Helical gear honing technology research with synchronous double honing wheel of no feed movement

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Abstract. Gear honing is a common finish machining method of hardened gear, which removes the cutting allowance with the pressure between honing wheel coated with abrasive and gear surface and relative sliding friction. At the same time, tooth profile shapes can be trimmed and spiral linear precision can be improved. Current honing methods need expensive machine tools with precision bearing as well as with large advanced multi-axis linkage CNC system, so manufacture and maintenance of the machine are extremely complex and costly. In this paper, honing wheel with double involutes helicoids worm was designed by elimination configuration error; The transmission mechanism and the retarding mechanism were simplified in honing machine with two servo motors. the gear honing processing was once completed, the entire width of the gear was once processed too. This method improved machining precision and reduces the manufacturing cost under the same cost.

1. Introduction

Honing gear movement is gear transmission form of a pair of crossed-axis helical gears movement by nature, and one helical gear would be equivalent to a honing wheel\cite{1}, and another would be equivalent to a unprocessed workpiece. Honing wheel itself was a helical gear with abrasive, whose gear tooth surface spread evenly the grits which was equivalent to blades. In the process of gear honing processing, when honing wheel and unprocessed helical gear rotated at a certain speed, due to the relative sliding between the tooth surface meshing point \cite{2}, abrasives cemented in the honing wheel gear surface realizes rapid movement.

Under the pressure of honing, abrasives cut into the metal layer, and cut down very fine chip particles, and removed the formation of allowance and finally finished helical gear achieved the required thickness and precision. At the same time, in order to guarantee the helical gear tooth width \cite{1}, the honing wheel shaft and helical gear shaft must realize reciprocating feed movement. So, in the process of traditional honing , honing wheel axial feed and twice gear tooth surface grinding could not be once finished, and must be second clamped, so this method came into being machining error and the clamping error easily, at the same time, was not conducive to production of automation and intellectualization.
2. Involute tooth surface forming principle of worm and gear

In staggered shaft helical gear transmission principle diagram [3], the two gear shaft were mutually disjoint in space, and an Angle between two axis is $\gamma$. As shown in figure 1. Two rotating angle velocity of helical gear rotating around its own axis $X_1$, $X_2$ were $\omega_1$, $\omega_2$ respectively. $P_1$, $P_2$ were parallel to two axis, and were tangent with dividing circle radius respectively, the two tangent intersect at point I. Assumptions MM' was a diagonal line in two overlapping plane, whose angle from the tangent $\delta_1$ was $\beta_1$, whose angle from the tangent $\delta_2$ was $\beta_2$, and helical gear I rotated about its own axis $X_1$, tangent plane with angular velocity omega, made gear I rotating around the axis $X_1$, the tangent plane $P_1$ motion along the $f_1$ direction, will drive straight line MM' movement to $f_1$ direction, at the same time MM' would give a force to the tangent plane $P_2$, drive $P_2$ movement along the $f_2$ direction. The tangent plane $P_2$ translation would drive gear II rotation with angular velocity $\omega_2$, $\beta_1$, $\beta_2$ are two gear indexing circular spiral Angle. When the base circle spiral Angle $\beta_{b1}$ of the gear I was close to $90^\circ$, each tooth shaped like a worm on the degree of cylindrical around in circles.

![Figure 1. Staggered shaft helical gear transmission principle diagram.](image)

As shown in figure 2 [4], the right-handed rotation involute helical gear tooth surface $\Sigma_1$ expanded by a $R_{b1}$ base cylinder and base circle helix Angle gear tooth surface $\Sigma_1$ expanded by a $R_{b2}$ base cylinder is to be tangency at tangency plane Q, and tangency line is ML. So ML was the straight generatrix of the spiral gradually plane. If $\Sigma_1$ was spiral grinding surface of worm honing wheel, and ML was generating straight generatrix of the honing wheel. When plane Q purely roll revolved around cylindrical $r_{b2}$, ML trajectory was tooth profile surface of the processed helical gear. When the two shaft Angle $\theta=\beta_1+\beta_2=90^\circ$, helical gear tooth surface for $\Sigma_1$ could be used to Vertical cross grinding.

![Figure 2. An involute tooth profile diagram.](image)
In this paper, a new no axial feed gear honing machine was compared with general gear honing machine, and it mainly has the following advantages: 1. Grinding was carried out on the gear tooth surface on both sides at the same time to eliminate clamping error of the gear processing; 2. Honing wheel using the 45 steel substrate would be surface electroplated by CBN coating after turning, in order to reduce the manufacturing difficulty and manufacturing cost; 3. Honing wheel with double involute worm mandatory honing gear could eliminate theory error; 4. Two servo motors controlled simplifies the transmission mechanism and the retarding mechanism, and significantly reduces the use cost and maintenance cost of machine tool.

3. Mechanical structure design scheme of machine tool

In machine tools design scheme, the grinding tool and the workpiece installation type were as shown in figure 3. Distance between axles of honing wheel and machined gear in horizontal direction was A, and distance between axles of two worm honing wheels in vertical direction was X, and b was breadth of tooth of machined gear, 2B was relative end face distance of two worm honing wheels, and \( r_{b1}, r_{b3} \) were base radius of two honing wheels respectively.

The theoretical analysis showed that worm honing wheels need be designed as a form with a certain taper, to realize gear grinding of the honing wheel within the range of tooth width, and to avoid undercutting phenomenon in the process of gear machining [5-6]. Big end radius was \( R_{\text{max}} \), and the small end radius was \( R_{\text{min}} \).

So the following formula need be meet.

\[
r_{b1} = r_{b2} = r_b
\]

\[
X_{\text{min}} \geq \sqrt{R_{\text{min}}^2 - r_b^2}
\]

\[
b = \sqrt{R_{\text{min}}^2 - r_b^2}
\]

The main parts of new no axial feed gear honing machine were two worm honing wheels which need be precise controlled in order to accomplish the accurate gear honing processing. So two sets of
servo motors were adopted as a power source, and respectively controlled two worm honing wheels to initialization, tooth setting, grinding, change phase feed motion. Machine tools planform was as shown in Figure 4. Left tooth surface honing wheel and right tooth surface honing wheel meant respectively two taper worm honing wheels, which are made of 45 # steel, and were coated by electroplating CBN [7-8]. Workpiece meant helical gear processed.

![Figure 4. The machine tools vertical view](image)

4. Experimental verification
The contents of the experiment were about two servo motors drive the gear honing operation include Synchronization and change phase. (In the following graph, red curve meant theory error curve, and blue curve meant actual error)

4.1. Machine tool dual axis synchronous start experiment
While machine tools process the helical gear, the synchronization of two worm honing speed from stationary state to Normal honing speed was not very good, so any synchronization starting experiment were carried to measure maximum synchronization errors and provide data suppose to cutter back-off in tool setting.

![Figure 5. Dual axis synchronous start experiment](image)
4.2. Machine tool dual axis slow down to stop experiment
Because of larger moment of inertia, the phase angle difference value of two worm honing wheels changed in process of machine slow down to stop, which need finish slow stop process experiment of machine tools. As shown in table 1, in the process of slowing down to stop, the change value from phase angle difference value to axial feed of worm honing wheels was provide.

| Motor velocity. (r/min) | Deceleration(r/ min²) | Axial feed variation (µm) |
|------------------------|-----------------------|--------------------------|
| 1                      | 1800                  | -15                      | ±22.5        |
| 2                      | 1500                  | -19                      | ±23          |
| 3                      | 1200                  | -7                       | ±10          |
| 4                      | 900                   | -10                      | ±15          |
| 5                      | 600                   | -9                       | ±17.5        |

The figure 6 and Table 1 showed that the machine tool would still need a cutter back-off operation whose allowance close to 0.03 mm to guarantee the helical gear tooth surface not damaged after finishing honing.

4.3. Synchronization precision test while machine load
Synchronization accuracy was shown after two worm honing wheels driven to the specified speed. As shown in figure 7, machine load synchronization precision with the driving speed of 1800 r/min, the acceleration of 35 r/min² was between ±7µm, which fully meet the processing requirements.
4.4. Phase-shifting experiment while machine load
Phase-shifting experiment was done when two worm honing wheels meet the specified requirements speed of 1800 r/min, each changed 50μm feed variation. As shown in figure 8, the result of the experiment showed that the machine tools have a smooth change-phase operation, and a error of 3μm between the actual change-phase value and requested change-phase value was existed, but completely meet the requirements of actual processing machine tool.

![Figure 7. Synchronization precision test while machine load.](image)

![Figure 8. Phase-shifting experiment while machine load](image)

5. Conclusions
A novel no axial feed gear honing machine was improved in processing method and machine tool structure optimization design, to reduce manufacturing costs on the premise of meet the requirements
of actual processing. The machine tools was driven by two independent worm honing wheel to complete all kinds of sports adopting dual-axial drive mode and reduces the complexity of the machine tool driving mechanism to improve the reliability of machine tools. Theoretical analysis and dual axis synchronous started experiment, dual axis slowed down to stop experiment, Synchronization precision test and Phase-shifting experiment showed that 5 grade precision Honing gear could be honing processed in designed machine tools, and could realize anticipated target.

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