism (sub-shaft mechanism) and the passive helical motion of the machined bevel gear.

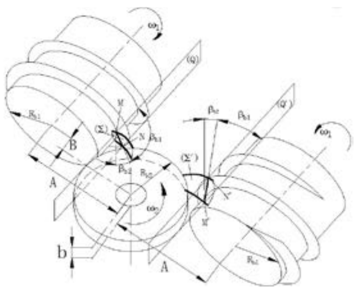

Figure 3. The transmission principle of novel precision gear honing machine

Figure 4. The novel precision gear honing machine tool transmission principle and prototype

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The novel precision gear honing machine had the advantages of simple structural design and parts processing, low manufacturing cost and high honing efficiency.

4. Parameter Design of Worm Grinding Wheel And Bevel Gear For Novel Precision Gear Honing Machine

The novel precision gear honing machine could honing bevel gears with different teeth numbers, different modulus and different tooth widths. For example, the bevel gear with the teeth number z=45, the normal modulus m_n =6, the reference circle normal pressure angle α_n =20°, and the tooth width b = 12 was used as the machined workpiece.

The specific parameters for designing and calculating the right-handed involute gear and the worm wheel wee shown in Table 1.

Table 1. Worm, helical gear specific parameters

Worm parameters		Bevel gear parameters	
Number of worm teeth	1	Number of teeth z	45
Rotate direction	right	Normal modulus m_n	6
Base circle helix angle β_{b1}	88.89°	Reference circle pressure angle α_n	20°
Spiral angle λ	1.01°	Base circle helix angle β_{b2}	1.01°
Normal pitch p_{1n}	17.713	Normal pitch p_{bn}	17.713
Base circle radius R_{b1}	160	Base circle radius R_{b2}	126.878
Spiral tooth length L	53.5	Tooth width b	12
Worm outer diameter	322.5	Reference circler adius R_2	135.023
Gear slot depth h	15	Tooth top circle radius R_{2e}	141.023
Working-side inner corner μ	4°	Root circle radius R_{2i}	127.523
Non-working side tooth back angle η	20°	Normal tooth thickness S_n	9.425

5. Finite Element Analysis and Optimization of Machine Tools

5.1. Finite Element Analysis of Machine Tool Spindle

The strength and rigidity of the machine tool spindle directly affected the machining accuracy of the machine tool. The CATIA spindle model part drawing was imported into the Workbench for meshing, and the boundary condition was added according to the actual working force state of the spindle (ignoring the small axial force). 1) The cylindrical bearing surface was subjected to the cylindrical surface constraint; 2) the torque and the concentrated force were applied to the connecting surface between the main shaft and the grinding wheel; 3) the torque was applied to the connecting surface between the main shaft and the motor shaft.

After finite element analysis and calculation, the total deformation of the main shaft and its equivalent stress cloud were obtained as shown in Fig. 5.

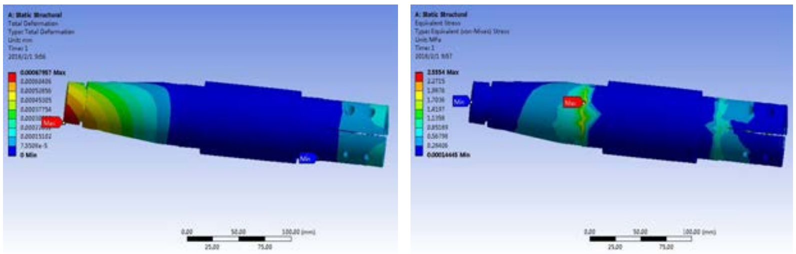

Figure 5. Total deformation of the main shaft and equivalent stress cloud

It could be seen from the above figure that the maximum total deformation of the main shaft was 0.68μm at the end of the grinding wheel installation, and the maximum stress was 2.556MPa, which was within the safe range and meets the design requirements.

5.2. Finite Element Analysis of Machine Tool

The modal analysis of the machine tool was used to study the natural frequency of each mode, avoiding resonance in the machine tool, affecting machining accuracy and equipment safety. Define the material properties of each part of the machine tool, and apply fixed constraints on the base of the machine bed, add the contact type between the spindle and the bearing, the bearing and the bed, the worm wheel and the spindle contact surface, the motor shaft and the main shaft surface, and remove the chamfer and small holes, Simulation results were shown in the Table 2.

Table 2. Machine tool natural frequency

Mode order	natural frequency(Hz)	Mode order	natural frequency(Hz)
1	341.8	4	484.12
2	342.87	5	509.51
3	473.26	3	514.59

From the modal analysis results, the natural frequency of the first-order mode was 341.8 Hz. According to the formula of rotational frequency calculation f=n/60, the vibration frequency caused by the rotation of the main shaft of the new precision gear honing machine tool was 1800/60=30Hz, and the vibration frequency caused by the rotation of the countershaft was 40/60=0.667Hz, which were much lower than the first-order natural frequency of the machine tool. This effectively avoided resonance and ensured the normal operation of the machine.

6. Acknowledgments

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