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The Design and Prototype Manufacture of a Planetary Gear Reducer

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Abstract

The gear reducer of the power system can be ordinary spur gear reducer, worm and worm gear reducer, or planetary gear reducer. Due to the compact size, light weight, and multi-degrees of freedom; planetary gear reducers are commonly used in various transmissions. One of its applications is used as the gear reducer for industrial purpose. The reduction ratios of 1-stage planetary gear reducers are limited to 3 ~ 10. This paper focused on the design and prototype manufacture of a 1-stage planetary gear reducer. First, according to the concept of train value equation, the planetary gear reducer with reduction ratio 4 is proposed. Based on the involute theorem, the gear data of the planetary gear reducer are obtained. Finally, based on the results of kinematic design and meshing efficiency analysis, the integrated design of the planetary gear reducer was carried out and the prototype was manufactured to verify the design theorem. The results of this paper can be used as a reference for engineers to design the gear reducers for industrial purpose.

Keywords: engineering design, planetary gear reducer, prototype manufacture, train value equation

1. Introduction

Traditionally, the reduction ratio of an ordinary spurs gear pair, worm and worm gear pair, and 1-stage planetary gear train is limited to 4~7, 10~100, and 3 ~ 10, respectively. Figs. 1 (a)-(c) show the ordinary spur gear reducer, worm and worm gear reducer, and 1-stage planetary gear reducer, respectively. Due to the reason of the compact size, light weight, and multi-degrees of freedom; planetary gear reducers are commonly used in various transmissions. One of its applications is used as the gear reducer for industrial purpose.

(a) Ordinary spur gear reducer (b) Worm and worm gear reducer (c) 1-stage planetary gear reducer

Fig. 1 Gear reducers

In the past, planetary gear trains were the subjects of intensive researches directed at kinematic analysis [1-5], kinematic design [6-13], and meshing efficiency analysis [14-19]. The purpose of this paper is to propose a planetary gear reducer with reduction ratio Rr=4 for industry purpose. The results of this paper can be used as a reference for engineers to design all kinds of planetary gear reducers. The research result can also provide the application experiences for the transmission design practice course.

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2. Train Value Equation

For a planetary gear train, shown in Fig. 2, we denoted the first sun gear as *i*, the last sun gear as *j*, and the carrier (arm) as *k*, respectively. The train circuit can be denoted as (*i*, *j*; *k*); the relationship among ω_i, ω_j, and ω_k can be expressed as:

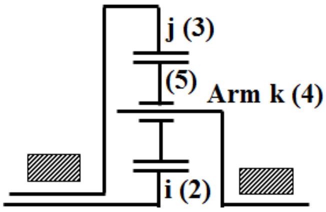

Fig. 2 Planetary gear train

$$\omega_i - \xi_{ji}\omega_j + (\xi_{ji} - 1)\omega_k = 0 \tag{1}$$

Here ξ_{ji} is the train value of sun gear *j* to sun gear *i*. The sum of the coefficients of Eq. (1) is equal to 0, i.e., $1 - \xi_{ji} + (\xi_{ji} - 1) = 0$. For a planetary gear train with the single train circuit, there are three members (*i*, *j*, and *k*) can be adjacent to input shaft, output shaft, and frame. If sun gear *j* is adjacent to the frame (ω_j=0), and sun gear *i* is adjacent to the input shaft ($\omega_i = \omega_{in}$), and carrier *k* is adjacent to the output shaft ($\omega_k = \omega_{out}$), according to Eq. (1), its reduction ratio (R_r) can be written as:

$$R_r = \frac{\omega_{in}}{\omega_{out}} = \frac{\omega_i}{\omega_k} = \frac{(\xi_{ji} - 1)}{1} = -(\xi_{ji} - 1) \tag{2}$$

For a planetary gear train with $\xi_{ji} < 0$, the reduction ratio $R_r > 1$. For the planetary gear reducer shown in Fig. 3, let Z_2=24, Z_5=24, and Z_3=72, then there is the train value ξ_{32}=-3. Since the sun gear *3* is adjacent to the frame (ω_3=0), and the sun gear *2* is adjacent to the input shaft ($\omega_2 = \omega_{in}$); the carrier *4* is adjacent to the output shaft ($\omega_4 = \omega_{out}$), according to Eq. (2), its reduction ratio R_r = 4.

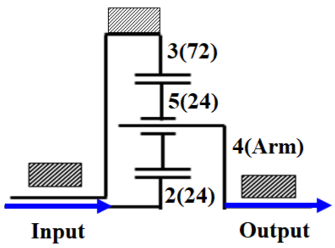

Fig. 3 Planetary gear reducer with reduction ratio R_r = 4

3. Latent Power Theorem and Meshing Efficiency

For a planetary gear train with sun gear *i*, ring gear *j*, and carrier *k*. T_i, T_j and T_k are the torques of members *i*, *j* and *k*, respectively. Since they rotate around the same axis, and according to the torque balance, we have:

$$T_i + T_j + T_k = 0 \tag{3}$$

Furthermore, the latent powers of sun gear *i* and sun gear *j* relative to carrier *k* (P_i^k and P_j^k)are defined as :

$$P_i^k = T_i \times (\omega_i - \omega_k) \tag{4}$$

$$P_j^k = T_j \times (\omega_j - \omega_k) \tag{5}$$

η_{ij}^k (η_{ji}^k) is the meshing efficiency of planetary gear train; if the latent power is transmitted from sun gear *i* (sun gear *j*) to sun gear *j* (sun gear *i*), when carrier *k* is relatively fixed. Based on the concept of latent power [14-19], the relationship between P_i^k and P_j^k can be expressed as:

$$-P_j^k = P_i^k \times \eta_{ij}^k \quad for\ P_i^k \geq 0\ and\ P_j^k \leq 0 \tag{6}$$

$$-P_i^k = P_j^k \times \eta_{ji}^k \quad for\ P_i^k \leq 0\ and\ P_j^k \geq 0 \tag{7}$$

The meshing efficiency of the planetary gear train is defined as the ratio of output power to input power, i.e.,

$$\eta_{m(PGT)} = -\frac{P_{out}}{P_{in}} \tag{8}$$

According to Eqs. (3) ~ (8), the meshing efficiency of planetary gear reducer can be expressed as follows:

$$\eta_{m(PGT)} = \frac{\left(1-\xi_{ji}\eta_{ij}^k\right)}{\left(1-\xi_{ji}\right)} \tag{9}$$

where η_{ij}^k (η_{ji}^k) is the meshing efficiency of planetary gear train; if the latent power is transmitted from sun gear *i* (sun gear *j*) to sun gear *j* (sun gear *i*) when carrier *k* is relatively fixed. The meshing efficiency of ordinary external gear pair ($\eta_{m(ex)}$) and internal gear pair($\eta_{m(in)}$) can be expressed as [20-22]:

$$\eta_{m(ex)} = 1 - \frac{1+1/R_r}{\beta_{A1}+\beta_{R1}}\left[\frac{f_a}{2}\beta_{A1}^2 + \frac{f_r}{2}\beta_{R1}^2\right] \tag{10}$$

$$\eta_{m(in)} = 1 - \frac{1-1/R_r}{\beta_{A1}+\beta_{R1}}\left[\frac{f_a}{2}\beta_{A1}^2 + \frac{f_r}{2}\beta_{R1}^2\right] \tag{11}$$

where R_r is the reduction ratio of gear pair, β_{A1} and β_{A2} are the angles of approach of driving and driven gears, f_a and f_r are the average friction coefficient of approach and recess.

For external (internal) gear pair, the meshing efficiencies are between 99.2% ~ 99.6% (99.7% ~ 99.9%). For the planetary gear reducer in Fig. 3, if the meshing efficiencies of external and internal gear pairs are 0.994 and 0.998, then the meshing efficiency of η_{ij}^k is $\eta_{ij}^k = 0.994 \times 0.998 = 0.992$. Then, according to Eq. (9), the meshing efficiency of the planetary gear reducer is 99.4%. Based on the above results, we concluded that the meshing efficiencies of planetary gear reducers are very good.

4. Engineering Design and Prototype

In the following paragraph, the planetary gear reducer, shown in Fig. 3, is the example to illustrate how to design the planetary gear reducer. Table 1 shows some important gear data of this feasible design example.

Table 1 Gear data of the planetary gear reducer shown in Fig. 3

	External gear pair (2, 5)		Internal gear pair (5, 3)
	Sun gear 2	Planet gear 5	Ring gear 3
Teeth Number	24	24	72
Normal module (mm)	1.25	1.25	1.25
Helical Angle	0^0	0^0	0^0
Shift Coefficient	**0**	**0**	**0.3**
Pitch Dia (mm)	30	30	90
Addendum Dia. (mm)	32.5	32.5	88.25
Base Dia. (mm)	28.19078	28.19078	84.57234
Center Distance (mm)	**30.2**		**30.2**
Pressure Angle (deg.)	21D 1M 4S		21D 1M 4S
Contact Ratio (**Approach/ Recess**)	1.44721 (0.72361 / 0.72361)		1.71049 (0.98689 / 0.72361)

According to the gear data in Table 1, the engineering design drawings shown in Figs. 4(a), 4(b), 4(c),and 4(d) are sun gear 2 (Z_2=24), planet gear 5 (Z_5=24), ring gear 3 (Z_3=72), and planetary gear set of planetary gear reducer. Figs. 4(e) and 4(f) show its corresponding 1/2 Section view and isometric view.

(a) Sun gear (Z_2=24) (b) planet gear (Z_5=24) (c) rnig gear (Z_3=72)

(d) planetary gear set (e) sectional view (f) isogonal view

Fig. 4 Engineering drawing of planetary gear reducer

Figs. 5(a), 5(b), 5(c), and 5(d) show the corresponding prototype photo of sun gear 2 (Z_2=24), planet gear 5 (Z_5=24), ring gear 3 (Z_3=72), and planetary gear set of planetary gear reducer. Figs. 5(e) and 5(f) show its corresponding prototype photo of 1/2 Section view and isometric view.

(a) Sun gear (Z_2=24) (b) Planet gear (Z_5=24) (c) Rnig gear (Z_3=72)

(d) Planetary gear set (e) Sectional view (f) Isogonal view

Fig. 5 Prototype photos of planetary gear reducer

5. Conclusions

The reduction ratios of 1-stage planetary gear reducers are limited to 3 ~ 10. This paper focuses on the integrated design and prototype manufacture of the planetary gear reducer (with reduction ratio R_r=4) for industry purpose. According to the kinematic design, a planetary gear reducer with R_r=4 is synthesized. According to the latent power theorem, its corresponding meshing efficiency is calculated to be 99. 4%. Finally, the engineering design of the planetary gear reducer is accomplished and its corresponding prototype is manufactured to verify the design theorem. The results of this paper can be used as reference for engineering to design the gear reducer for industrial purpose and will enhance the competitiveness of gear industrial.

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Conflicts of Interest

The authors declare no conflict of interest.

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