Hydraulic motor with swinging planetary drive of bevel gears and its force & efficiency calculation

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Abstract: A new kind of hydraulic motor with offset swining planetary drive of bevel gears and the application in Capstan is presented; the researched of the calculation of the efficiency of the mechanism is made. Compared to the former structure, new kind of structure has many advantages over that of the old structure. The hydraulic driving system in the traditional derrick car is: hydraulic motor drives a reducer, and then the reducer in turn drives a capstan. Another hydraulic driving system is: an axial piston motor and an internal cycloid pinwheel drive are applied, so that the reducer and the capstan are combined into one so that simplified the transmission system. In the third version, a hydraulic motor is applied, which can be considered as the combination of hydraulic motor with axial piston and the planetary reducer and then drives the capstan, so that simplified the transmission system as well. The new kind of hydraulic motor with offset swing planetary drive of bevel gears, which combined the hydraulic motor, the internal planetary reducer with bevel gears, and the capstan together, is the most compact structure. It is of more advantage in the occasion when space is extremely limited. In the paper, two kind of construction of this mechanism is presented, and the analysis of the efficiency of this kind of transmission is made as well.

Keywords: Hydraulic Motor, Planetary Drive of Bevel Gears, Capstan

1 Introduction

This paper present a new kind of hydraulic motor with offset swing planetary drive of bevel gears and the application in Capstan, and researched the calculation of the efficiency of the mechanism. Compared to the former structure, new kind of structure has many advantages over that of the old structure. The hydraulic driving system in the traditional derrick car is: hydraulic motor drives a reducer, and then the reducer in turn drives a capstan [1, 2, 3]. Another hydraulic driving system is: an axial piston motor and an internal cycloid pinwheel drive are applied, so that the reducer and the capstan are combined into one so that simplified the transmission system [4,5]. In the third version, a hydraulic motor is applied, which can be considered as the combination of hydraulic motor with axial piston and the planetary reducer and then drives the capstan, so that simplified the transmission system as well. The new kind of hydraulic motor with offset swing planetary drive of bevel gears, which combined the hydraulic motor, the internal planetary reducer with bevel gears, and the capstan together, is the most compact structure. It is of more advantage in the occasion when space is extremely limited. In the paper, two kind of construction of this mechanism is presented, and the analysis of the efficiency of this kind of transmission is made as well. The authors are to emphasize the relevance work to the mechanism rather than just introducing a hydraulic motor.

2 The structure of the hydraulic motor with offset swinging planetary drive of bevel gears

As showed in fig.1 Z_1 and W_2 formed the internal bevel gearing, Z_1 =47, Z_2=48, Z_3 and Z_4 formed the periphery constraint pair, $Z_3 = Z_4 = 84$, Z_1 and Z_3 are fixed with each other, and driven by the spindles through the linkages. The spindles are periphery spaced evenly on the hydraulic cylinder. So that Z_3 would make pure rolling along the pith taper of the fixed bevel gear and swinging. In practice it is the revolving about a fixed point of the tip of the pith taper. Since Z_1 and Z_2 formed the gearing with few teeth difference, Z_2 would rotate in opposite direction at low velocity. Z_2 was installed on the skew axis 5. The offset swinging of Z_2 and Z_3 would make skew axis 5 to rotate, in turn, drive the cylinder distributor 4 to rotate as well, so as to realize the distribution of liquid and, through the spindle and linkages, made the internal bevel gear Z_1 to swing circulatory. The driver is Z_1 the driven member is Z_2 and skew axis 5 is equivalent to carrier H. [1,2,3].

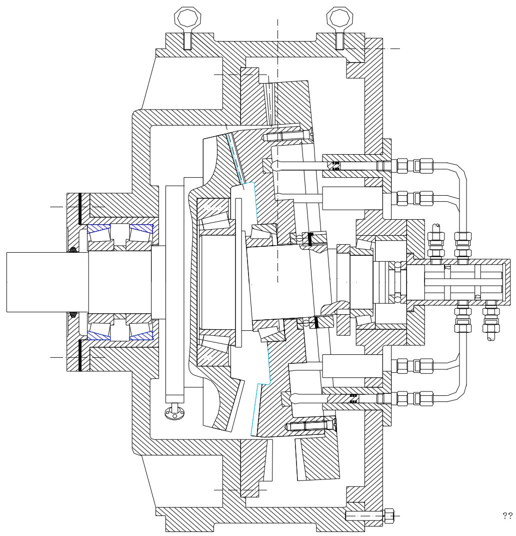


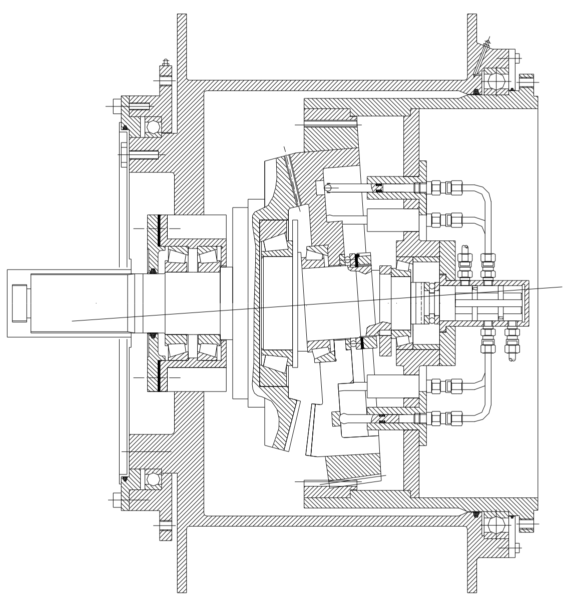
Fig.1 Hydraulic motor planetary drive of bevel gears

Z_1 and Z_2 formed the internal bevel gearing

Z_3 and Z_4 formed the periphery constraint pair

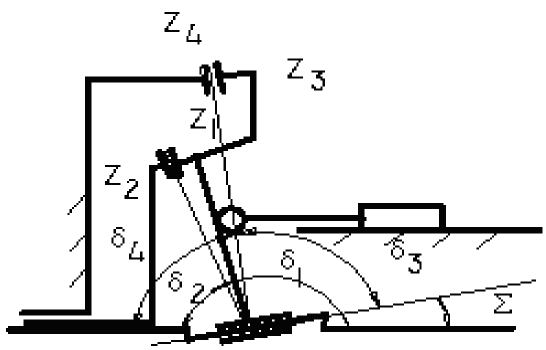
Z_1 and Z_3 are fixed with each other, and driven by the spindles through the linkages.

3 The application of hydraulic motor in capstan



a) One of the new designs

The output spindle drives the capstan.



b) Simplified sketch

Fig.2 Hydraulic motor of planetary drive of bevel gears and the application in capstan

4 The invention of the with offset swinging planetary drive of bevel gears

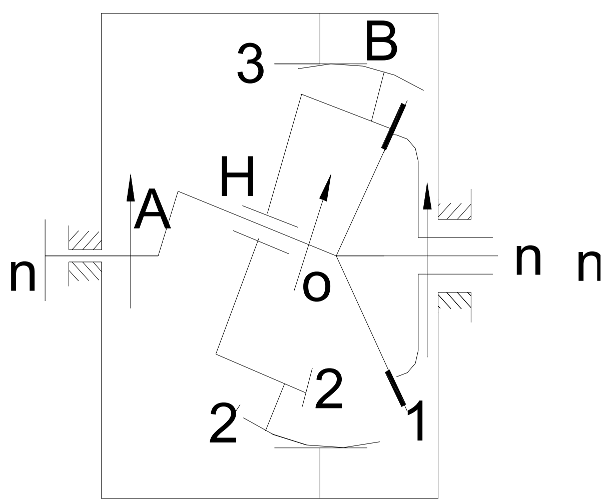


Fig3 The offset planetary drive of Bevel gear

The mechanic principal graph is shown in Fig.3, the gear 1 rotate about its fixed axis, the gear 2 swinging about the fixed point O, is corresponded to the planetary gear .The output axis H correspond to the carrier, it forced the axis of gear 2 OA rotate about the centre line nn of the reducer. It's angular velocity is ω_H, and gear 2 rotate relative to H, the velocity is ω_2^H , since there are few tooth difference between two gears, and the periphery-constraint-pair[6,7,8,9] B constrained the gear 2 to rotate about nn, if the input axis rotate in velocity ω_H, the gear 1 would rotate at low velocity ω_1 and in reverse direction, if the whole mechanic was given a reverse velocity $-\omega_H$, it would become a transformed mechanic with carrier fixed, the ratio of transform mechanic is:

$$i_{13}^{H}=\frac{\omega_1^H}{\omega_3^H}=\frac{z_2}{z_1}\ \frac{z_3}{z_2^{'}}\ =\frac{z_2}{z_1}\qquad (z_3=z_2^{'}) \qquad (1)$$

To find the rotation direction of gear 1 relate to gear 3, we must use method of “arrow drawing “ ,as shown in Fig.1,Let the arrow of gear 1 up word (represent the direction of the periphery velocity).Since gear 1 and gear 2 are internal meshing with each other, the direction of arrow’s should both point to the pitch point, so that the direction of arrow of gear 2 also upward. Gear 2 and gear 3 being the periphery constraint pairs, the direction of arrows should both point to the pitch as well. There for, the rotate direction of gear 1 is the same as that of gear 3.The ratio of transformed mechanic is positive.

$$i_{13}^{H}=\ \frac{\omega_1-\omega_H}{0-\omega_H}=-\frac{\omega_1}{\omega_H}+1$$

$$\frac{\omega_1}{\omega_H}=i_{1H}=1-i_{13}^{H}=1-\frac{z_2}{z_1}=\frac{z_1-z_2}{z_1}\quad <0$$

$$i_{H1}=\frac{\omega_H}{\omega_1}=\frac{z_1}{z_1-z_2}<0 \qquad (2)$$

Because z_1-z_2 is very small, ordinary equal 1, $i_{H1}$is very large .The rotation is in the opposite direction.
The inversion of the offset planetary drive

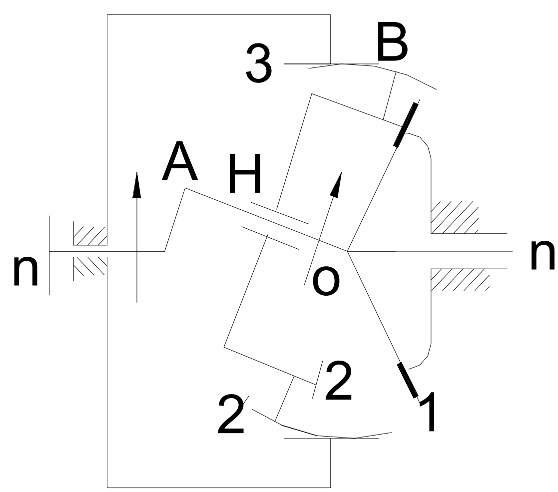


Fig4 The inversion of the offset planetary drive

If the gear 1 in the reducer was fixed, while let the gear 3 to rotate and power, as shown in Fig.4, it became a new kind of swinging bevel gear with few tooth difference reducer. The transformed mechanic of this kind is the same as what mentioned in section 2.The ratio of transformed mechanic is

$$i_{31}^{H}=\ \frac{\omega_3-\omega_H}{0-\omega_H}=\ \frac{z_1}{z_2}=-\frac{\omega_3}{\omega_H}+1$$

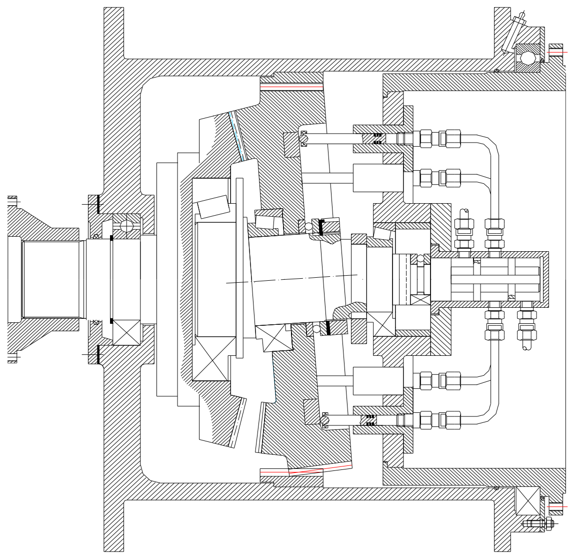
$$i_{3H}=1-\frac{z_1}{z_2}\ =\frac{z_2-z_1}{z_2}\quad >0$$

$$i_{H3}=\ \frac{z_2}{z_2-z_1}\quad >0 \qquad (3)$$

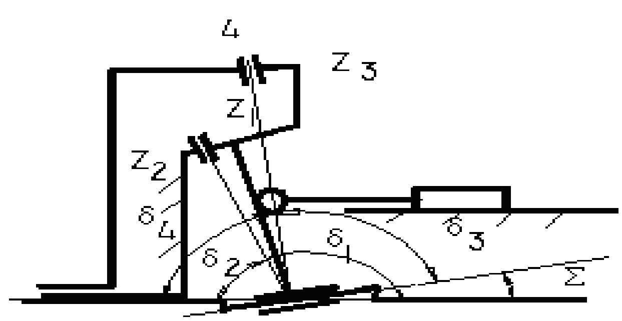
As mentioned before, since z_2-z_1 is small ,so that i_{H3} is very large ,the direction of output and input are the same .Compare Equ.(2) and Equ.(3) we can find that the ratio of new kind reducer is slightly larger than that of the former reducer.[10,11]

5 The new kind of hydraulic motor with offset swinging planetary drive of bevel gears

As showed in fig.5, is the new kind of hydraulic motor with swinging bevel gear, in which the gear Z_2 is fixed, while the Z_4 can revolve as the out put member, which is the fixed frame in the former structure. There we used the inversion principle of the offset swinging planetary drive of bevel gears.



a) Another new design
The outside cover can rotate about its axis.



b) Simplified sketch

Fig.5 New kind of hydraulic motor planetary drive of bevel gears

6 The application of new kind hydraulic motor in capstan

The hydraulic driving system in the traditional derrick car is: hydraulic motor drives a reducer, and then the reducer in turn drives a capstan. As showed in Table 1

Another hydraulic driving system is: an axial piston motor and an internal cycloid pinwheel drive are applied, so that the reducer and the capstan are combined into one, as showed in Table 1, so that simplified the transmission system.

In the third version, a hydraulic motor is applied, which can be considered as the combination of hydraulic motor with axial piston and the planetary reducer, as showed in Table 1,and Then drives the capstan, so that simplified the transmission system as well.

The new kind of hydraulic motor with offset swing planetary drive of bevel gears, which combined the hydraulic motor, the internal planetary reducer with bevel gears, and the capstan together, as showed in Table 1, is the most compact structure. It is of more advantage in the occasion when space is extremely limited.

Table 1 the contrast of the transmission systems

Traditional: capstan ------ reducer---------- hydraulic motor

Apply hydraulic motor: capstan ------- (reducer+ hydraulic motor)

Apply cycloid pin driver: (capstan+ reducer) ----------- hydraulic motor

Apply new kind hydraulic motor: (capstan + reducer+ hydraulic motor)

7 Kinematical analyses

The vector $\omega_H, \omega_4, \omega_4^H$ and ω_2^H is parallel to the fixed axis, ω_3^H coincide with the skew axis. ω_3 Along the generating line of the pitch cone of Z_2, all the vectors formed the velocity polygon as showed in Fig.6. From the triangle we can get:

$$AC = \omega_{H3},\ AB = \omega_{H4},$$
$$CD = \omega_3,\ BD = \omega_4$$
$$AD = \omega_H,\ BC = \omega_{34}$$

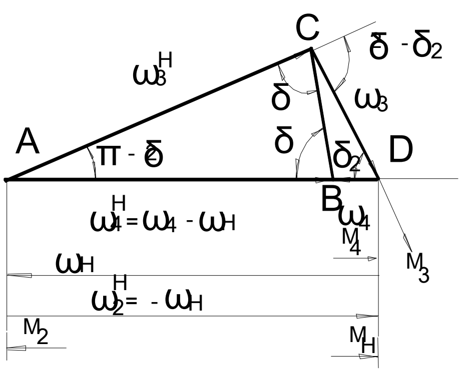


Fig.6 Kinematical analysis

Because of the periphery constraint pair, we have:

$$\omega_3^H = \omega_4^H, \tag{4}$$
$$\angle ABC = \angle ACB \tag{5}$$

Since: $\delta_3 = \delta_4 = \delta$

$$\angle CAB = \pi - 2\delta \tag{6}$$

$$\angle BDC = \delta_2 \tag{7}$$

$$\angle BCD = \pi - (\pi - \delta) = \delta \tag{8}$$

$$\delta_2 = \delta - \delta_2 \tag{9}$$

Because of the installation condition of the bevel gear:

$$\delta_1 + \delta_2 = \delta_3 + \delta_4 \tag{10}$$

From the Sine Law, there are following relationships between the angular velocities:

$$\frac{\omega_4}{\sin(\delta - \delta_2)} = \frac{\omega_3}{\sin(\pi - \delta)} \tag{11}$$

$$\frac{\omega_H}{\sin(2\delta - \delta_2)} = \frac{\omega_3}{\sin(\pi - 2\delta)} \tag{12}$$

There are following relationships between the relative angular velocities:

$$\omega_3^H = \omega_4^H \tag{13}$$

$$\omega_2^H = -\omega_H \tag{14}$$

8 Efficiency analyses when carrier output power

Suppose that the driving torque M_3 is acted on the gear Z_3. The input power is

$$N_3 = M_3\omega_3 \tag{16}$$

In the converted mechanism, the input power:

$$N_3^H = M_3\omega_3^H + M_3\omega_3\cos(2\delta - \delta_2) \tag{17}$$

The lost power by friction of the converted mechanism:

$$N_f = N_3^H(1 - \eta_0) \tag{18}$$

The efficiency of the practical mechanism:

$$\eta = \frac{(N_3 - N_f)}{N_3} = 1 - \frac{\omega_3^H \cos(2\delta - \delta_2)(1 - \eta)}{\omega_3} \tag{19}$$

$$M_3\omega_3^H = 2\delta - \delta_2 \tag{20}$$

From triangle ACD

$$\frac{\omega_3^H}{\sin\delta} = \frac{\omega_3}{\sin(\pi - 2\delta)} \tag{21}$$

The method of determinant: Since H is the output member its torque and angular velocity must be in the opposite direction. M_H is to right, M_2 to the left. So that we can write down the torque equilibrium equation, the power equilibrium equation of the converted mechanism, and the power equilibrium equation as following:

$$M_3\cos\delta - M_2 + M_H = 0 \tag{22}$$

$$M_3\omega_3^H\cos(2\delta - \delta_2)\eta_0 - M_2\omega\omega_2^H = 0 \tag{23}$$

$$M_3\omega_3\eta - M_H\omega_H = 0 \tag{24}$$

By letting the determinant of the equations above equals to zero. We can get:

$$\eta = \frac{\omega_2^H\omega_H\cos\delta_2 - \omega_3^H\eta_0\cos(2\delta - \delta_2)}{\omega_3\omega_2^H} \tag{25}$$

9 Efficiency analyses when capstan output power

Since that Z_4 is the driven member, its torque must be in the opposite direction with its angular velocity, M_4 points to right. So that we can write down the torque equilibrium equation and the power equilibrium equation as following:

$$M_3 \cos\delta_2 - M_4 - M_2 = 0 \tag{26}$$

$$M_3 \omega_3 \eta - M_4 \omega_4 = 0 \tag{27}$$

In the converted mechanism, ω_4^H and M_4 are in the same direction, the power is of positive value, while ω_2^H and M_2 are in the opposite direction. So that, in the converted mechanism, the power flux is from Z_4 to Z_3, and than joint with N_3^H , and finally output at $Z_{2.}$, as showed in the fig2. The power equilibrium equation of the converted mechanism:

$$- M_2 \omega_2^H + M_3^H \omega_H \eta + M_4^H \omega_H \eta = 0 \tag{28}$$

By letting the determinant of the equations （12-14） equals to zero. We can get:

$$\eta = \frac{\omega_4 (\omega_3^H \eta_0 - \omega_2^H \cos\delta_2)}{\omega_3 (\omega_2^H - \omega_4^H \eta_0)} \tag{29}$$

10 Conclusion

The new kind of hydraulic motor with offset swing planetary drive of bevel gears, which combined the hydraulic motor, the internal planetary reducer with bevel gears, and the capstan together, is the most compact structure. It is of more advantage in the occasion when space is extremely limited.

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