7.3 Worm, worm wheel and worm gear pair

Controllable condition

In order to realize the correct meshing condition of controllable point contact cylindrical gear pair, the relation between worm and the geometrical parameter of cutter must be in control. The relation is called controllable condition. At the moment, the adopted contact condition is: the diameter of cutter d_0 is larger than the diameter of worm d_1; multi-head cutter is replaced by single cutter, which is $z_0 < z_1$; the lead angle of cutter r_0 is larger than the lead angle of worm r_1. Now the controllable condition is:

$$m_{x0}\, z_0 / m_{x1}\, z_1 = d_0 tg\, r_0 / d_1 tg\, r_1$$

$$m_{x1} / m_{x0} = \cos r_0 / \cos r_1$$

$$tga_{x1} / tga_{xo} = \cos r_0 / \cos r_1$$

$$a_0 = a + \frac{1}{2}(d_0 - d_1)$$

$\in$ =The $|r_0 - r_1| = |\Delta r_0|$ the moving angle of cutter axial line

The auxiliary condition of ZC worm is $p_{n1} = p_{n0}$

Cylindrical worm gear pair with controllable point contact

In order to make cylindrical worm gear pair with point contact, the geometrical parameter and size of tool need to be given based on the purpose and under the limit of the correct meshing condition of worm gear pair when processing worm wheel with indirect generating method. Cylindrical worm gear pair with point contact designed based on this principle is called cylindrical worm gear pair with controllable point contact. The given purpose mainly refers to: “realizing artificial fuel tank” and “optimal meshing figure”.

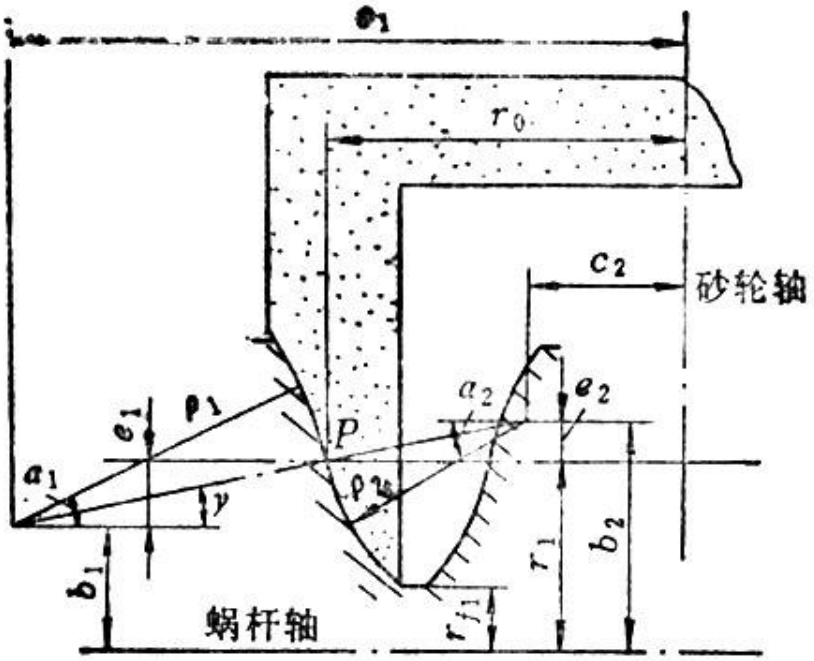
End face toroid enveloping cylindrical worm

It is put forward by a Chinese professor, An Zhaoda,. It is concave cylindrical worm formed by end face (single or double circular arc) toroid enveloping surface. (Figure 7-29 shows double circular arc tooth profile). It belongs to enveloping curved-profile cylindrical worm. When processing worm with grinding wheel (or hobbing), the center distance a_0 of grinding wheel axial line and the axial line of worm stays unchanged, the axial angle is $\Sigma = 90^\circ$.As there is fixed position for the

diamond center of gyration of grinding wheel dressing, one only need to move axially the grinding wheel when dressing it and there is no need to adjust the corrector. In this way, the consistence of tooth profile and its position can be acquired. The correction workmanship of grinding wheel is good and extends its service life. Therefore, this kind of worm has simple workmanship, precise tooth profile and it is easy to promote.

End face toroid enveloping cylindrical worm gear pair

It consists of End face toroid enveloping cylindrical worm and matched worm wheel manufactured under direct or indirect generating method. It represents line (or point) contact. The meshing features are basically the same to ZC_1 worm. But currently, it is rarely used and need further study.


e_1
r_0
c_2
砂轮轴
a_2
e_2
e_1
ρ_1
P
a_1
ρ_2
γ
r_1
b_2
b_1
蜗杆轴
r_{f1}

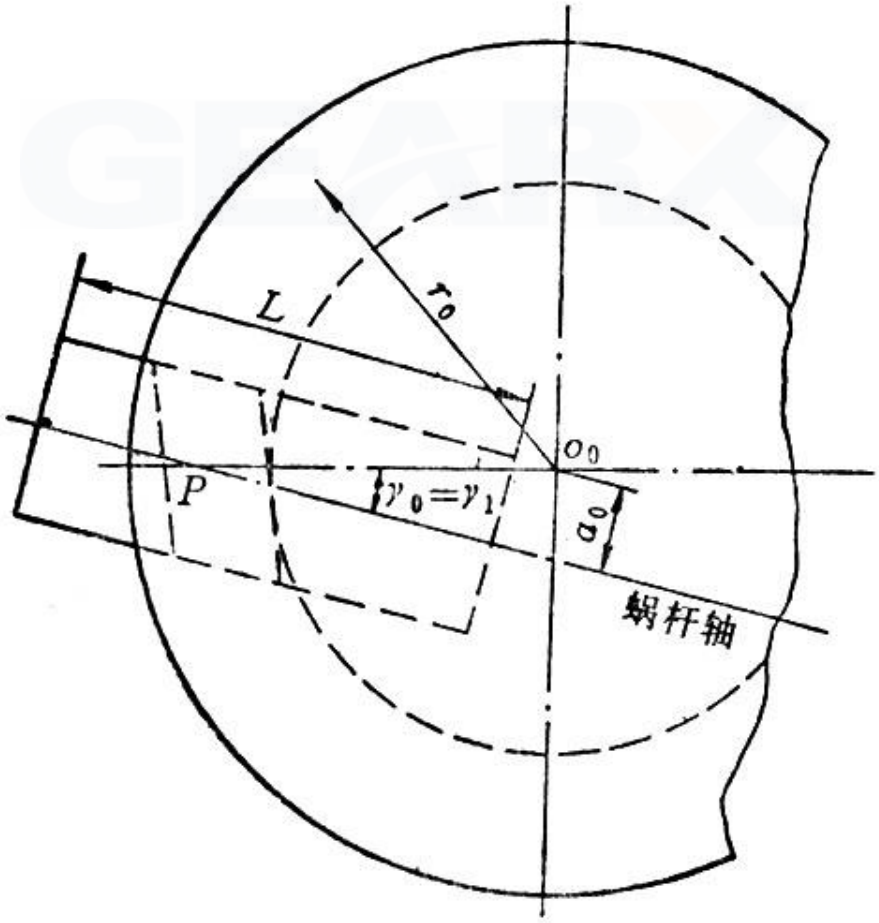

L
r_0
o_0
P
$\gamma_0=\gamma_1$
a_0
蜗杆轴

图 7-29

Double circular arc tooth cylindrical gear pair

It is Former Soviet Union C.B. Shavchenko that put forward a new type of circular arc cylindrical worm gear pair based on ZC_3 worm gear pair (adopt convex-concave common tangent tooth profile). In reference [6], sectional type tooth profiles with hobbing and lathe tool that have different tooth profile are raised for the first time (Figure 7-30a, b). This kind of worm gear pair belongs to enveloping curved-profile cylindrical worm gear pair. The worm presents convex-concave double circular-arc tooth profile in the axial plane, while the worm wheel is manufactured with direct generating method. It has good contact characteristics: it fully uses the contact feature of worm convex circular arc tooth profile; the joint use of convex and concave tooth profile effectively benefit from the large deflection; it avoids the undercutting of worm wheel and the tipping of tooth top; the shape of contact line is good for the formation of dynamic pressure oil film; sectional type tooth profile avoids weak zone (Figure 7-30c) contact; the available small value of circular arc radius fully develop the merits of circular arc tooth profile; but the workmanship of worm and hobbing is poor, and it is hard to abrade the worm.

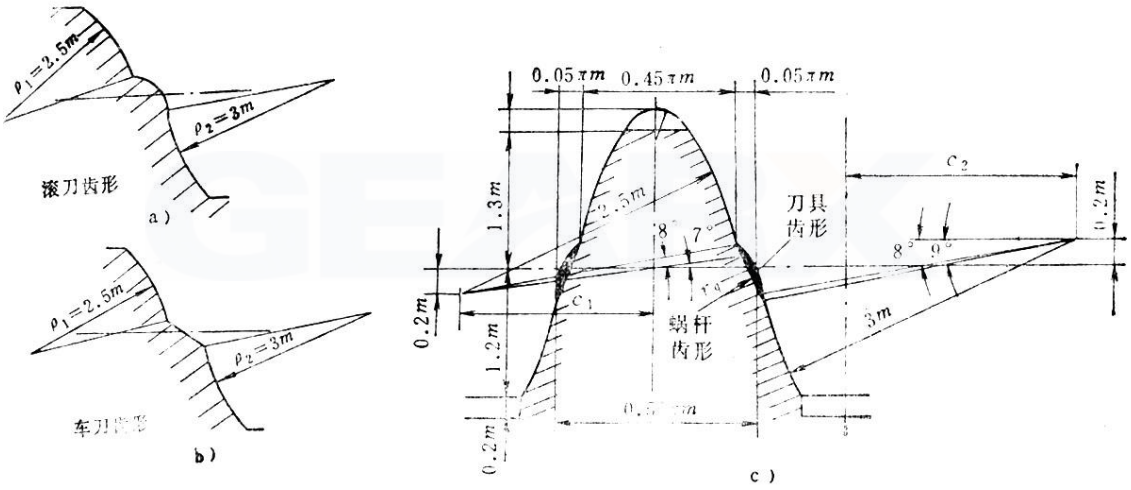


图 7-30

End face double toroid enveloping cylindrical worm gear pair

It is a new kind of cylindrical worm gear pair put forward by An Zhaoda. The worm is enveloped by end face toroid grinding wheel and there is a fixed center distance a0 between the axial line of grinding wheel and worm, the axial angle is $\Sigma = 90^{\circ}$.The grinding wheel dressing process when processing worm is easy as well as convenient, with which one can manufacture hard tooth surface worm with high precision. The worm is processed under direct generating method. The composed worm gear pair has good meshing characteristics; the shape of contact line do favor to the formation of dynamic pressure oil film. Both the bearing capacity and transmission efficiency are relatively high. But until now, there is no theoretical analysis on its application in production. Therefore, further study is needed to figure

out its better use.

Offset cylindrical gear pair

Offset cylindrical gear pair is a kind of hyperboloid gear pair. The pinion of this kind of gear pair is a helical cylindrical (spiral) gear and the matched bull gear is an end face gear. The two gears are installed offset. Offset cylindrical gear pair is a special case (Figure 7-31).

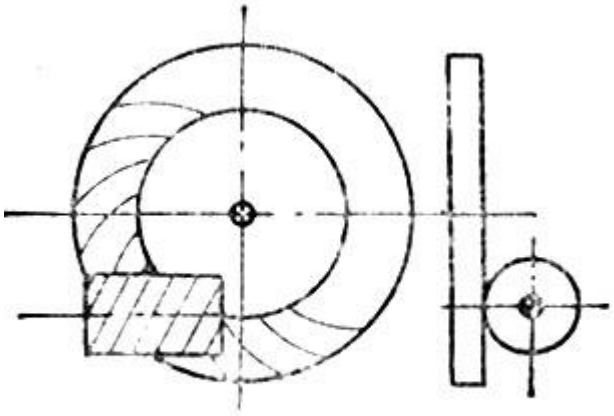
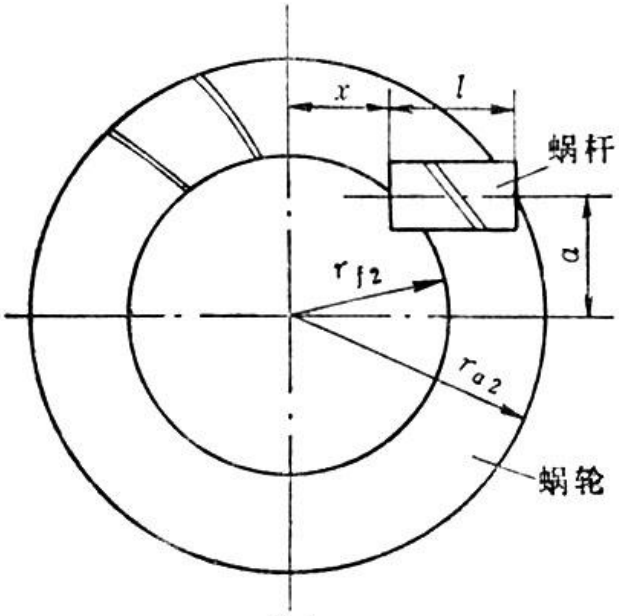


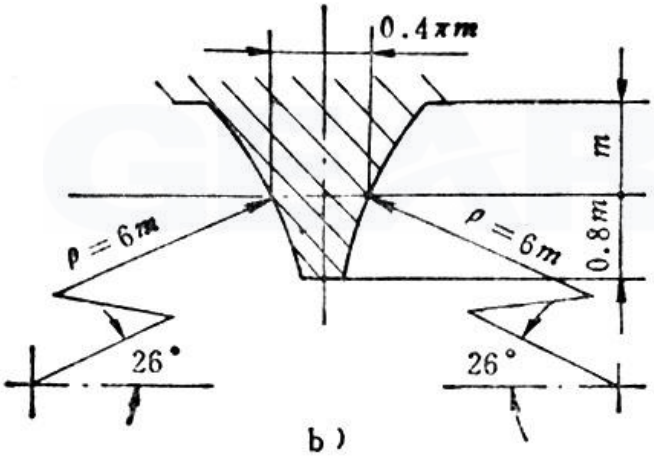
图 7-31

Curved tooth offset cylindrical worm gear pair

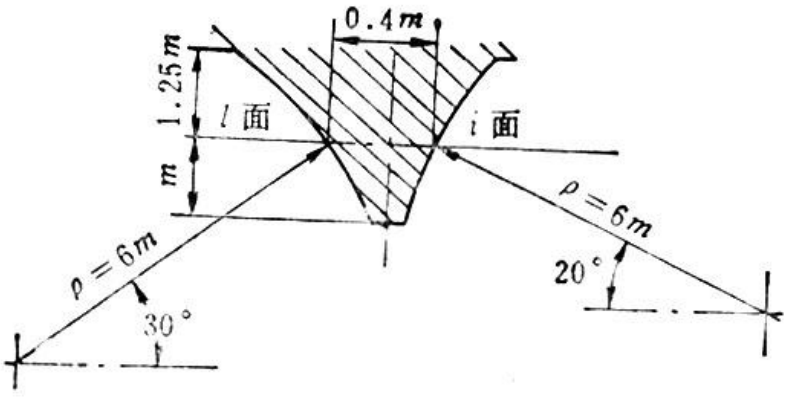
Curved tooth offset cylindrical worm gear pair is composed of cylindrical worm with curved tooth profile and its matched transverse worm wheel (Figure 7-32a). Currently, the curved tooth profile of worm is mostly using C and C3 (Figure 7-32b, c) and the worm wheel is manufactured under direct generating method. It has the general characters of offset worm gear pair.


x
l
蜗杆
a
r_{f2}
r_{a2}
蜗轮

a)


0.4πm
m
0.8m
ρ=6m
ρ=6m
26°
26°

b)


0.4m
1.25m
m
l面
i面
ρ=6m
ρ=6m
30°
20°

c)

图 7-32

Taking offset cylindrical worm gear pair of C_3 tooth profile as an example, its features are: good contact line shape which is better for the formation of dynamic pressure oil film; the induced radius of curvature is big, and there are lots of meshed tooth number; it had good workmanship and can worm smoothly with little noise and large bearing capacity and high transmission efficiency. Compared with ZC worm gear pair, it can improve the bearing capacity for 60%— 150%, and its transmission efficiency 10%; compared with ZA worm gear pair, its bearing capacity can improve 200%～300%, and its efficiency 15%～20%. The deficiency of this kind of worm gear pair is that undercutting occurs easily and the meshing characters and installation position is not symmetrical. Big pressure angle or asymmetry tooth profile must be applied to avoid undercutting problems.

Circular arc tooth offset cylindrical gear pair

Details can be seen from “curved tooth offset cylindrical worm gear pair”.

Rolling friction worm gear pair

Rolling friction worm gear pair refers to worm gear pair replacing sliding friction with rolling friction between worm and the conjugate tooth surface of worm wheel. There are many kinds of worm gear pair. The most commonly used are cycled ball bearing cylindrical gear pair and bowl toroid worm gear pair.

For this kind of worm gear pair, the complete line contact has been replaced by point contact between its tooth surfaces. And in real work practice, it becomes intermittent elliptical contact after the elastic deformation of tooth surface. Generally, the friction coefficient exists between “conjugate” tooth surface is small, with high transmission efficiency, smooth working condition and small noise; but it has complicated structure, relatively poor workmanship and high cost.

Roll ball double enveloping worm gear pair

It is composed of enveloping worm and its matched worm wheel taking precise roll ball as gear tooth (Figure 7-33). This kind of worm gear pair has high precision that can serve as dividing worm wheel; it has large overlap ratio with many meshed tooth number; the friction coefficient is small and the transmission efficiency is high; the workmanship is better than common enveloping worm gear pair; it has large radial force in operation; oil film cannot form easily on the tooth surface and the lubrication condition is poor.

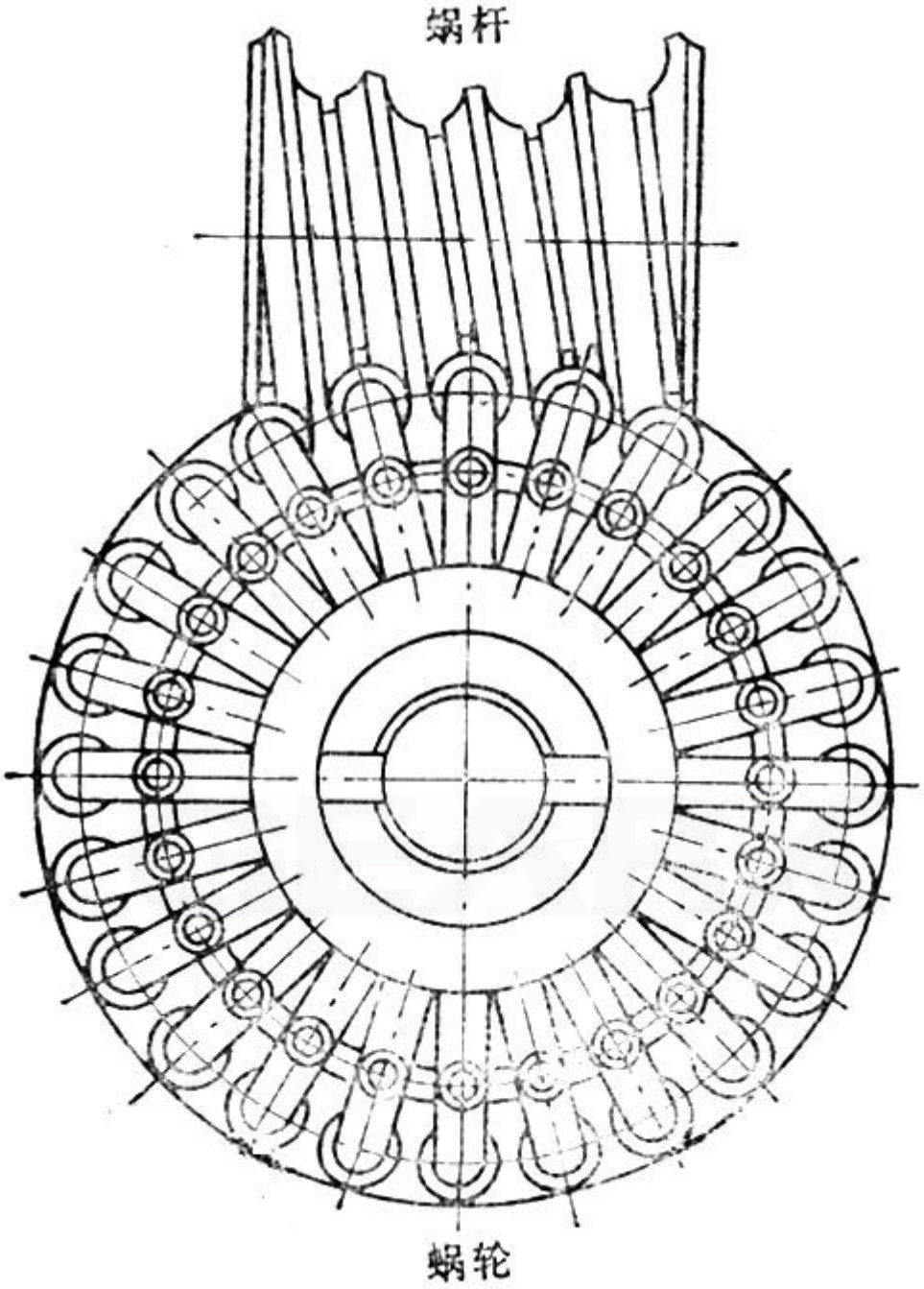


图 7-33

Circulate roll ball cylindrical worm gear pair

Cylindrical worm helical surface is replaced by circulate arranged roll ball. It can compose worm wheel pair with matched worm wheel (Figure 7-34). It can be classified into single type, double-end type and multi-thread worm. The figure shows single circular cylindrical worm gear pair. When the worm is rotating, the roll ball rolls in the spiral chute, moving in circulation and pushing the operation of worm wheel. This whole process is called meshing movement of worm gear pair. This kind

of worm gear pair has small friction factor between their tooth surfaces, high transmission efficiency, but the structure is complicated and cost high.

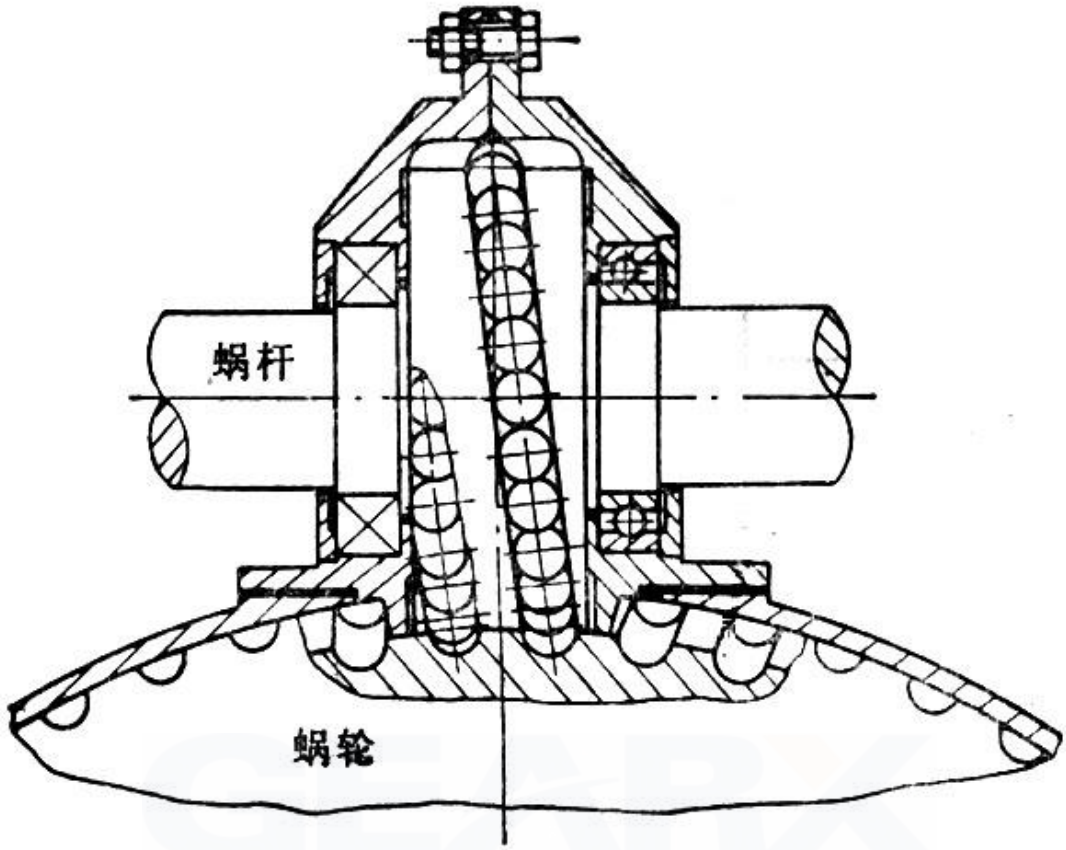
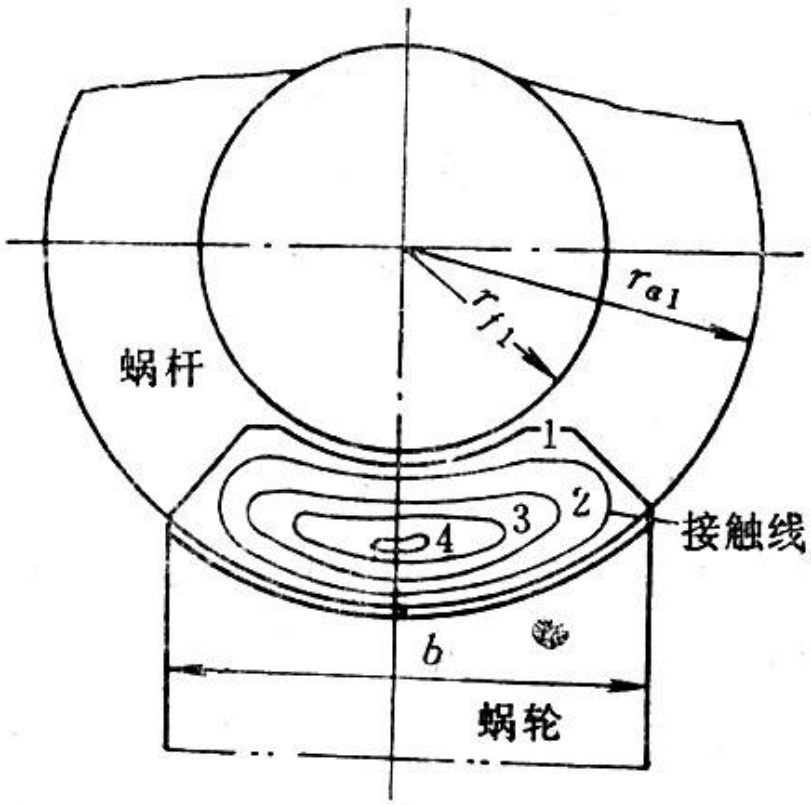


图 7-34

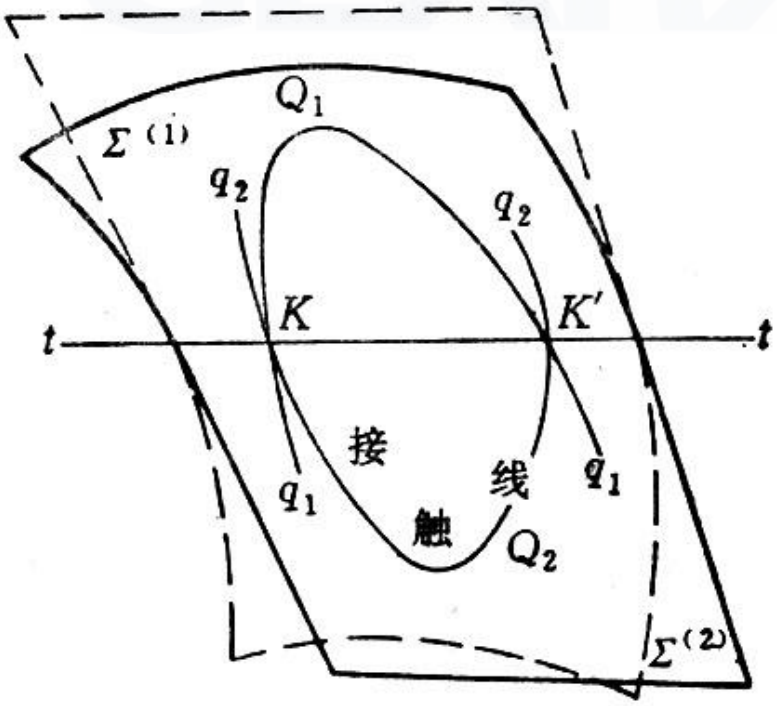
Enclosed type line contact cylindrical worm gear pair

Enclosed type line contact cylindrical worm gear pair is composed of cylindrical worm with specific tooth profile and its matched worm wheel. The features: with specific tooth profile, the worm gear pair presents enclosed type contact line (Figure 7-35a, b). During the engagement process, the enclosed contact line of worm gear pair gradually shrink and get off meshing when it becomes line contact. As shown in Figure a, the contact line is 1, and the slipping order is from 1 to 4 (Figure 7-35a); the area surrounded by the enclosed line forms an “oil pocket”. The meshing process is a shrinkage process of “oil pocket” as well as oil pressure formation. Therefore, the formation of the enclosed contact line is better for improving the dynamic pressure lubrication condition of conjugate tooth surface. Enclosed type line contact cylindrical gear pair has good workmanship, large bearing capacity and small noise.

Figure b shows the condition for forming enclosed type contact line of conjugate tooth surface.



a)



b)

图 7-35

Double-transmission

Making use of the basic principle of second contact, double worm gear pair can be designed by meshing one worm with two worm wheels. This kind of transmission type can improve the bearing capacity and transmission efficiency. Besides, it can also be designed into speed-dividing system (Figure 7-36).

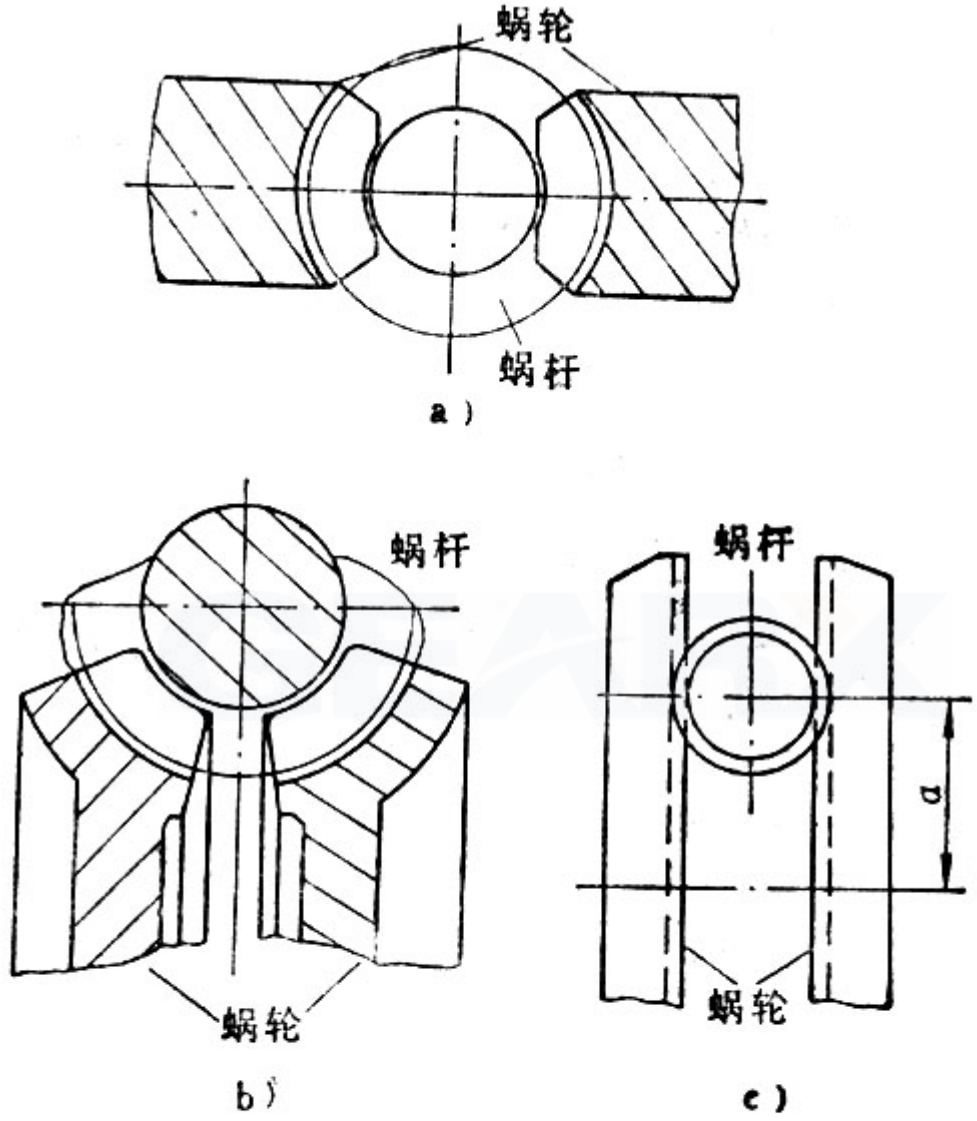


图 7-36

a）双重圆柱蜗杆传动 b）双重β传动

c）双重偏置蜗杆传动

β Transmission (β-transmission)

It is a variable type of cylindrical worm gear pair. This kind of worm gear pair makes full use of the favorable meshing zone and rotates an angle β towards the

meshing-out side in the meshing zone of worm wheel corresponding to the central plane. Therefore, it is called β transmission (Figure 7-37). This kind of worm gear pair takes advantage of the good section of contact line. It also improves the dynamic pressure lubricated condition of tooth surface and it is especially remarkable on ruled surface cylindrical worm gear pair. The Figure shows its recommendation for ruled surface cylindrical worm gear pair, θ=45°—50°, $\beta_1 = 20°$, $\beta_2 = 15° - 20°$. Circular arc toothed cylindrical worm gear pair can also adopt β transmission, and θ=35°—40°is recommended. When x=0.5~1 $\beta_1 = \beta_2 = 10°$, θ =45°; when x=1 ～ 1.5, $\beta_1 = \beta_2 = 5° = 10°$, θ=45°—48°, the formation can be seen from Figure a and b.

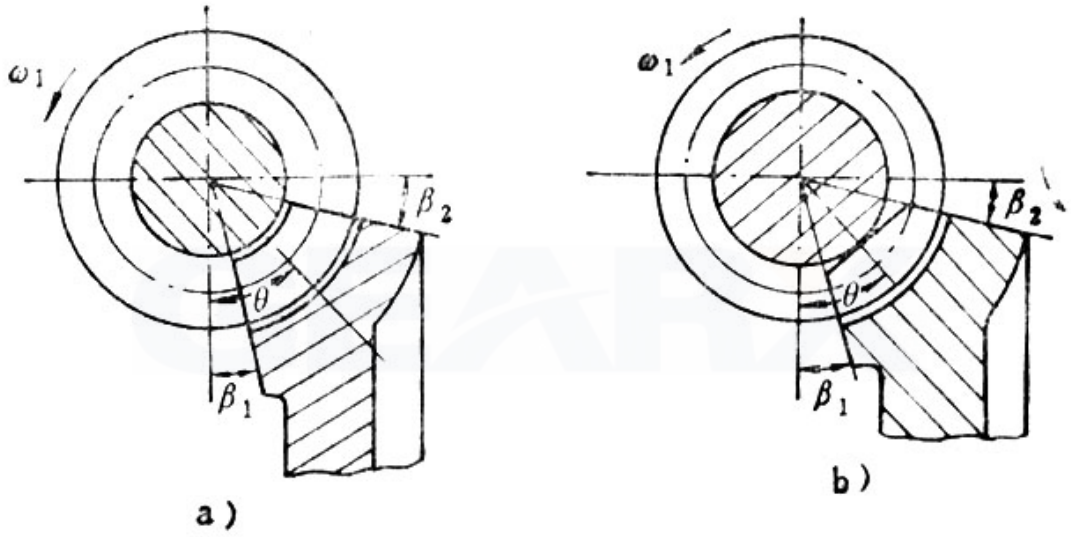


图 7-37

a）单包围 b）非包围

Double pitch point no orthogonal worm gear pair

Double pitch point no orthogonal worm gear pair is a new type of worm gear pair (Figure 7-38) put forward by scholars of Former Soviet Union in 1960s (Figure 7-38).

The worm can be made into cylindrical worm with different tooth profile. Worm wheel is manufactured with direct generating method. It has both inner gear circle and outer gear circle. Due to the structure of worm wheel, the worm wheel can only be manufactured into no orthogonal axes and the axial angle is $0<\sum<90$. It is a combination of an inner meshing worm gear pair and an external worm gear pair. During the meshing process, there are two instantaneous pitch points. Therefore, it is called double pitch points.

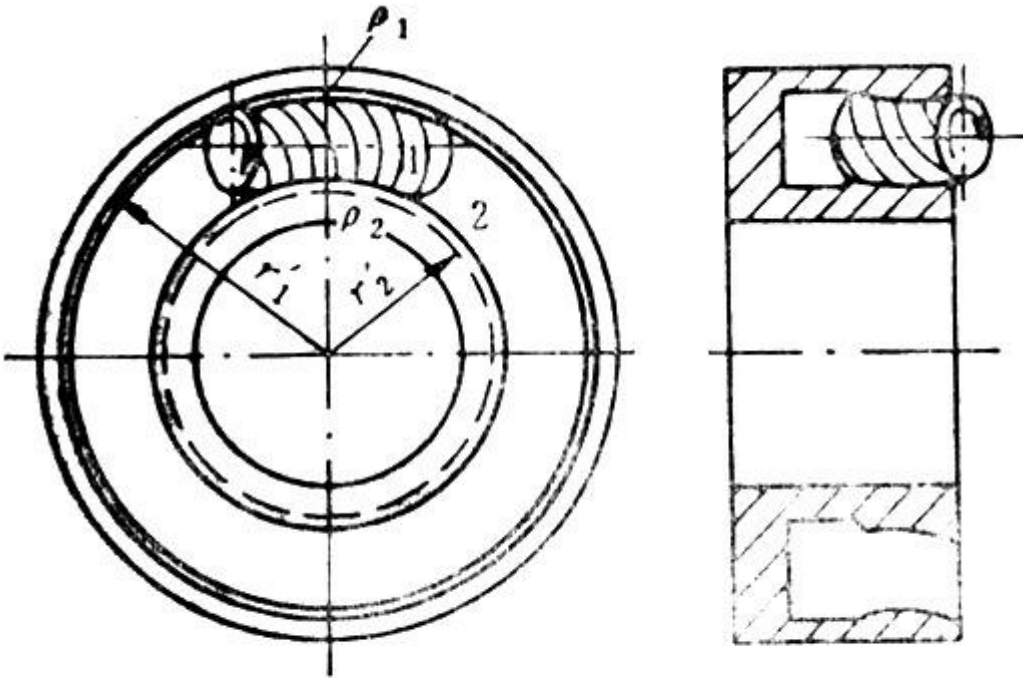


图 7-38

Double pitch point worm gear pair has many features: compared with cylindrical worm gear pair, it has high bearing capacity and transmission efficiency; the bending moment beard by worm shaft is very small or been eliminated; it has good processing workmanship but it is sensitive to installation precision. So far, this kind of worm gear pair has not been deeply studied and applied. Digital TK-worm

Based on the formation of helicoid of turning typed double enveloping worm with straight line generatrix, digital TK-worm refers to enveloping worm that replaces lathe tool with digital conical milling cutter and processed under generating method. From Figure 7-39, one can know that the axis of finger cutter is linked with its formation circle, and its edge is tangent to the formation circle. When processing worm, the cutting tool, not only rotating around its own axial line in a high speed, but also rotating based on the given transmission ratio along the formation circle. Digital TK-worm has good gearing grinding workmanship.

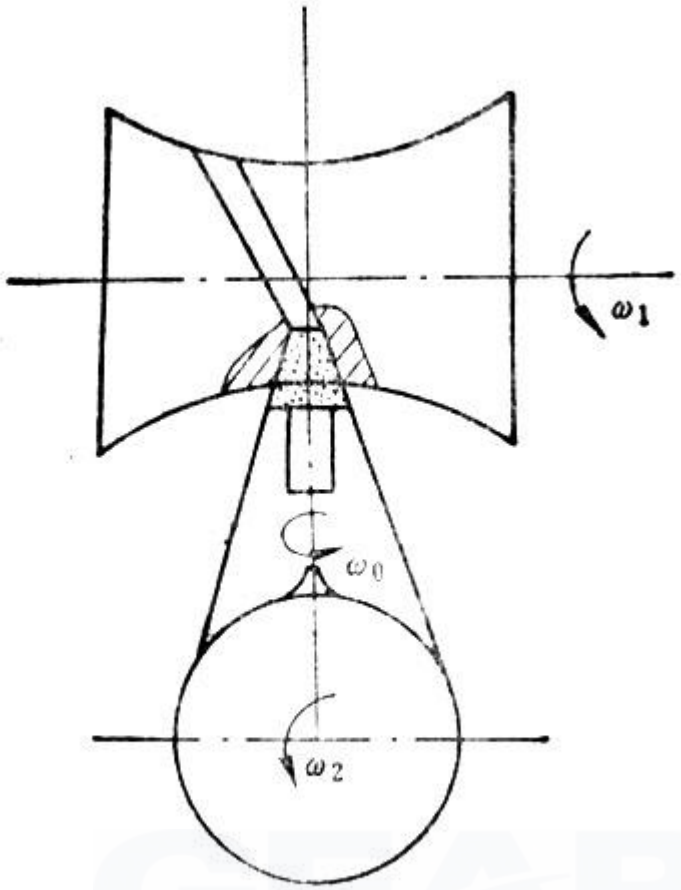


图 7-39

Digital cone double enveloping worm gear pair

Digital cone double enveloping worm gear pair consists of digital TK-worm and worm wheel generated directly by generating gear (tooling). In general, the shaft angle is ∑=90°and this kind of gear pair belongs to enveloping worm gear pair with double encirclement. As a form which is most similar to TA-worm pair, it inherits the meshing advantages of TA-worm pair. They can be showed here: worm with high precision, hard tooth surface and low roughness can be realized, which effectively solve the tool shaping problems; “basic” TA-worm pair has two contact lines, in which the “static line” is an edge line on the tooth surface with largest induced curvature. In this kind of worm gear pair, the contact line becomes a group of “dynamic” contact line slipping on the narrow zone. It helps reduce the contact stress and improves the workmanship of multi-end worm and undercutting is not easy to occur. Even compared to double wildhaber-worm gear pair, this kind of gear is also good enough. Through “angle modification”, the meshing width of “static line” will become larger and it being advantages to the realization of superiority of double contact lines. This kind of worm gear pair can be used in multi-end, small transmission ratio and large size occasion.

Angular correction digital TK-worm

The process of finger conical tool generated into enveloping worm is equivalent to the engagement process of generating gear and worm. If the axis of generating gear (finger type conical hobbing or grinding wheel) and the axial line of worm wheel is not overlapped and the inclination angle is Δr, then the generated worm is called "angular correction" digital TK-worm.

Curved enveloping worm

Curved enveloping worm refers to worm taking curved tooth profile worm wheel (gear) as generating wheel and manufactured under generating method. The workmanship of the generating wheel is good but the tooth grinding technology of worm is not that good.

β Change wildhaber-worm

When generating the helical surface of enveloping gear with plane generating gear, one needs to choose a plane and makes the initial angle being β, then change the angle β in the worm processing process from the starting point of worm to the throat, and then change the angle in an opposite way. Processing worm in this way is called β change wildhaber-worm. This kind of correction typed enveloping worm can effectively prevent the sharpness of worm tip and undercutting problem. So far, the worm is not widely used and further study need to be done.

Point contact cylindrical lantern enveloping worm gear pair

Taking the convex circular arc shaped active face as an end face of worm gear tooth and putting it in the central plane, when processing worm, one need to do it on the basis of the given center distance a_0, transmission ratio i_0, make the worm rotating surrounding its axial line and the tool surrounding the axial line of worm wheel, then the trace surface of the blade profile is the helical surface of enveloping worm. The gear tooth of worm wheel is the bush roller whose diameter has matched relation to the circular arc diameter of cutting tool. This kind of worm gear pair (Figure 7-40) presents point contact and it is called point contact cylindrical lantern enveloping worm gear pair. The main engagement characteristics are: point contact, good installation workmanship; sliding friction between conjugate surfaces becomes rolling friction and transmission efficiency is improved. Large worm gear pair has even better performance. The figure shows the principle of cutting tool processing worm.

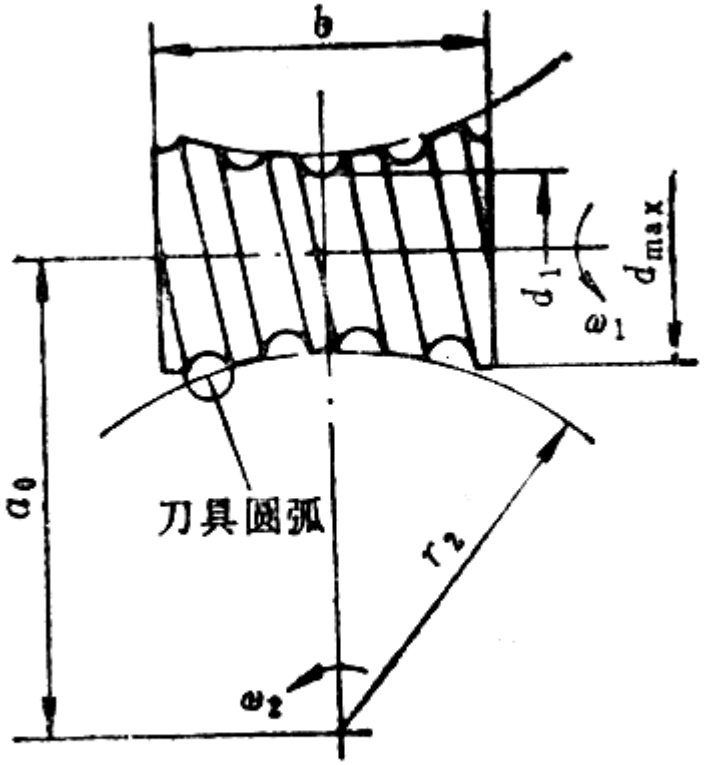


图 7-49