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Research on Worm Helical Gear Drive Design Method based on Multipurpose Application

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Abstract:

This paper compares and analyses the worm gear pair engagement and cylindrical helical gear and worm engagement, puts forward the application by replacing the worm gear with cylindrical helical gear with smaller drive load, and analyses the advantages of the helical gear processing and assembly. Finally, illustrates the application by replacing the worm gear with helical gear with example.

Keywords: *Helical gear, Worm gear pair, Center height.*

I. INTRODUCTION

The worm gear pair retarder is a power drive mechanism, reducing the motor speed to the required speed by conversing the speed of the gear, with larger torque. It is widely applied in the mechanisms transmitting power and motion. When processing the worm gear, the special worm hobbing cutter shall be used in theory. Because there are many worm gear specifications, no special hobbing cutter in actual working, and other similar hobbing cutters would be used as substitution, such as flying knife, but such processing brings trouble. Therefore, the worm gear can be replaced by helical gear when the load of the worm gear pair is small, which facilitates the processing [1].

II. ANALYSIS OF WORM GEAR PAIR ENGAGEMENT AND HELICAL GEAR AND WORM ENGAGEMENT

When the worm and worm gear engage, the worm takes the axial modulus as the standard value, the tooth profile of the worm end face has three states, Archimedes spiral line, extended involute and involute. When the worm engages with the cylindrical helical gear, the helical gear takes the normal modulus and the normal profile angle as the standard value, so the worm takes the normal modulus and the normal profile angle as the standard value, and the tooth profile of

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the worm end face is extended involute. We usually call it Zn worm. So the helical gear is designed with the normal modulus as the standard value when the worm is replaced by helical gear [2].

Fig. 1 shows the engagement of the worm and worm gear. The worm axial pitch Px=BC=AC'=πM, the worm gear end face pitch Pt=πM, Px=Pt.

Fig. 2 shows the engagement of the worm and helical gear. The normal pitch of the helical gear Pn2=πMn, and the normal pitch of the worm Pn1=BD=AD'=πMn, and they can be engaged correctly only when Pn1=Pn2=πMn.

M Worm axial modulus (the end face modulus of the worm gear)

Mn Normal modulus

Generally, when the worm is engaged with the worm gear, the worm is limited by its diameter coefficient q, with larger change. It is not convenient to process the worm gear that is engaged with it because there is no corresponding worm gear hobbing cutter. The center distance has accurate requirement and the processed worm gear pair has high requirement for the matching spots. The center line of the worm shall coincide with the center plane of the worm gear. The smaller the △L is, the better it is (as Fig. 1) [3], otherwise it can't reach the best engagement state, which increases the engagement noise and the accelerated wearing. Therefore, the special worm gear hobbing cutter is needed when processing the worm gear. If there is no special worm gear hobbing cutter and the flying knife is used to process, the machine must have tangential tool holder, with complicated operation and low efficiency. It is not recommended to use this method to process the worm gears [4].

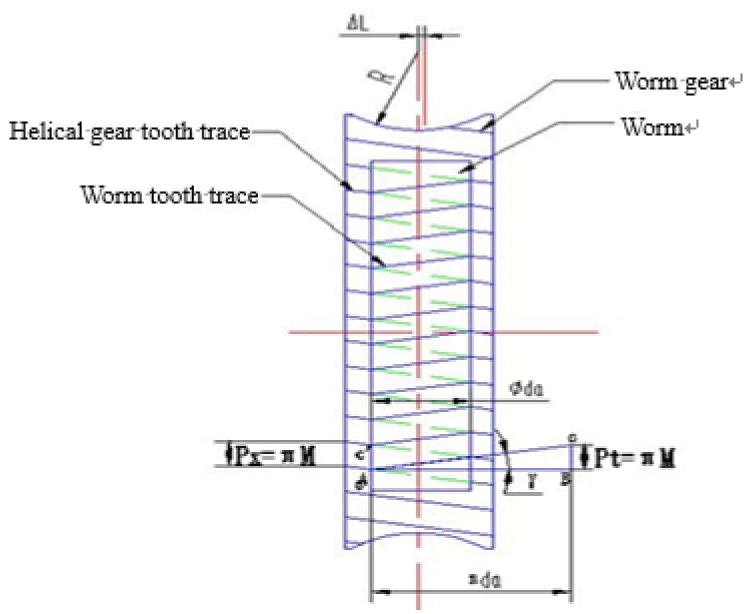

Fig 1: Worm and worm gear engagement schematic

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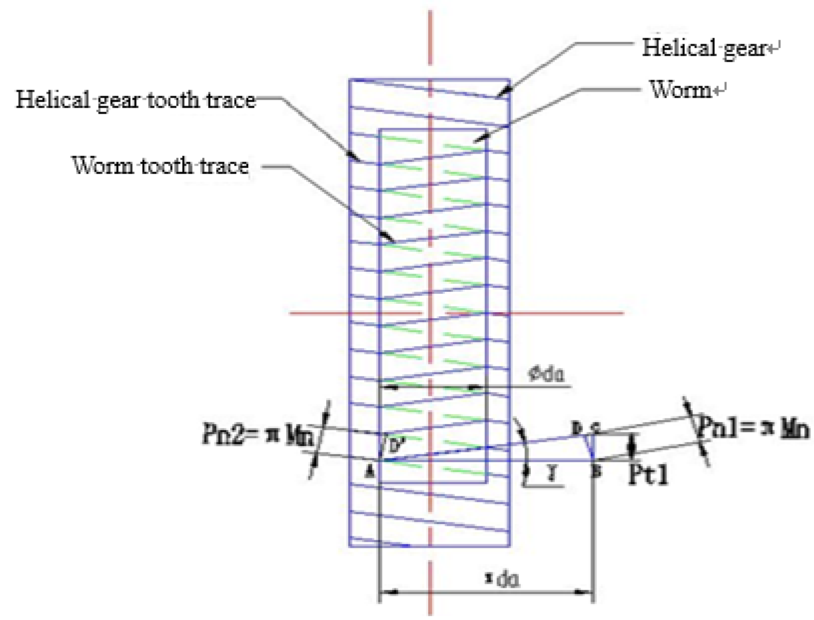

Fig 2: Worm and helical gear engagement schematic

When the worm is engaged with the helical gear, it is not limited by the worm diameter coefficient q. The center distance can be determined according to the speed ratio and stiffness. It is more convenient to process the helical gear than processing the worm gear. No special worm gear hobbing cutter is needed, and the machining of helical gear can improve the tooth surface precision with shaving and grinding, to improve the retarder precision. Besides, there is no strict requirement for the axial position of the cylindrical helical gear by the worm, and it is more convenient to install and remove the helical gear [5].

III. EXAMPLE PROVING

3.1 Worm Gear Pair Retarder State

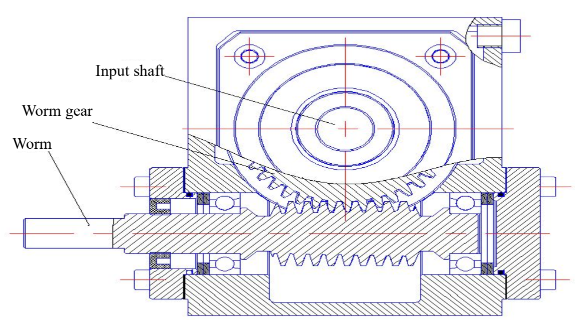

Fig 3: Worm gear pair retarder schematic

Worm gear pair retarder is the single head worm gear pair, speed ratio requirement i=40:1, center distance requirement a=44.5mm, Worm parameter is the number of teeth Z1=1, axial modulus Mt=1.65, normal pressure angle α=20°, pitch diameter d_1 =23. Precision grade

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3.2 Basic Parameters Calculation of Helical Gear Replacing Worm Gear [6]

The calculation of the engagement of the worm and the helical gear is the same as that of the general gear.

$$\mathrm{Tan}\gamma = \frac{Z_1 m_{t1}}{d_1}$$

$$m_{n1} = m_{t1} * \cos\gamma$$

$$h_{a1} = m_{t1} h_{a1}^*$$

$$d_{a1} = d_1 + 2h_{a1}$$

$$P_{n1} = \pi m_{n1}$$

$$P_{n1} = P_{n2}$$

$$P_{n2} = \pi \times m_{n2}$$

$$a = \frac{d_1}{2} + \frac{d_2}{2}$$

$$d_2 = \frac{Z_2 m_{n2}}{2\cos\beta}$$

$$h_{a2} = 2m_{n2} h_{a2}^*$$

$$d_{a2} = d_2 + 2h_{a2}$$

Where: γ is the lead angle of worm, Z_1 is the worm head number, m_{t1} is the worm axial modulus, d_1 is the worm pitch diameter, h_{a1}^* is the worm addendum coefficient, h_{a1} is the worm addendum, d_{a1} is the outside diameter of worm. m_{n1} is the worm normal modulus, P_{n1} is the worm normal tooth thickness, P_{n2} is the normal pitch of helical gear, m_{n2} is the normal modulus of helical gear, a is the center distance, d_2 is the pitch diameter of helical gear, β is spiral angle of helical gear; h_{a2}^* is the addendum coefficient of helical gear, h_{a2} is the addendum of helical gear, d_{a2} is the outside diameter of helical gear.

Calculated with the above formula, the detailed parameters of the worm are:

Z_1=1, m_{t1}=1.65, m_{n1}=1.6458, γ=4.1033°, d_1=23, d_{a1}=φ26.3 (0/-0.1), P_{n1}=5.17

Helical gear detailed parameters:

Z_2=40, β=4.1033°, m_{n2} =1.6458, d_2=φ66.001, d_{a2}=φ69.29 (0/-0.1)

3.3 Determination of the Engagement Backlash of the Cylindrical Helical Gear and Worm

The engagement backlash of the cylindrical helical gear and worm can be calculated referring to worm gear pair clearance.

3.3.1 Determination of Minimum Normal Backlash of the Cylindrical Helical Gear and Worm Drive [7]

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At normal temperature (20℃), the minimum normal backlash of the cylindrical helical gear and worm drive can be determined according to the following table, backlash category pair f $j_{n\min}$=16μm.

Table 1 Minimum normal backlash of drive jnmin value

(μm)

Center distance of drive a/mm	Backlash category							
	h	g	f	e	d	c	b	a
≤30	0	9	13	21	33	52	84	130
>30~50	0	11	16	25	39	62	100	160
>50~80	0	13	19	30	46	74	120	190
>80~120	0	15	22	35	54	87	140	220
>120~180	0	18	25	40	63	100	160	250
>180~250	0	20	29	46	72	115	185	290
>250~315	0	23	32	52	81	130	210	320
>315~400	0	25	36	57	89	140	230	360
>400~500	0	27	40	63	97	155	250	400
>500~630	0	30	44	70	110	175	280	440
>630~800	0	35	50	80	125	200	320	500
>800~1000	0	40	56	90	140	230	360	560
>1000~1250	0	46	66	105	165	260	420	660
>1250~1600	0	54	78	125	195	310	500	780
>1600~2000	0	65	92	150	230	370	600	920
>2000~2500	0	77	110	175	280	440	700	1100

Note:
1. The minimum circumferential backlash of drive jimin≈jnmin (cos γ' cos αn), where γ' is pitch cylindrical lead angle of worm, αn is normal profile angle of worm.
2. This table considers the standard temperature of 20℃, if the temperature is higher, the line expansion factor shall be considered.

3.3.2 Determination of Maximum Normal Backlash of Cylindrical Helical Gear and Worm Drive [8]

At normal temperature (20°C), the maximum normal backlash $j_{n\max}$ of the cylindrical helical gear and worm drive can be calculated in the formula below:

$$j_{n\max}=(|E_{SS1}|+T_{S1}+T_{S2}\cos\gamma')\cos\alpha_n+2\sin\alpha_n\sqrt{\frac{1}{4}F_r^2+f_a^2}$$

Where: $j_{n\max}$ Maximum normal backlash of worm pair

$|E_{SS1}|$ Absolute value of upper deviation of worm tooth thickness

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T_{s1} Worm tooth thickness tolerance

T_{s2} Helical gear tooth thickness tolerance

γ' Worm pitch cylindrical lead

α_n Normal pressure angle of worm pair

F_r Radial runout tolerance of helical gear ring

f_a Center distance limit deviation

By finding out the corresponding values and formulas in the gear manual, the calculation is as follows:

$$j_{n\min}=16\mu m,\ |E_{SS1}|=|\frac{j_{n\min}}{\cos\alpha_n}+E_{S\Delta}|=|\frac{16}{\cos 20°}+48|=62$$

T_{s1}=45, T_{s2}=90(refer to the tooth thickness tolerance of worm gear)

$$\text{Tan}\ \gamma'=\frac{Z_1}{d_1+2x_2} \Longrightarrow \gamma'=\gamma=4.1033°$$

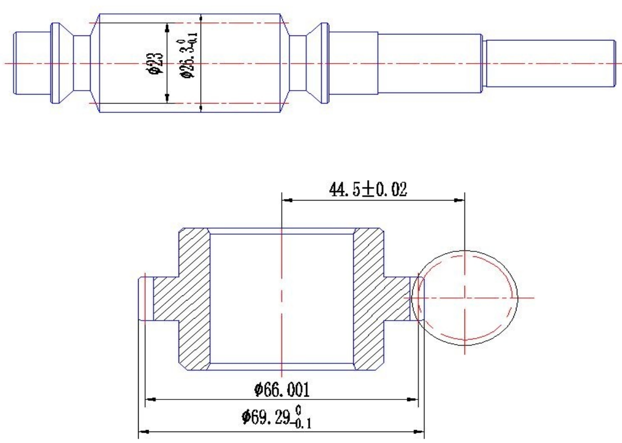
α_n=20°, F_r=40, f_a=31

$$j_{n\max}=(62+45+90\cos 4.1033)\cos 20+2\sin 20\sqrt{\frac{1}{4}40^2+31^2}=210\mu m$$

The calculated engagement backlash between the helical gear and the worm shall be between 16-210 μm.

IV. IMPLEMENTATION RESULT

The helical gear and worm with this design provides convenient assembly, besides, the worm and helical gear can engage completely without the worm aligning with the helical gear center height. It can pass the performance testing and the indicators meet the requirements, the specific results are shown in Fig. 4 below [9].



Worm type	Normal vertical profile	
Axial modulus	Mt	1.65
Normal modulus	Mn	1.6458
Worm head	Z1	1
Helical gear tooth	Z2	40
Normal pressure angle	α	20°
Pitch lead angle	γ	4.1033°
Pitch diameter of worm	d1	23
Pitch diameter of helical gear	d2	66.001
Engagement center distance	a	40.5±0.02
Engagement backslash	Jn	0.016-0.21

Fig 4: Helical gear and worm parameter schematic

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V. SUMMARY

This paper compares and analyses the worm gear pair engagement and helical gear replacing the worm gear for engaging with the worm, finds out the similarity and differences of the engagement. The processing advantages of the helical gear comparing with worm gear are listed in details, the specific parameters of helical gear replacing worm gear are listed, and the examples are given to prove how to replace the worm gear with the helical gear in more detailed calculation.

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