5.4 Worm and Worm Gear

5.4.1 General Terms

Lead

When a spiral line of rotational surface is intersecting with the same generatrix, then the distance between two arbitrary adjacent intersecting points is called lead. The lead of spiral line on the surface of cylinder is P_z=Pz=π m_xz. This is a common term related to worm. See Figure 5-122.

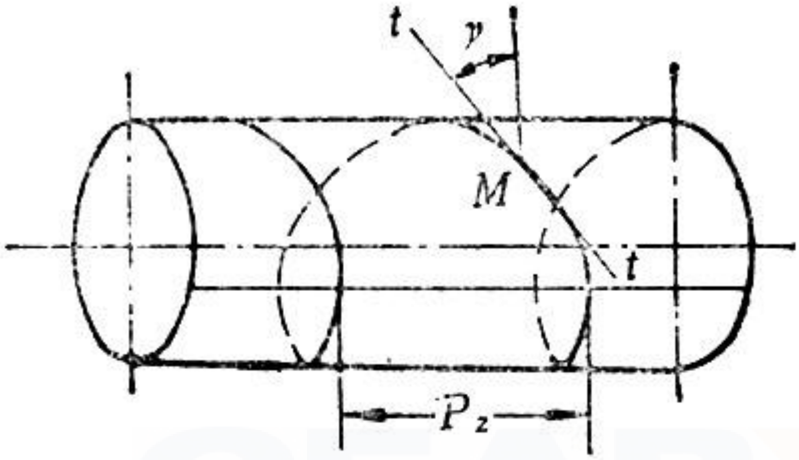


图 5-122

Lead of Worm

On an axial plane, the axial distance between worm and the same-side tooth profile of an adjacent gear tooth is called lead of worm. Lead of worm also refers to the distance measured by the movement of a tooth trace along the direction of axial line. The value is equal to the number gotten from the multiplication of axial pitch and head number, namely, P_z=P_xz=π m_xz. The lead of cylindrical worm is shown in the Figure 5-113. See Figure 5-123.

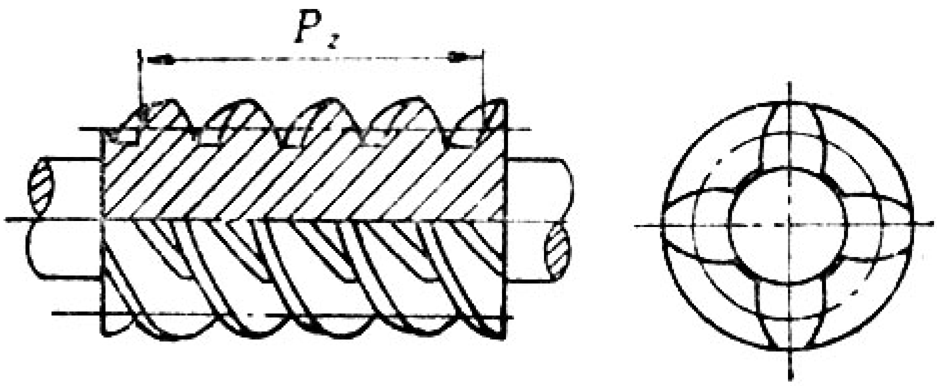


图 5-123

Lead Angle

In the helical surface, the acute angle γ formed between the tangent of a point M getting through by a spiral line and the transverse plane of the helical surface of this point is called the lead angle of spiral line at the point M. Lead angle is a common term relating to worm. Generally speaking, lead angle of worm refers to the lead angle of spiral line at the speculated point on the reference surface. Cylindrical worm lead angles is: $tg\gamma = m_x z_1 / d_1 = z_1 / q = p / r$※ (p is spiral parameter). Lead angle on a spiral line is complementary to that at the same location. See Figure 5-122.

Diametral Quotient

The quotient of the diameter of reference circle of worm divided by module is called diametral quotient. According to GB10085—88, diametral quotient is the second parameter (non-basic parameter) determined by module and the diameter of reference circle.

Worm Facewidth

Worm facewidth refers to the length of toothed-part of worm measuring along the axial line direction on the reference surface. In general, cylindrical worm always takes: $b_1=(1.25+0.1z_2)$ m. When adopting grinding gear, the Δ b need to be added 20～45mm, namely, Δ b=20～45mm, as the increasing of module. As for enveloping worm, $b_1 = d_2 \sin \varphi\omega$, in this formula, $\varphi_\omega = \frac{360°}{z} \times 0.5(z' - 0.45) = \frac{180°}{z}(z' - 0.45)$

z′, which refers to the tooth number that being enveloped. As for spiroid worm, $b_1=0.7a+m_\delta$, and m_δ refers to the module of the generatrix. See Figure 5-124.

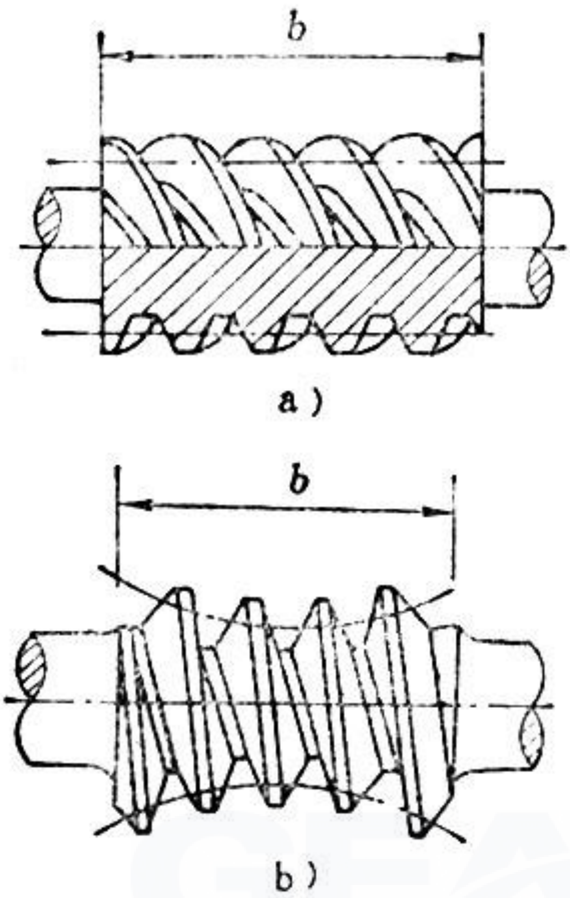


图 5-124

a） 圆柱蜗杆 b） 环面蜗杆

Mid-plane

Mid-plane refers to the plane formed by the center-to-center line between the worm axis and worm pair. When the shaft angle $\Sigma = 90°$, mid-plane also refers to the plane that includes worm axis which is vertical to worm wheel axis. Mid-plane is calculating plane for worm gear pair. The geometric size of worm, worm wheel can be calculated in this plane. See Figure 5-125.

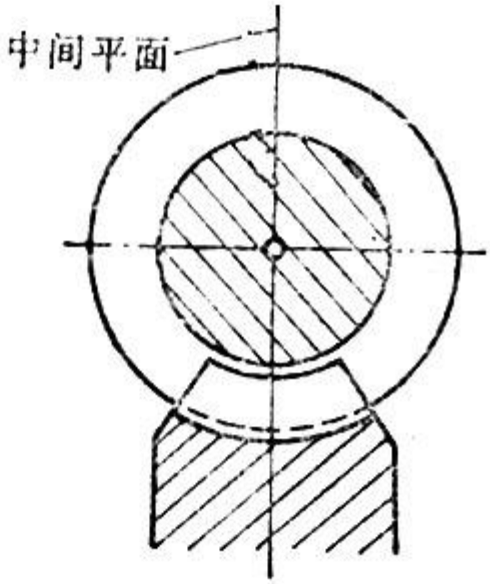


图 5-125

Axial Plane of Worm

Axial plane of worm refers to the plane that includes worm axis. When $\Sigma = 90°$, the vertical worm shaft includes the mid-plane of worm wheel shaft, which is one of the worm shaft planes. This plane is stipulated as the plane for calculating the size of worm and worm wheel.

Transverse Tooth Profile of Worm

The transversal cut by direction-vested plane on a worm helical plane is called transverse tooth profile of worm. The most commonly used terms relating to tooth profile are: transverse tooth profile of worm, axial tooth profile of worm, normal tooth profile of worm and base cylindrical tangent tooth profile of worm, etc.

Edge Contour Curve of Worm Turning Tool

Edge contour curve of worm turning tool refers to edge contour curve of turning tool which forms local rotation axes cylindrical helical surface. Edge contour curve of worm turning tool is one of the main factors that determine the type of worm: the commonly used are: straight line, arc, double-arc, elliptical arc and involute, etc. (Figure 5-126)

Generating Rolling Line of Worm

A line on tooling that can form gear teeth flank according to its tooth shape, location and movement is called generating rolling line of worm. In fact, it is the edge contour of cutter. The commonly used generating rolling line includes: straight line, arc, and double-arc, elliptical arc and involute, etc.

Cutter Generating Line in Common Use of Worm

Cutter generating line is the generatrix that forms tooth flank of the first gear product. It is a basic geometric factor that determines the meshing character of gear pair and its operation quality. Considering the meshing character and performance of gear pair, the generally used generating line are straight line, inner arc, convex arc, biarc, elliptical arc, involute and cycloid, etc. (Figure 5-126)

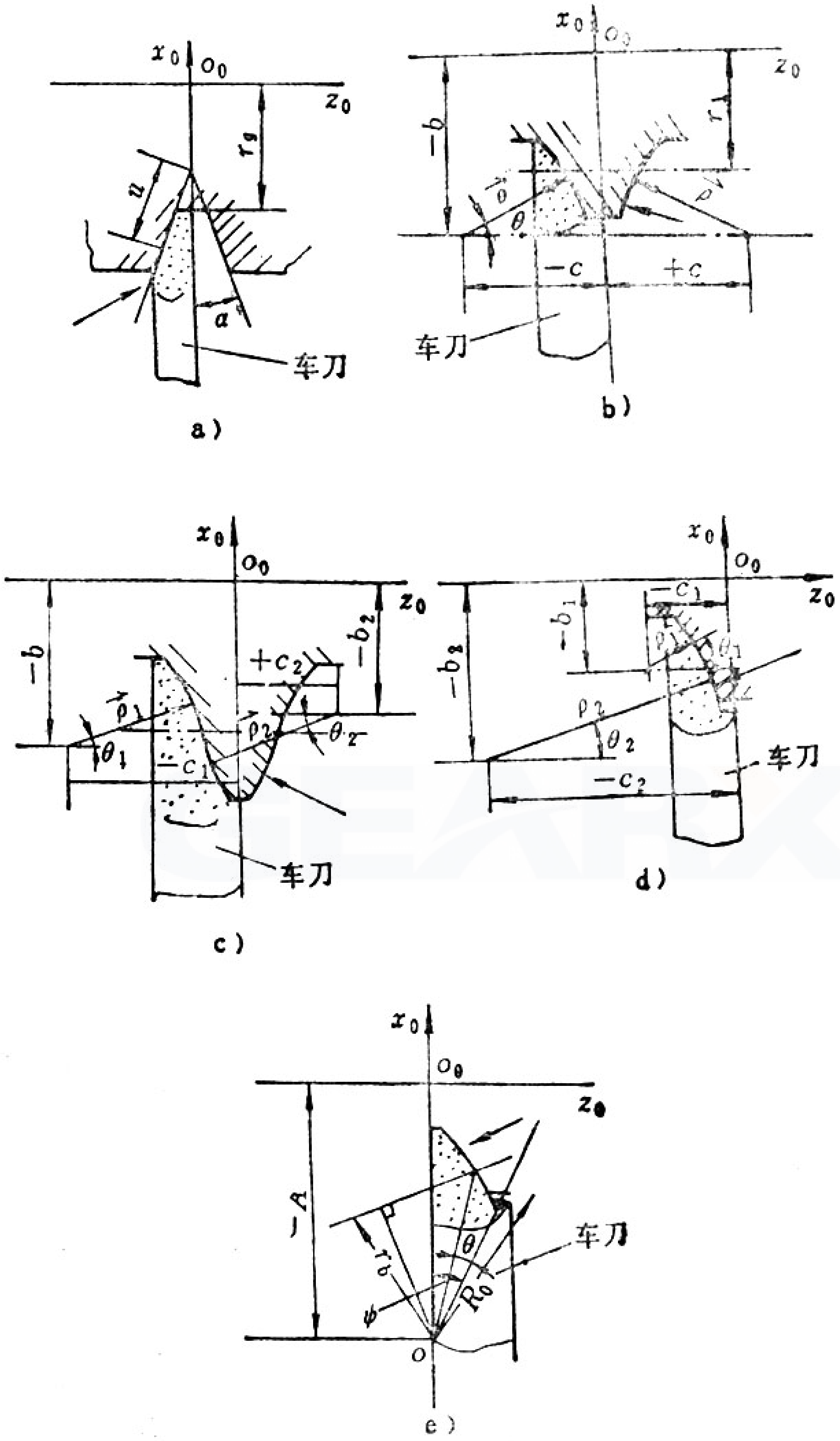


图 5-126

a) 直线　b) 圆弧　c) 双圆弧

d) 椭圆弧　e) 渐开线

Generating Angle of Worm

In a given plane, the acute angle formed between the transverse plane of worm and the tangent of given point on generating line of cutter is called generating angle of worm.

Generating Rolling Line of Worm Tooth Surface

A curve line section (including straight line), rolling across worm axis, forms a worm helix surface. This curve is called generating rolling line. The commonly seen generating rolling line of worm tooth surface includes straight line, arc, elliptical arc, biarc and involutes. (Figure 5-126)

Number of Threads, Number of Starts

The number of a worm spiral bur is called number of starts (number of threads). Currently, the number of starts of worm pair applied in China is commonly being $z1=1\sim4$. In order to improve the efficiency of worm-drive, people pay lots of attention to multi number of starts of worm.

Hands of Worm

See “right-hand teeth” and “left-hand teeth”.

5.4.2 Worm Wheel

Worm Wheel

When a gear, as the bull wheel of alternating-axis gear pair, is meshed with its matched worm, the gear is called worm wheel. Worm wheel in general refers to helical gear of changed shape. Commonly, the reference surface of worm wheel is a toroid, but sometimes being cylinder or plane. Worm wheel ring of which the reference surface is toroid can be seen in Figure 5-127.

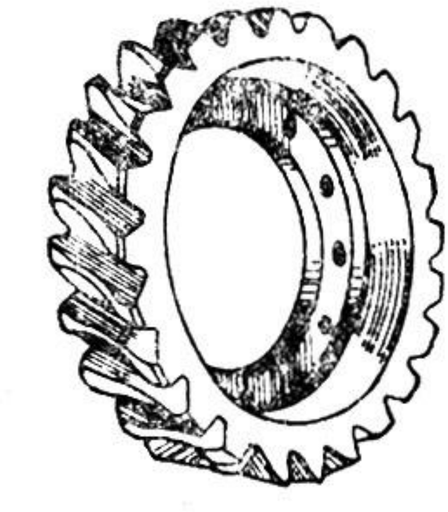


图 5-127

Mid Plane of Worm Wheel

Mid plane of worm wheel refers to the transverse plane of worm including line of centers. Mid plane of worm wheel is overlapped with the mid plane of worm gear pair.

Reference Toroid of Worm Wheel

Reference toroid of worm wheel is a given imaginary toroid sharing the same shaft with worm wheel. Its tracing circle is the reference circle of worm matched with worm wheel in standard worm gear pair. The neutral circle radius is the center distance of worm gear pair and its mid plane is overlapped with that of worm gear pair. (Figure 5-128)

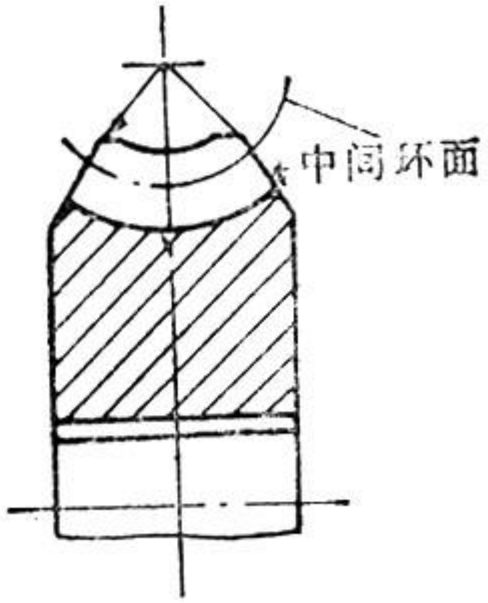


图 5-128

Tip Cylinder of Worm Wheel

The tip surface of addendum surface of worm wheel, which is shown as cylinder or the shape of cylinder is called tip cylinder of worm wheel. (Figure 5-129)

图 5-129

Tip Surface of Worm Wheel

Tip surface of worm wheel is located at the top gear teeth surface of worm. It is used to limit the radial size of the external cylinder and the tip toroid of worm wheel.

Tip surface of worm wheel can be the combination of cylinder and torus, conical surface, plane and toroid etc. (Figure 5-130)

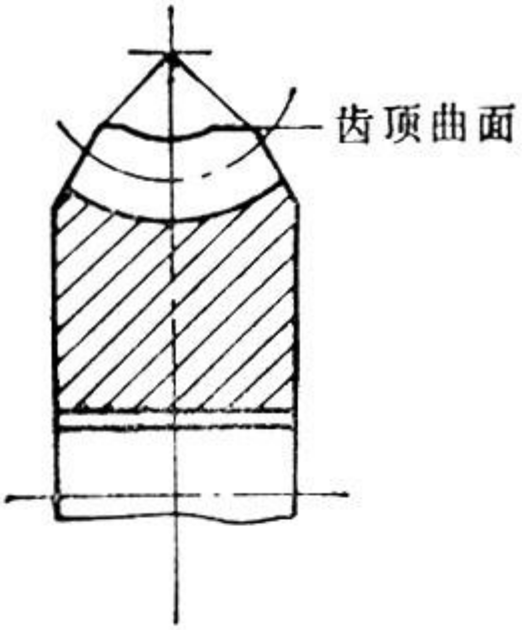


图 5-130

Gorge

On the tip surface of worm wheel, tip surface being toroid is called gorge. Taking the axis of worm wheel as axis, the toroid formed by gorge tracing circle is called gorge of worm wheel. See Figure 5-131.

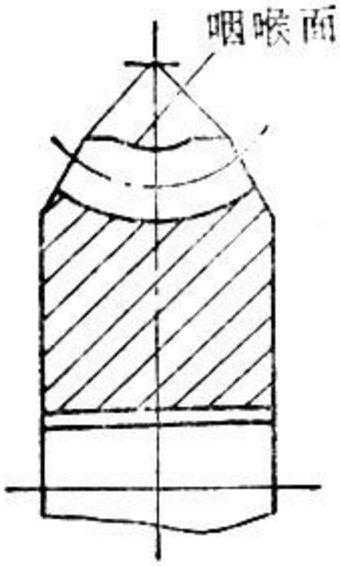


图 5-131

Root Toroid of Worm Wheel

Root toroid of worm wheel is an imaginary toroid that is consistent with the tooth bottom of worm wheel. (Figure 5-132)

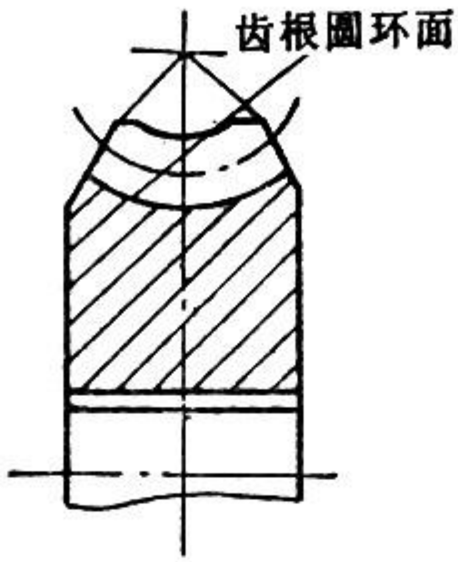


图 5-132

Tip Circle of Worm Wheel

Tip circle of worm wheel refers to the intersecting line between tip cylinder of worm wheel and transverse plane. Tip circle of worm wheel is the largest circle of cylindrical worm wheel. (Figure 5-129)

Tip Diameter of Worm Wheel

Tip diameter of worm wheel refers to the diameter of the tip circle of worm wheel. (Figure 5-129)

Circle at Root of Gorge

Circle at root of gorge refers to the inner circle of tip toroid of worm wheel. When $\Sigma = 90°$, circle at root of gorge also refers to the intersecting line formed between gorge (or addendum surface) and mid plane of worm gear pair. (Originally called tip circle of worm wheel) (Figure 5-133)

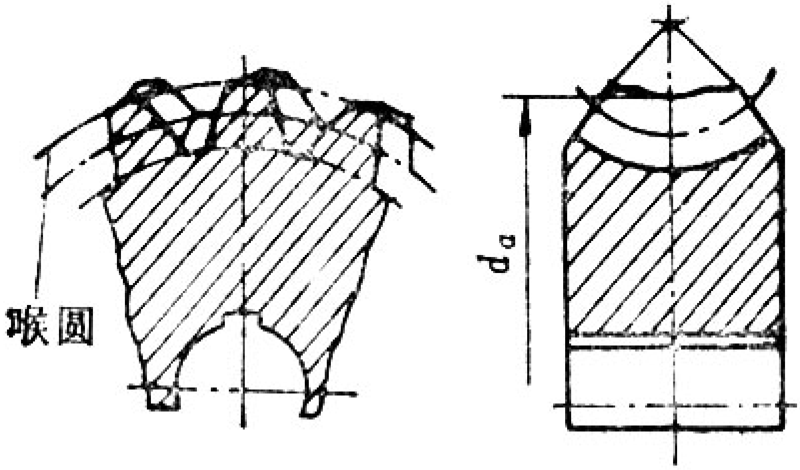


图 5-133

Diameter at Root of Gorge of Worm Wheel

The inner circle diameter of tip toroid of worm wheel（Figure 5-133） (originally called addendum circle diameter of worm wheel). The value is:

$$d_{a2} = d_2 + 2h_a = d_2 + 2h_a^* m + 2mx$$

$$= m(z_2 + 2h_a^* + 2x)$$

In this formula, x should use its own unit.

Generant Circle of Gorge

Generant circle of gorge refers to the tracing circle of tip toroid of worm wheel. (Figure 5-134).

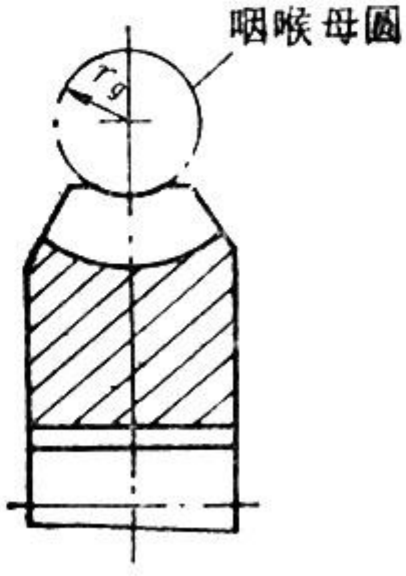


图 5-134

Gorge Radius

Gorge radius here refers to the gorge radius of worm wheel. $r_{g2}=a-r_{a2}=r_{f1}+c^*m$. The gorge radius can hold a value that is relatively bigger than that of above mentioned as a way to improve the lubrication conditions. (Figure 5-134)

Reference Circle of Worm Wheel

Reference circle of worm wheel refers to the inner circle of reference toroid of worm wheel. It also refers to the intersecting line formed between the reference toroid circle of worm wheel and the mid plain of worm gear pair. Reference circle of worm wheel is the basic circle used to calculate the geometric size of worm wheel. The value is ： $d_2=2(a-r_1')=mz_2\equiv d_2'$.

Reference Diameter

Reference diameter here refers to the diameter of reference circle of worm wheel, it only bears relation with module and the number of teeth, namely, $d=mz_2$. It bears no relation to the modification coefficient of worm wheel.

Root Circle of Worm Wheel

Root circle of worm wheel is the inner circle of root toroid of worm wheel. When $\Sigma=90°$, root circle of worm wheel refers to the intersecting line of root toroid and mid-plane of worm pair. (Figure 5-135)

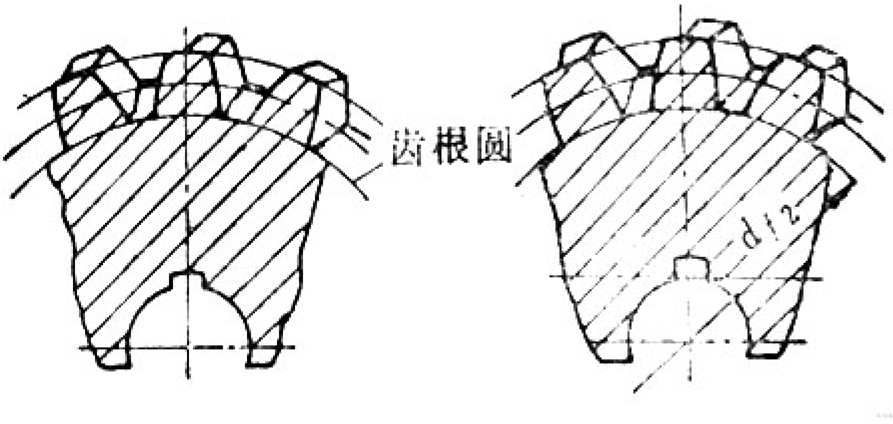


图 5-135

Root Diameter of Worm Wheel

Root diameter of worm wheel refers to the inner circle diameter of root toroid of worm wheel. The value is：

$$d_{f2} = d_2 - 2h_{f2} = d_2 - 2(h_a^* + c^*)m + 2mx$$

$$= m(z_2 - 2h_a^* - 2c^* + 2x)$$

In this formula, x should use its own unit. See Figure 5-135.

Tooth Depth of Worm Wheel

Tooth depth of worm wheel refers to the radial distance between gorge circle (or tip circle) and root circle of worm wheel. The value is:

$$h_2 = r_{a2} - r_{f2} = (2h_a^* + c^*)m$$

Addendum of Reference Circle of Worm Wheel

Addendum of reference circle of worm wheel refers to the radial distance between the gorge circle (or tip circle) and reference circle of worm wheel. The value is:

$$h_a = \frac{1}{2}(d_{a2} - d_2) = m(h_a^* + x)$$ 。

In this formula, x should contain its own unit.

Face Width of Worm Wheel

Face width of worm wheel refers to the calculating width of teeth of worm wheel.

For cylindrical worm wheel, face width refers to the distance between the transverse line and the two intersecting point of tracing circle of reference toroid in axial plane of worm wheel shaft. (Figure 5-136) For conic worm wheel, face width of worm wheel refers to the length of gear tooth of worm wheel measuring along the generatrix direction.

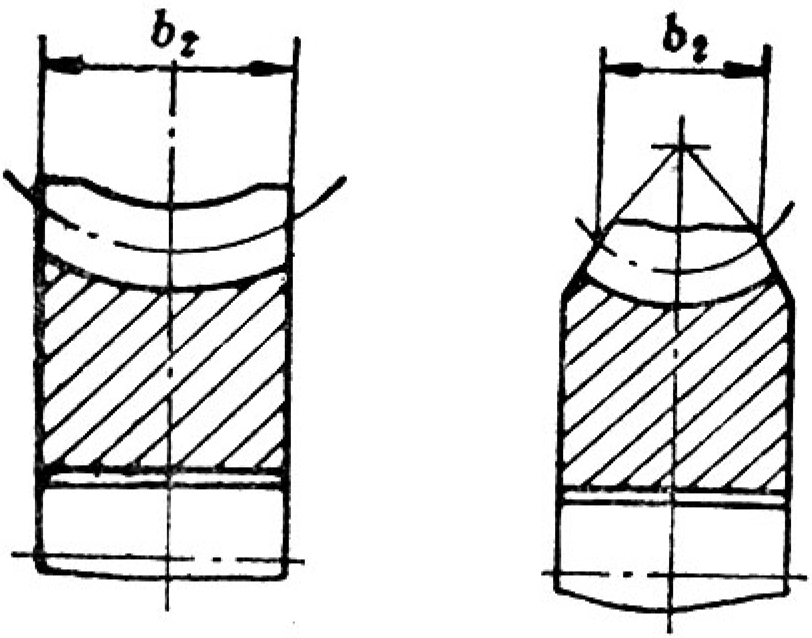


图 5-136

Working Face Width of Worm Wheel

On the reference toroid of worm wheel, working face width of worm wheel refers to the distance of practical contacting area measured on its axis.

Width Angle

Width angle refers to the central angle pointed by the face width of worm wheel. See Figure 5-137.

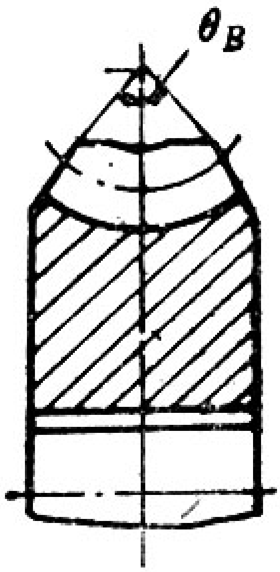


图 5-137

Sizing Worm Wheel with Half Tooth Width

For cylindrical worm gear pair, in the theoretical meshing area of worm wheel, the meshing can't run properly and the meshing in central area is in the position of "glued dangerous area". In order to avoid the meshing of these two areas and improve its capacity and transmission efficiency, sizing worm wheel with half tooth width is carried out as shown in the Figure 5-138. This kind of worm gear pair has good meshing characters. But it weakens the bending strength of worm wheel and only applicable in single operation.

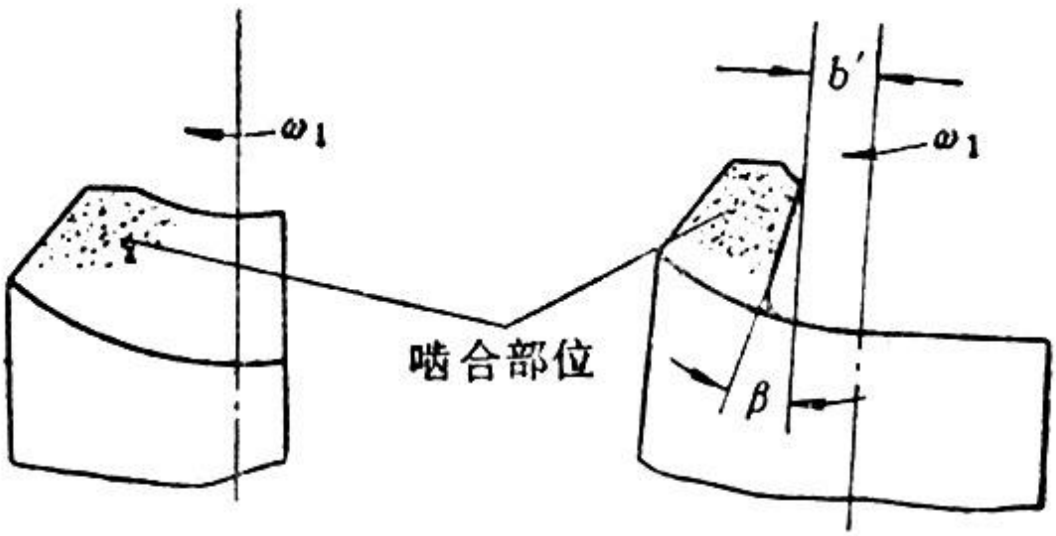


图 5-138

Sizing Worm Wheel

In order to avoid or decrease the meshing of dangerous area, sizing worm wheel is invented. This means to cut out the area that do harm to the formation of dynamic pressure oil-film as a way to realize its good meshing characters. This kind of worm wheel is called sizing worm wheel. Sizing worm wheel, matched with worm, is called sizing worm gear pair. The form of worm wheel is mainly shown in Figure 5-139.

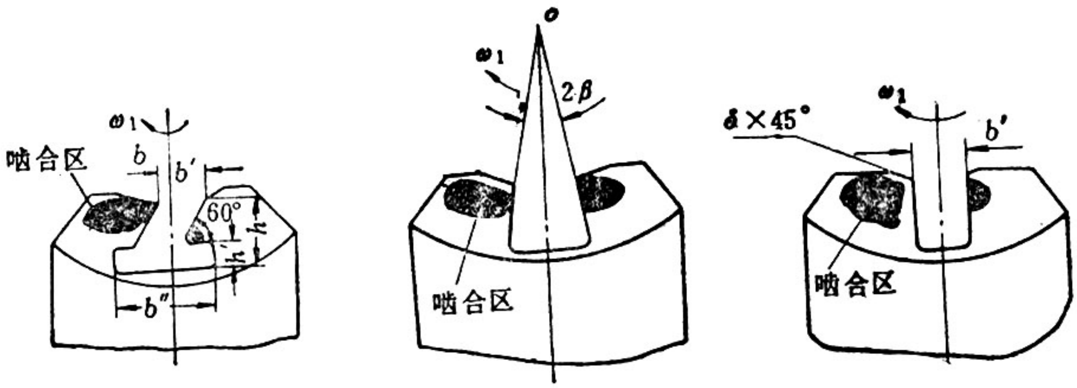


图 5-139

Dig Nest Worm Wheel

Putting the finger cutter in tooth space of worm wheel and cut the "dangerous area" in the tooth surface of worm wheel, the tooth surface is shown like nest-shaped vessel (Figure 5-140). Dig nest worm wheel and its matched worm can compose into dig nest worm gear pair. This kind of worm pair can form a meshing location with good performance and lubrication can be stored inside the vessel. After the cutting of "dangerous area", the oil temperature can be decreased and the anti-glued capacity and driving efficiency can be improved.

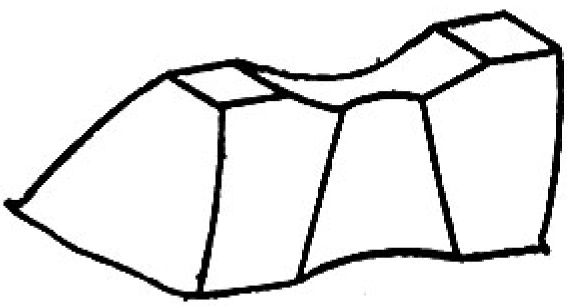


图 5-140

Increment of Gorge Radius

In order to realize "artificial oil protection", and make the shape be wedge, the root surface of worm and the addendum toroid of worm wheel must be realized.

Increasing the gorge circle radius is also a good measurement. Generally, $r_g = r_{f1} + c^* m$, the increased gorge circle radius is $R_g = r_g$※Δr_g，$\Delta r_g =$（0.5～0.9）m. Δr_g is called the increment of gorge radius. See Figure 5-141.

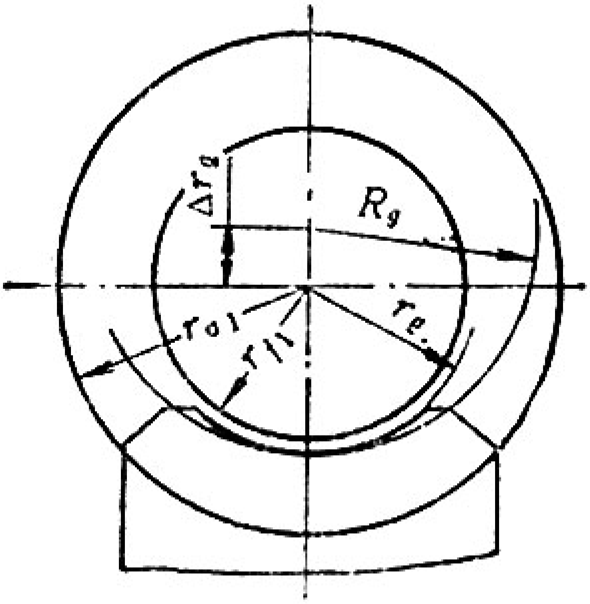


图 5-141

5.4.3 Cylindrical Worm

Reference Cylinder of Worm

The reference surface of cylindrical worm is cylinder, and this is called reference cylinder of worm (Figure 5-142). Reference cylinder of worm is the calculating basic flank of geometric size of gear teeth of worm wheel. It divides gear teeth into addendum and tooth depth. Tooth thickness, tooth space width on reference cylinder is generally stipulated as standard value.

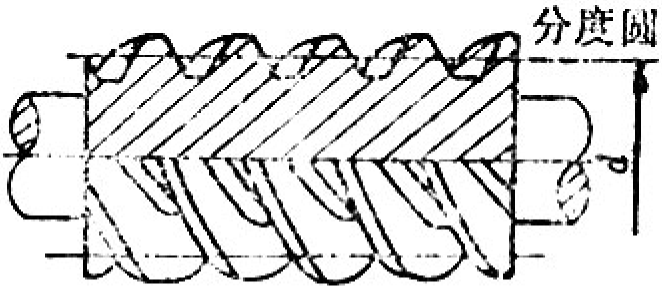


图 5-142

Reference Circle of Worm

Reference circle of worm refers to the intersecting line of reference cylinder of cylindrical worm and its transverse plane. Reference circle of worm is the basic circle calculated by the geometric size of the transverse plane of worm. It divides the gear teeth into addendum and tooth root whose diameter is d_1=mq. GB10088-88 stipulates the standard series of reference circle diameter of cylindrical worm and divides it into the 1 series and the 2 series.

Reference Diameter of Cylindrical Worm

The diameter of reference circle of cylindrical worm is equal to the multiplication of module and the diameter coefficient (d_1=mq). According to GB10088-88, the radius of reference circle has been more serialized and standardized. It bears no relation to the radial modification coefficient.

Cylinder of Worm

Cylinder of worm refers to the same-shaft cylinder of cylindrical worm.

Tip Cylinder of Worm

The tip surface of cylindrical worm is cylinder, so the cylinder is called tip cylinder of worm. See Figure 5-143.

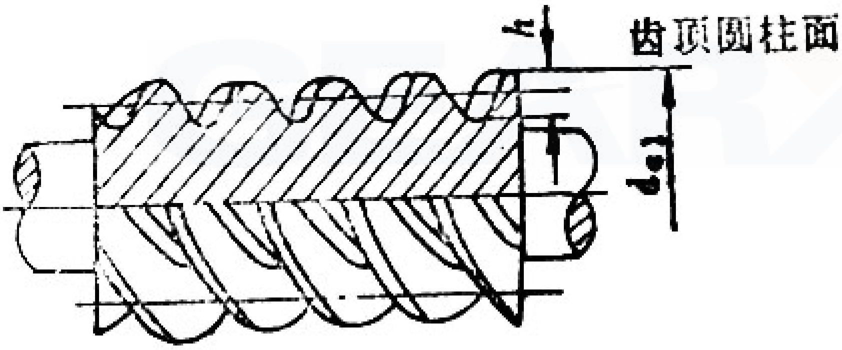


图 5-143

Addendum Circle of Cylindrical Worm

The intersecting line of addendum cylinder of cylindrical worm and transverse plane is a circle. This circle is called addendum circle of cylindrical worm.

Addendum Diameter of Cylindrical Worm

The diameter of addendum circle of cylindrical worm is called addendum diameter of cylindrical worm (Figure 5-143). The value is d_{a1}=mq+2h.

Root Cylinder of Worm

The root surface of cylindrical worm is cylinder. Root cylinder of worm also refers to the cylinder which is tangent to the notch base of worm. See Figure 5-144.

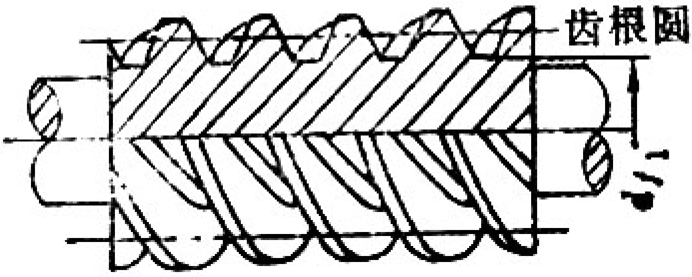


图 5-144

Dedendum Circle of Cylindrical Worm

The intersecting line of root cylinder of cylindrical worm and transverse plane is a circle, namely, dedendum circle of cylindrical worm. $d_{f1} = d_1 - 2(h_a{*} + c{*})m$.

Root Diameter of Cylindrical Worm

The diameter of root cylinder of cylindrical worm is called root diameter of cylindrical worm. It is a geometric size that bears no relation to radial modification coefficient. $d_{f1} = d_1 - 2h_{f1}$. See Figure 5-144.

Reference Line of Cylindrical Worm

The intersecting line of reference cylinder of cylindrical worm and the axial plane of worm is called reference line. The reference line of cylindrical worm is a straight line, and the axial pitch of worm, tooth thickness and tooth space width are all measured on this straight line. See Figure 5-145.

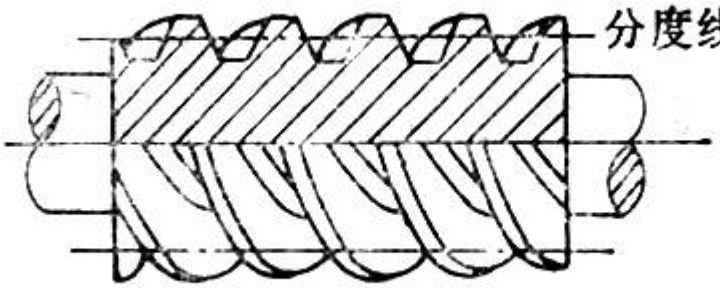


图 5-145

Normal Helical Line of Cylindrical Worm

On the reference cylinder of cylindrical worm, the spiral line which intersects with the spiral line of reference cylinder is called normal helical line of cylindrical worm. Normal helical line of cylindrical worm is hand-opposite with the helical line of reference cylinder.

Total Depth of Cylindrical Worm

Total depth of cylindrical worm refers to the radial distance between the tip cylinder and the root cylinder of cylindrical worm. The value is $h_1 = r_{a1} - r_{f1} = m(2h*_a + c*)$. It bears no relation to the modification coefficient.

Addendum of Cylindrical Worm

Addendum of cylindrical worm refers to the radial distance between the tip cylinder and reference cylinder of cylindrical worm. The value is $h_{a1} = r_{a1} - r_1 = h_a * m$. It bears no relation to addendum modification. (Figure 5-146)

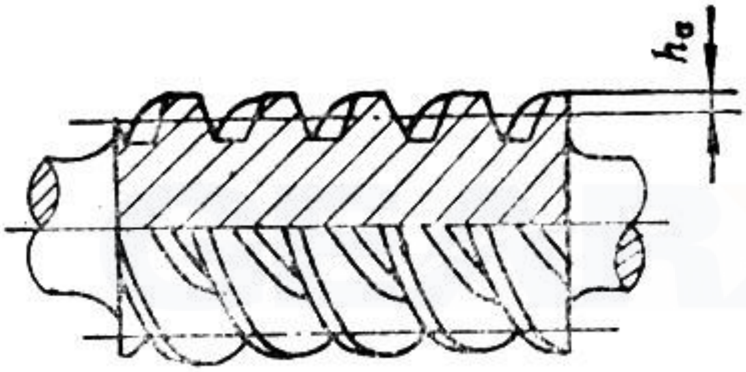


图 5-146

Dedendum of Cylindrical Worm

Dedendum of cylindrical worm refers to the radial distance between the reference cylinder and root cylinder of cylindrical worm. The value is $h_{f1} = r_1 - r_{f1} = m(h*_a + c*)$. It bears no relation to modification coefficient. (Figure 5-147)

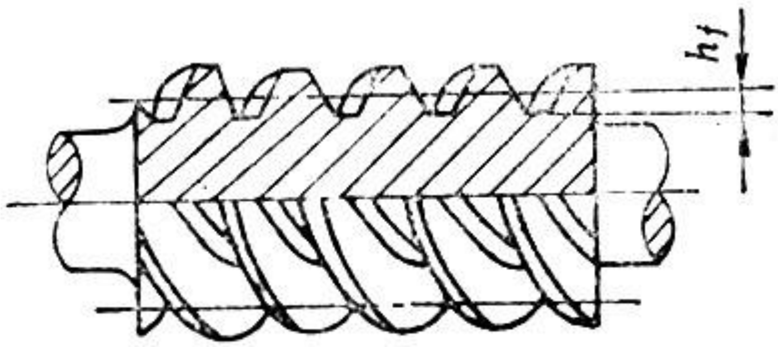


图 5-147

Tooth Profile Angle of Cylindrical Worm

In a preset cross section, the acute angle formed between the transverse plane of cylindrical worm and the generating line of tooth flank of worm or the tangent formed between the generating lines or reference cylinder at their intersecting pint is called tooth profile angle of cylindrical worm. The common terms are normal tooth profile angle and axial tooth profile angle.

Normal Tooth Profile Angle of Cylindrical Worm

Normal tooth profile angle of cylindrical worm refers to the tooth profile angle measured inside of the normal plane of reference cylinder helical line of cylindrical worm. Please see "tooth profile angle of cylindrical worm".

Generating Angle of Cylindrical Worm

In a preset plane, the acute angle formed between then transverse plane of cylindrical worm and the tangent formed at the given point of generating line of cutter. The commonly used terms are axial generating angle and normal generating angle.

Axial Generating Angle of Cylindrical Worm

Generating angle measured inside the axial plane of cylindrical worm is called axial generating angle of cylindrical worm. See "generating angle of cylindrical worm"

Normal Generating Angle of Cylindrical Worm

Generating line measured inside the normal plane of cylindrical worm is called normal generating angle of cylindrical worm. See "generating angle of cylindrical worm"

Axial Tooth Profile Angle of Cylindrical Worm

Generating angle measured inside the axial plane of cylindrical worm is called axial tooth profile angle of cylindrical worm.

Radius Chamfer of Worm

Transitional arc radius formed between worm tooth flank and tip surface measured on the axial plane of worm is called radius chamfer of worm. (Figure 5-148)

Radius of Tooth Fillet of Worm

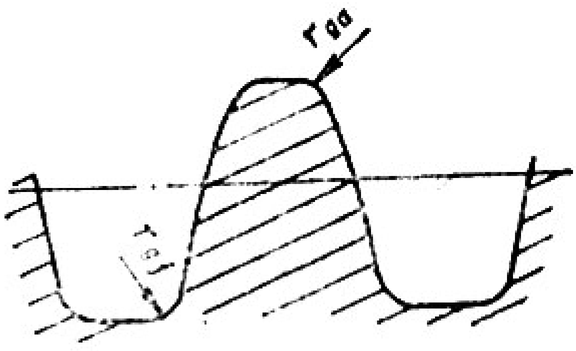


图 5-148

Transitional arc radius formed between worm tooth flank and root surface measured on the axial plane of worm is called radius of tooth fillet of worm. (Figure 5-148)

Helical Line of Cylindrical Worm

The intersecting line formed between the helical surface of cylindrical worm and cylinder with the same axis line of worm is called helical line of cylindrical worm. The diameter of this cylinder is d_y, the lead angle of helical line is γ_y, then $\mathrm{tg}\gamma_y d_y = mz_1$ (Figure 5-149).

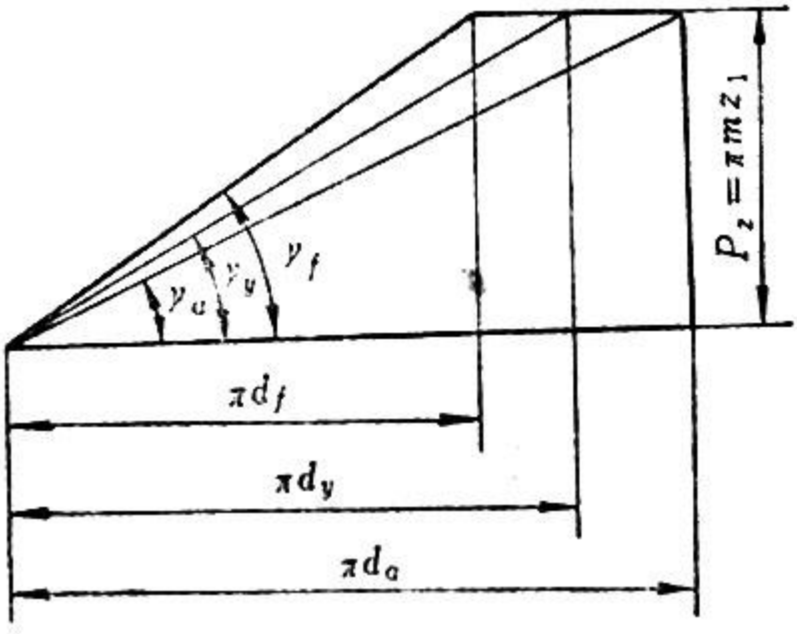


图 5-149

Helix of Reference Cylinder of Worm

The intersecting line formed between a teeth flank of helical surface of cylindrical worm and reference cylinder is called helix of reference of cylinder of worm. Generally, this helix is always seen as helix of cylindrical worm. The lead angle formula is $tg\gamma_1 = \frac{z_1}{q} = \frac{mz_1}{d_1}$.

Axial Tooth Pitch of Cylindrical Worm

The distance between two same-sides, adjacent tooth profiles on the reference line of worm inside the axial plane of cylindrical worm is called axial tooth pitch of cylindrical worm. The formula is $p_x = \pi m_x$ (Figure 5-150)

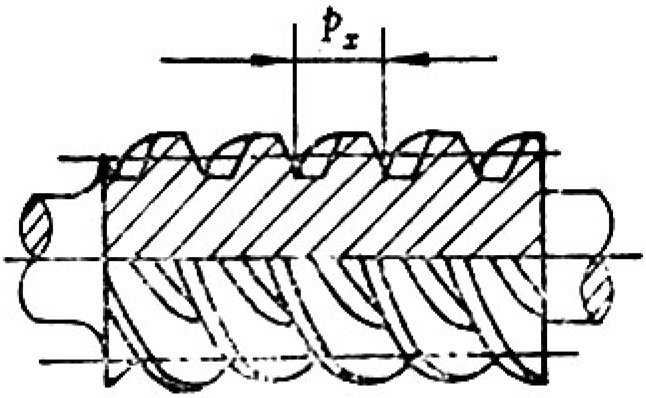


图 5-150

Axial Tooth Thickness of Cylindrical Worm

One helical tooth of a worm has two tooth profile lines in the axial plane, then the distance of these two tooth profile lines measured on this reference line is called axial tooth thickness. Generally it is stipulated as standard value and its size bears no relation to radial modification. Straight sided axial worm ZA-worm has a rule: $s_x = \frac{1}{2}\pi m$. The axial arc tooth cylindrical worm has a rule: $s_x = 0.4\pi m$. (Figure 5-151)

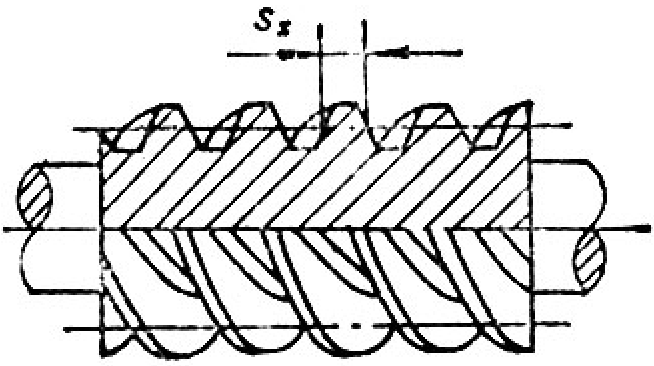


图 5-151

Axial Space Width of Cylindrical Worm

In the axial plane of cylindrical worm, the distance of tooth profile line of the two sides of tooth space measured on reference line is called axial space width. See Figure 5-152. It is commonly set as standard value and bears no relation to radial modification. The relation between axial space width and axial thickness is

$p_x = s_{x1} + e_{x1} = \pi m$.

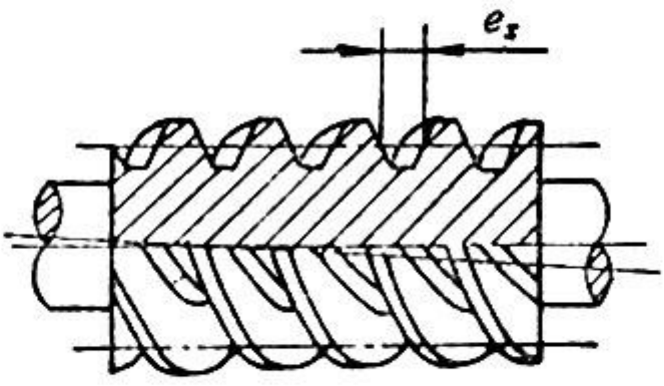


图 5-152

Basic Tooth Form of Cylindrical Worm

Basic tooth form of cylindrical worm refers to the basic tooth form of ruled surface in a given cross section stipulated in GB10087—88. This kind of basic tooth form is applicable to the ZA worm (m≥1, $\Sigma = 90°$), ZI worm, ZN worm and ZK worm. What stipulated inside the axial plane of worm (Figure 5-153a) are: addendum h_a=1m, working depth of tooth $h' = 2m$; when short tooth is applied h_a=0.8m; the axial tooth pitch $p_x = \pi m$; the tooth thickness in the mid line and tooth space width is equal; clearance c=0.2m, it can decrease to 0.15m or increase to 0.35m when necessary; radius of tooth fillet $\rho_f = 0.3m$, it can decrease to 0.2m or increase to 0.4m when necessary, it is also allowed to be manufactured into single arc (Figure 5-153b).

Tooth profile angle or generating angle of basic worm has a rule: ZA worm $a_x = 20°$; ZN worm $a_n = 20°$; ZI worm $a_n = 20°$; ZK worm $a_0 = 20°$. In power drive operation, the tooth form angle is allowed to be increased when $\gamma > 30°$, and $25°$ is recommended. In reference drive operation, tooth form angle is allowed to be decreased and $15°$ or $12°$ is recommended.

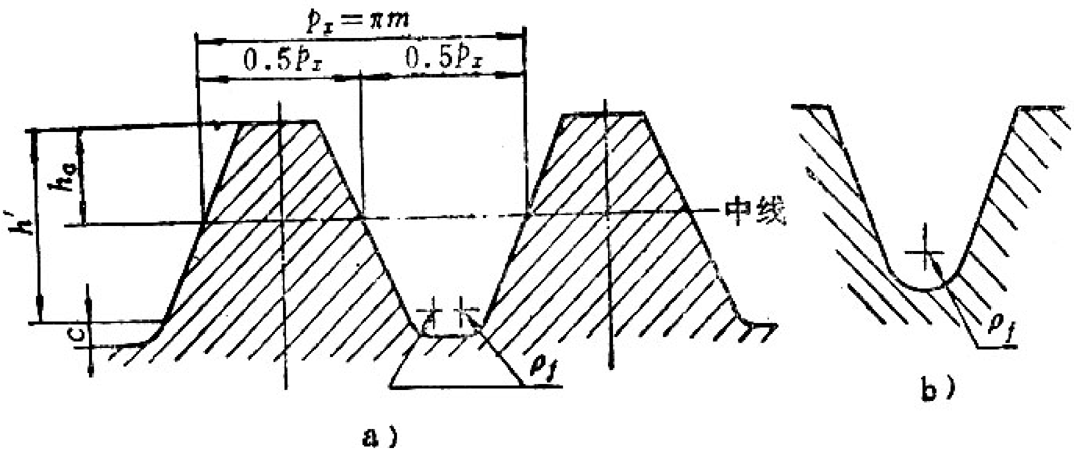


图 5-153

1-form

According to Japanese standard JGMA131—02, the tooth form of Archimedes cylindrical worm is 1-form, which is called A-form by China's GB standard and Germany DIN standard.

2-form

According to JGMA131—02, the tooth form of normal straight profile cylindrical worm is 2-form, which is called N-form by GB and DIN.

3-form

According to JGMA131—02, the tooth form of conical enveloping cylindrical worm is 3-form, which is called K-form by GB and DIN.

4-form

According to JGMA131—02, the tooth profile of involute cylindrical worm is 4-form, which is called I-form by China GB, E-form by Germany DIN and involute-form by UK standard BS.

H-flank form

Tooth form of toroid enveloping cylindrical worm is called H-flank form by Germany DIN. According to China Standard, it is called C_l-form.

E-flank form

The tooth form of involute cylindrical worm is called E-flank form, which is called I-flank form by China Standard.

Base Cylinder of Involute Helicoid Worm

Base cylinder of involute helicoids worm is a cylinder which has same axis with worm. When forming helicoid of worm, its generating line makes pure rolling on this cylinder. This cylinder is called base cylinder.

Base Circle of Involute Helicoid Worm

The intersecting line of base cylinder of involute cylindrical worm is a circle. This circle is called base circle of involute helicoids worm.

Base Diameter of Involute Helicoid Worm

Base diameter of involute helicoid worm bears no relation to addendum modification coefficient.

$$d_b = d_1 \frac{\mathrm{tg}\gamma}{\mathrm{tg}\gamma_b} = \frac{m z_1}{\mathrm{tg}\gamma_b}$$ 。

Base Cylinder Lead Angle of Involute Helicoid Worm

The acute angle formed between the tangent of helical line of base cylinder at a point and the transverse flank of worm is called base cylinder lead angle of involute helicoid worm. The relation between base cylinder lead angle of involute helicoid worm and helical line lead angle of reference cylinder is $\cos\gamma_b = \cos\gamma\cos\alpha_n$.

Base Pitch of Involute Helicoid Worm

In the section of base cylinder of involute helicoid worm, the distance between two generating line of the same-side adjacent tooth flank is called base pitch of involute helicoid worm, $p_b = \pi m \cos\gamma_b$.

Worm

A helical gear, with one or a few helical teeth, big helical angle, small lead angle, and whose tooth width is larger than lead, and can compose gear pair with alternating axis with worm wheel, is called worm. The commonly used worm are cylindrical worm, enveloping worm and spiroid worm, etc. (Figure 5-154)

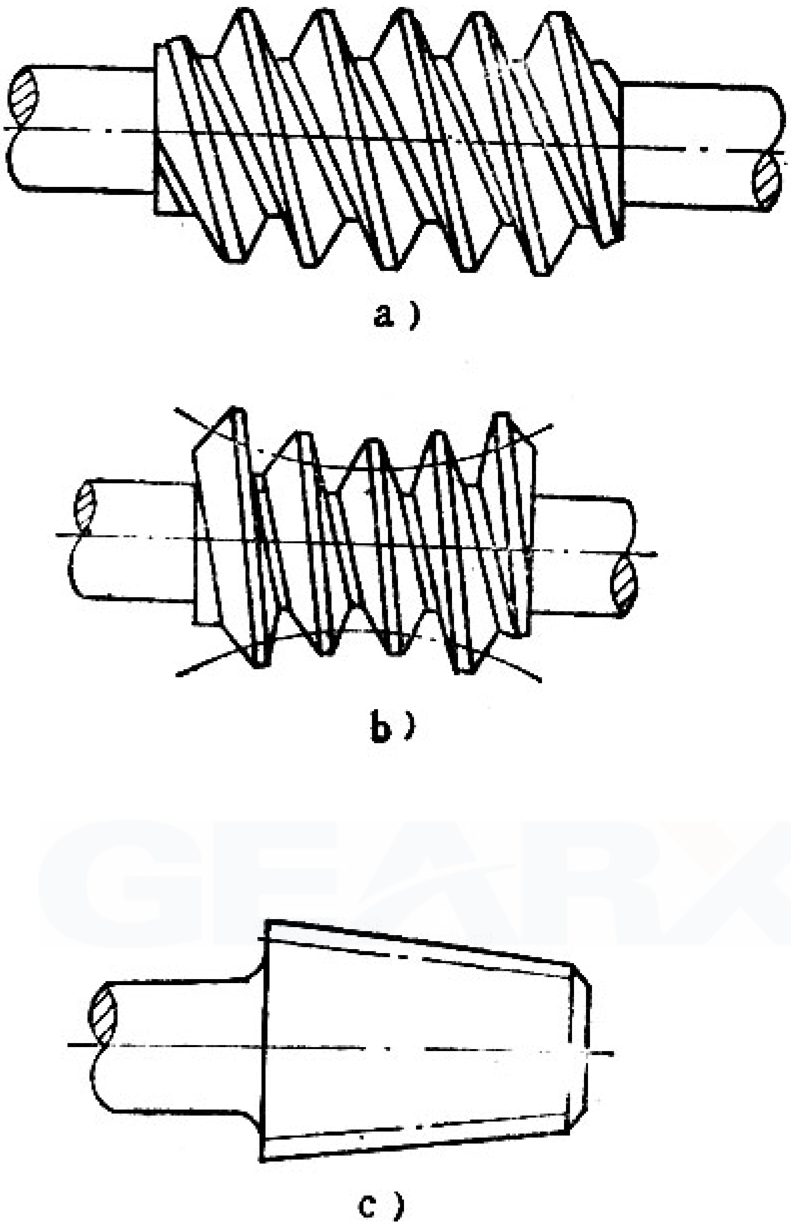


图 6-164

a）圆柱蜗杆 b）环面蜗杆 c）锥蜗杆

Cylindrical Worm

Worm whose reference surface is cylinder is called cylindrical worm. Cylindrical worm can be divided into ruled surface cylindrical worm, curved surface cylindrical worm. It can also be divided into turning side worm and enveloping worm.

Cylindrical Worm with Ruled Surface

Cutting the helical surface of cylindrical worm with a plane, if the cutting line (profile line of the helical surface) is a straight line, then this kind of cylindrical worm is called cylindrical worm with ruled surface. The helical surface is formed by the helical movement of this straight line; namely, the helical surface is always a trace surface of straight edge turning tool making helical movement at the relative position against blank worm. The types are listed as follows:

Ruled surface cylindrical worm
- Straight sided axial worm ZA-worm [ZA Worm]
- Involute helicoid worm [ZI Worm]
- Straight sided normal worm [ZN worm]
  - Tooth space straight sided normal worm [ZN_1 Worm]
  - Tooth straight sided normal worm [ZN_2 Worm]
  - Flank straight sided normal worm [ZN_3 Worm]

Turning Type Worm

The helical surface of worm is the trace surface of edge profile of turning tool when it makes helical movement against blank worm. This kind of worm manufactured with tracing method is called turning type worm. The commonly used are:

Turning typed cylindrical worm
- Straight sided axial worm ZA-worm [ZA Worm]
- Tooth straight sided normal worm [ZN_2 Worm]
- Tooth space straight sided normal worm [ZN_1 Worm]
- Flank straight sided normal worm [ZN_3 Worm]
- Involute helicoid worm [ZI Worm]
- Cylindrical worm with axial circle-arc tooth [ZN_8 Worm]
- Straight profile toroid helicoids worm [TA Worm]
- Turing typed spiroid

Cylindrical Worm

Cylindrical worm refers to the cylindrical worm with equal helical surface lead of worm gear teeth on the two sides. General-service cylindrical worms are all single lead.

Straight Sided Axial Worm

Straight sided axial worm is a kind of turning typed cylindrical worm with ruled surface. On general lathe, putting the edge of trapezoidal turning tool in the axial plane of blank worm and make the lathe tool running helically against blank worm, then the tracing surface of edge profile is called helical surface of worm, namely, straight sided axial worm, which is abbreviated as ZA worm. The axial tooth profile of this worm is a straight line and its transverse tooth profile is straight sided axial worm. (Figure 5-115)

Mating Worm Wheel of Archimedes Worm

Mating worm wheel of archimedes worm refers to the worm wheel that can match with archimedes worm so as to form archimedes worm gear pair. It is manufactured with generating method directly on common gear-hobbing machine. The tooth flank of worm is the enveloping surface of helical surface of archimedes worm. In axial plane of worm, the tooth profile of worm is involute, it is involute helical gear with changed shape.

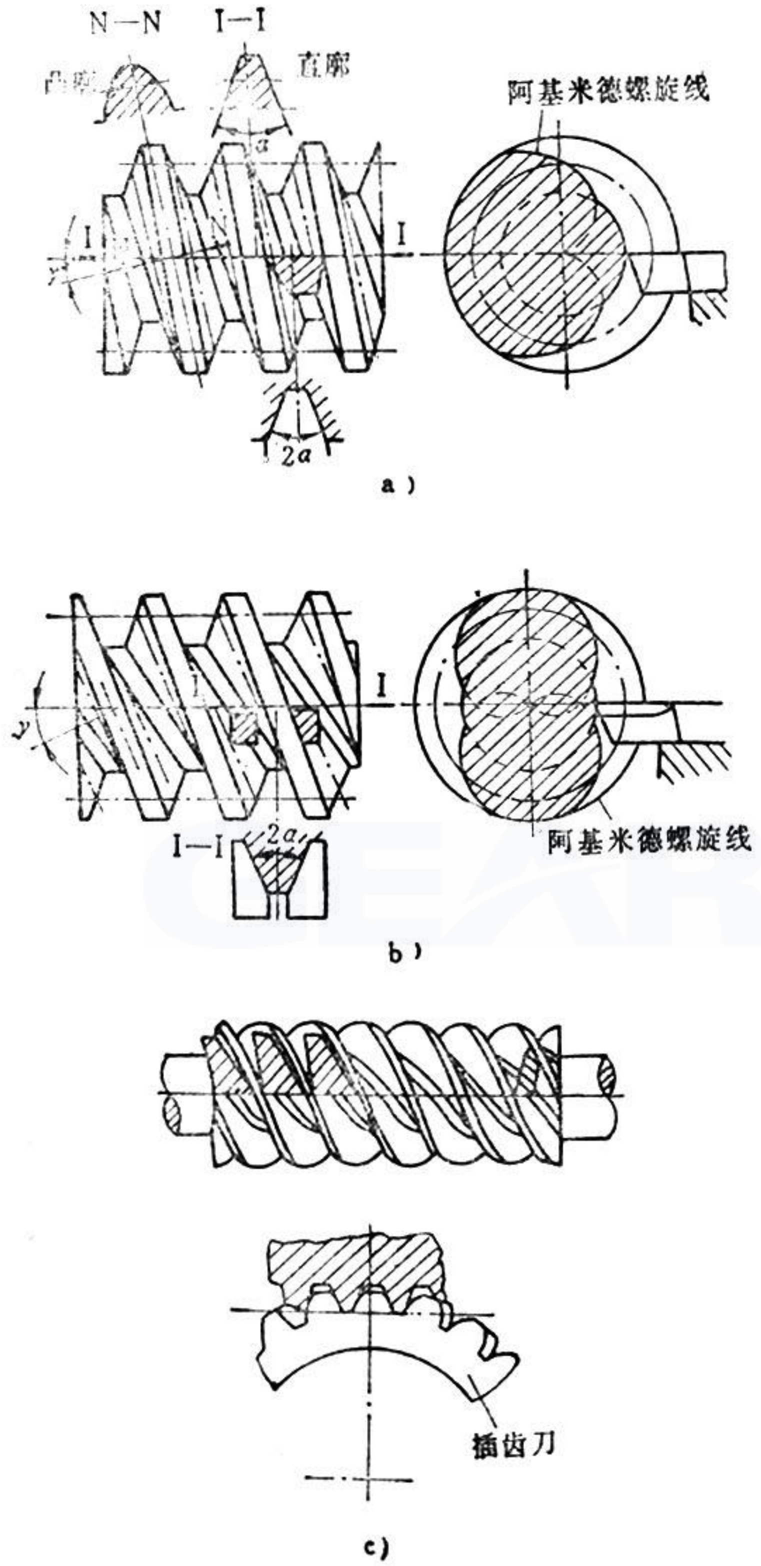


图 5-155

a）γ≤3°时用一把刀车削 b）γ>3°时用两把刀车削 c）用插刀加工

Straight Sided Normal Worm

Straight sided normal worm belongs to turning typed cylindrical worm with ruled surface. In the normal plane of helical surface, tooth profile is straight line with good turning performance. It can be divided into tooth space straight sided normal worm, tooth straight sided normal worm and flank straight sided normal worm.

N_1 (Tooth Space Straight Sided Normal Worm)

Tooth space straight sided normal worm belongs to turning typed cylindrical worm with ruled surface. On general lathe, putting the edge of trapezoidal turning tool on the normal plane vertical to the imaginary helical line that passing through the central point of tooth space and parallel to the helical line of reference cylinder, making the lathe tool running helically against the blank worm, then the tracing surface of edge profile is called helical surface of worm. This kind of worm turning technology has good performance but poor grinding technology, which is not applicable in hard-toothed worm. In such normal plane of imaginary helical line, the tooth profile of worm is straight line, and the tooth profile inside the transverse plane is long involutes. (Figure 5-156)

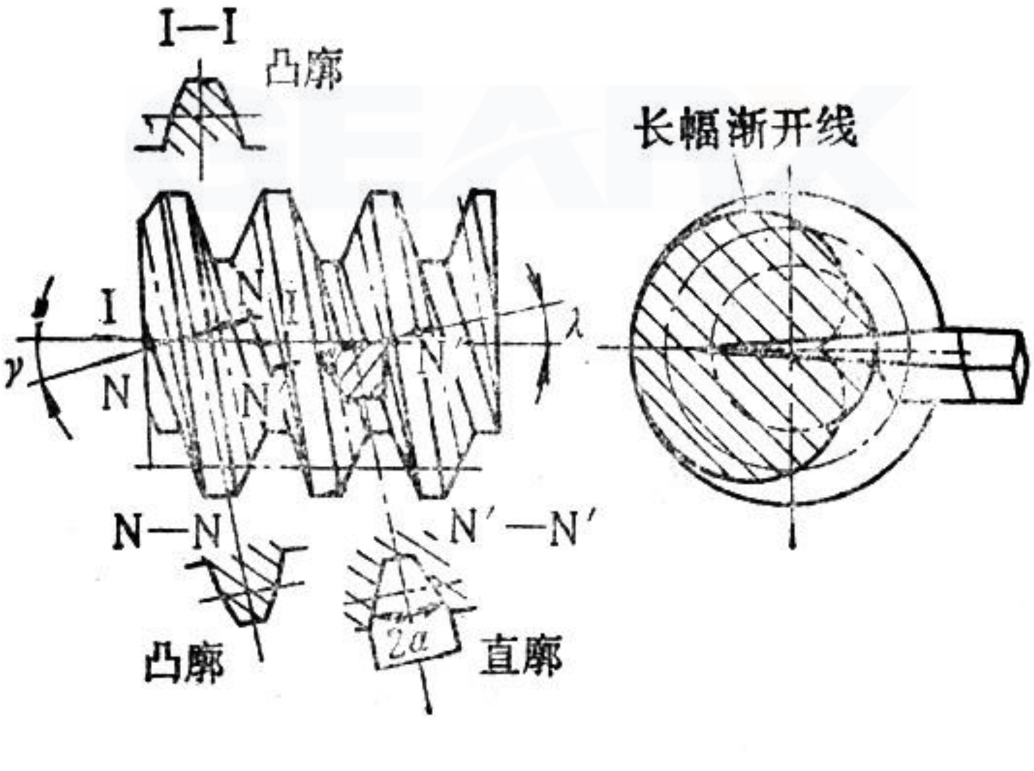


图 5-156

N_8 (Flank Straight Sided Normal Worm)

Flank straight sided normal worm belongs to turning typed cylindrical worm with ruled surface. On general lathe, putting the edge of turning tool on the normal plane which is vertical to the helical line of reference cylinder, making the lathe tool running helically against the blank worm, then the tracing surface of edge profile is called tooth surface of worm. The turning technology of ZN8 worm has relatively good performance but has some difficulty in grinding operation. In such normal plane, the worm has straight tooth profile and its transverse tooth profile has long involutes. (Figure 5-157)

This kind of worm is barely used.

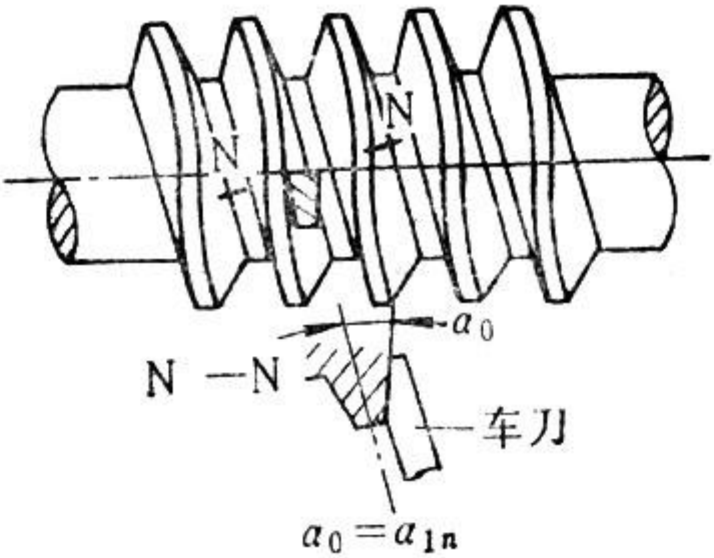


图 5-157

N_2 (Tooth Straight Sided Normal Worm)

Tooth straight sided normal worm belongs to turning typed cylindrical worm with ruled surface. On general lathe, putting the edge of trapezoidal turning tool on the normal plane which is vertical to the imaginary helical line that passing through the central point of tooth thickness and parallel to the helical line of reference cylinder, making the lathe tool running helically against the blank worm, then the tracing surface of edge profile is called helical surface of worm. The turning technology of ZN_2 worm has relatively good performance but has some difficulty in grinding operation. In such normal plane of imaginary helical line, the tooth profile of worm is straight line and the tooth profile in transverse plane is long involutes. (Figure 5-158)

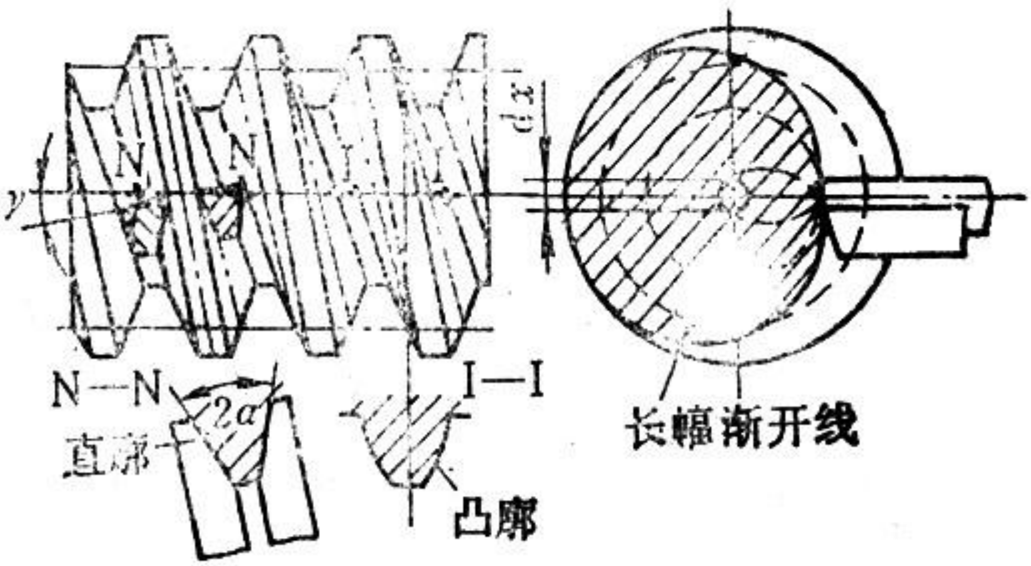
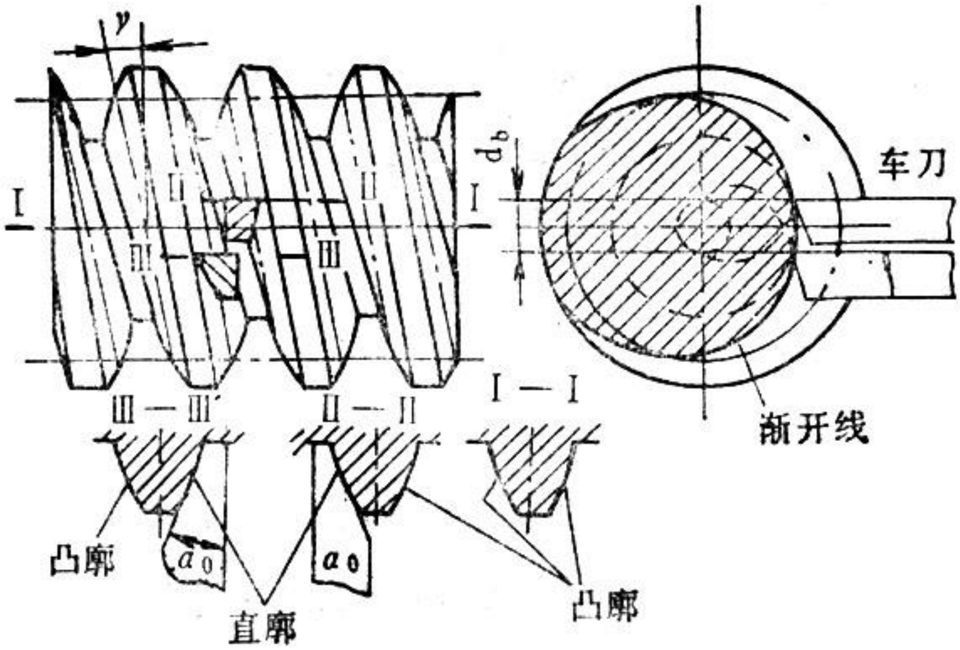


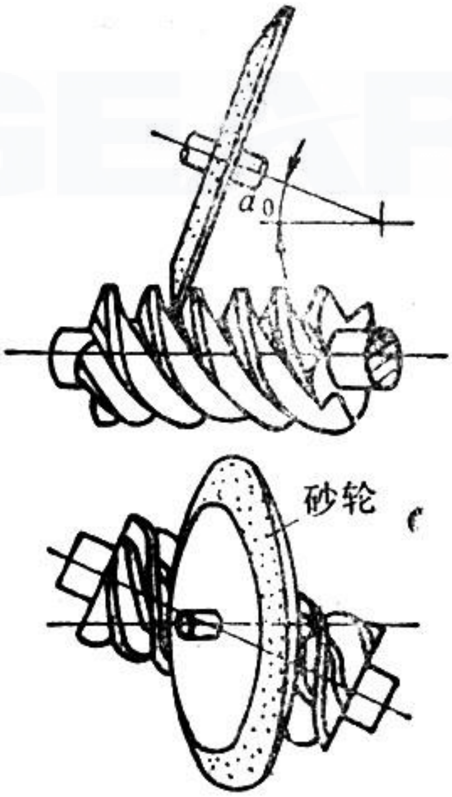
图 5-158

Involute Helicoid Worm

Involute helicoid worm belongs to turning typed cylindrical worm with ruled surface. On general lathe, putting the edge of trapezoidal turning tool on the section of base cylinder of blank worm and making the lathe tool running helically against the blank worm, then the tracing surface of edge profile is tooth flank of worm——involute helical surface (Figure 5-159a). Besides, the helical flank of worm can also be grinded by surface grinding (Figure 5-159b), then hard-tooth flank worm with high accuracy will be accessible. In the tangent plane of base cylinder, the tooth profile of involute worm is straight line and the tooth profile inside the transverse plane is involute.



a）



$a_0 = a_{1n}$

b）

图 5-159

Cylindrica1 Worm with Curved Surface

Cutting the helical plane of cylindrical worm with a plane, if the transversal (profile) is a curve, then this kind of worm is called cylindrical worm with curved surface. The helical surface of worm of cylindrica1 worm with curved surface can be the tracing surface of lathe tool with curved edge or be enveloping flank of disk cutter. These types are listed as follows:

Cylindrica1 worm with curved surface:

- Milled helicoid worm with disk [ZK_1 Worm]
- Milled helicoid worm with finger [ZK_2 Worm]
- Transverse milled helicoid worm [ZK_3 Worm]
- Enveloping worm with toroid [ZC_1 Worm]
- Cylindrica1 worm with toroid [ZC_3 Worm]
- Cylindrical worm with axial circle-arc tooth [ZC_3 Worm]

Enveloping Type Worm

Manufactured with generating method, the helical surface of worm is enveloped surface of active face of cutter. This kind of worm is called enveloping type worm. Enveloping type worm can be used in hard-toothed flank and have good performance in manufacturing quality. The commonly seen are:

Enveloping type cylindrical worm:

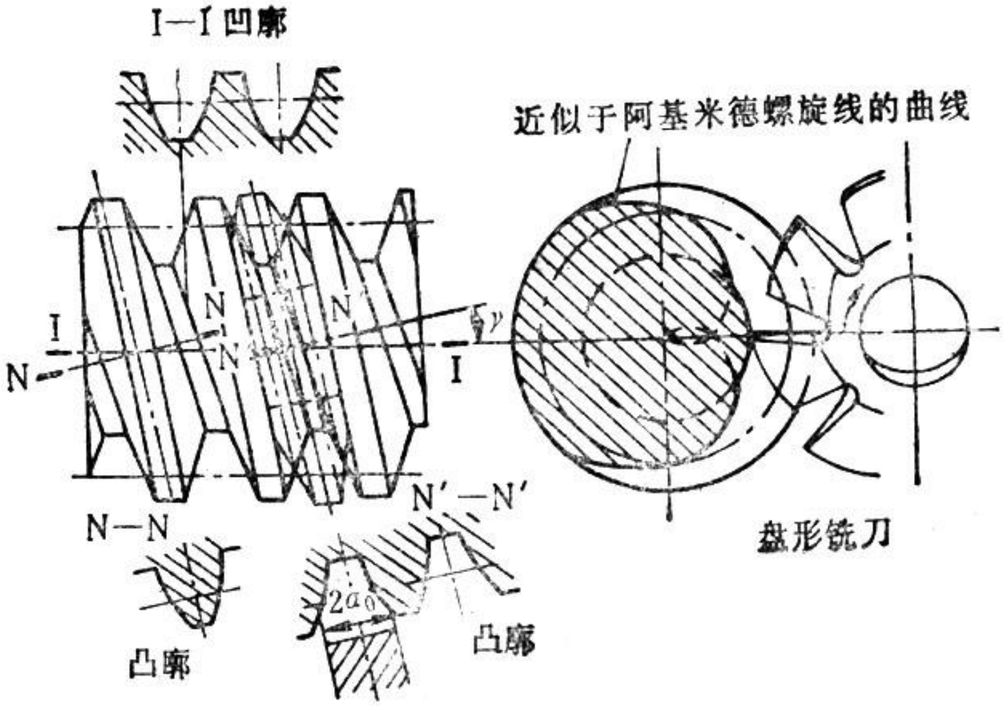
- Milled helicoid worm with disk (ZK_1 Worm)
- Milled helicoid worm with finger (ZK_2 Worm)
- Transverse milled helicoid worm (ZK_3 Worm)
- Enveloping worm with toroid (ZC_1 Worm)
- Cylindrica1 worm with toroid (ZC_2 Worm)
- Planar enveloping worm with toroid (TP Worm)
- Toroid enveloping worm with cone generatrix (TK Worm)
- Involute enveloping worm with toroid (TI Worm)

Milled HeIicoid Worm

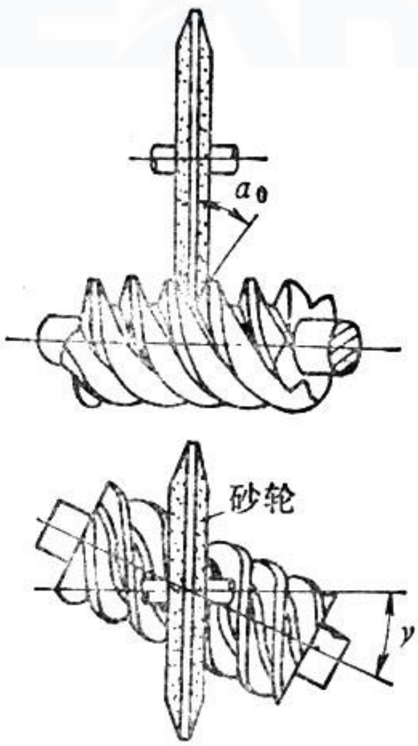
Milled heIicoid worm belongs to enveloping type cylindrical worm with curved surface. The tooth flank is conical enveloping flank. This kind of worm is called ZK worm. It can be divided into milled helicoid worm with disk (ZKl worm), milled helicoid worm with finger (ZK2 worm) and transverse milled helicoid worm (ZK3 worm).

Milled Helicoid Worm with Disk

Milled helicoid worm with disk belongs to enveloping type cylindrical worm with curved surface. It is cylindrical worm enveloped (generated) by cone grinding wheel with disk (or milling cutter). Generally, make the axial plane of tool with disk overlap with the normal plane of imaginary helical line which is passing through the central point of tooth space and parallel to the helical line of reference cylinder. When tool with disk moving across not only its own axis but also the balk worm, then the enveloping surface of milled helicoid edge profile forms helical surface of worm. This kind of worm has good grinding technology and can make hard-tooth flank worm with high accuracy, which has a quite promising future. (Figure 5-160)


I—I 凹廓
近似于阿基米德螺旋线的曲线
N
N
N
N'
I
I
γ
N—N
N'—N'
$2\alpha_0$
凸廓
凸廓
盘形铣刀

a)


α_0
砂轮
γ

b)

图 5-160

Milled Helicoid Worm with Finger

Milled helicoid worm with finger belongs to enveloping type cylindrical worm with curved surface. Putting the milled cutter with finger (or conical surface grinding wheel) on the intersecting position of axial line passing through the central point of tooth space and the axis of blank worm, when the finger-shaped cutter rolling not only across its own axis, but also make helical movement against blank worm, then the enveloping flank of the edge is the tooth flank of worm. ZK2 has good performance and applicable to hard-toothed flank with high accuracy. (Figure 5-161)

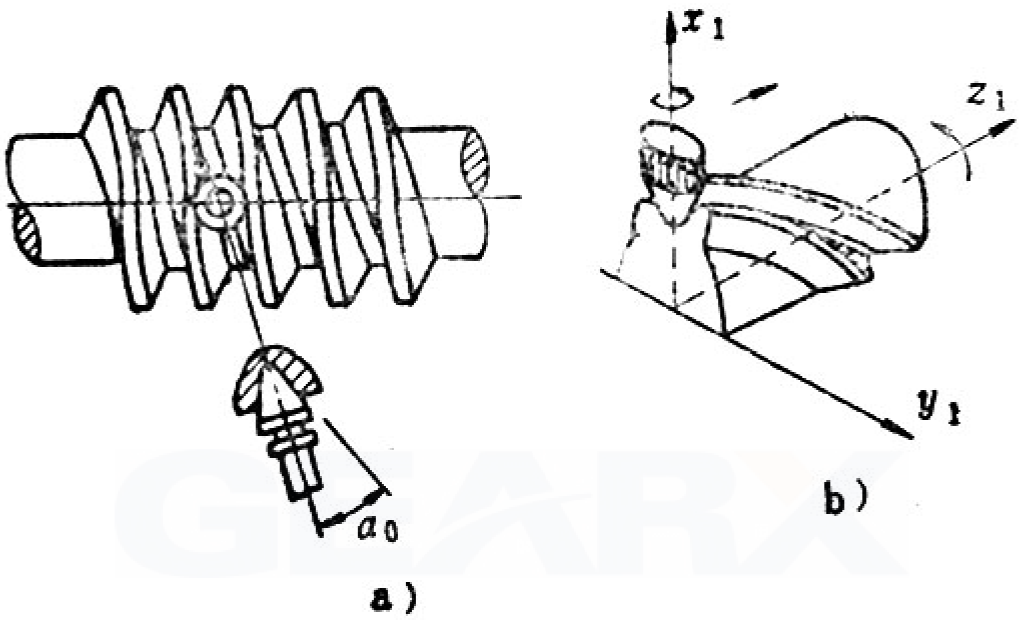


图 5-161

ZK_3 (Transverse Milled Helicoid Worm)

Transverse milled helicoid worm belongs to enveloping type cylindrical worm with curved surface. Putting the axis whose end has the butterfly-shaped tapered cutter (or grinding wheel) at the position where the axis is alternatively vertical to the axis of worm, when the cutter rolling not only across its own axis, but also make helical movement against blank worm, then the enveloping flank of the cutter is the tooth flank of worm. The worm tooth flank has good performance and applicable to case-hardened worm with high accuracy (Figure 5-162).

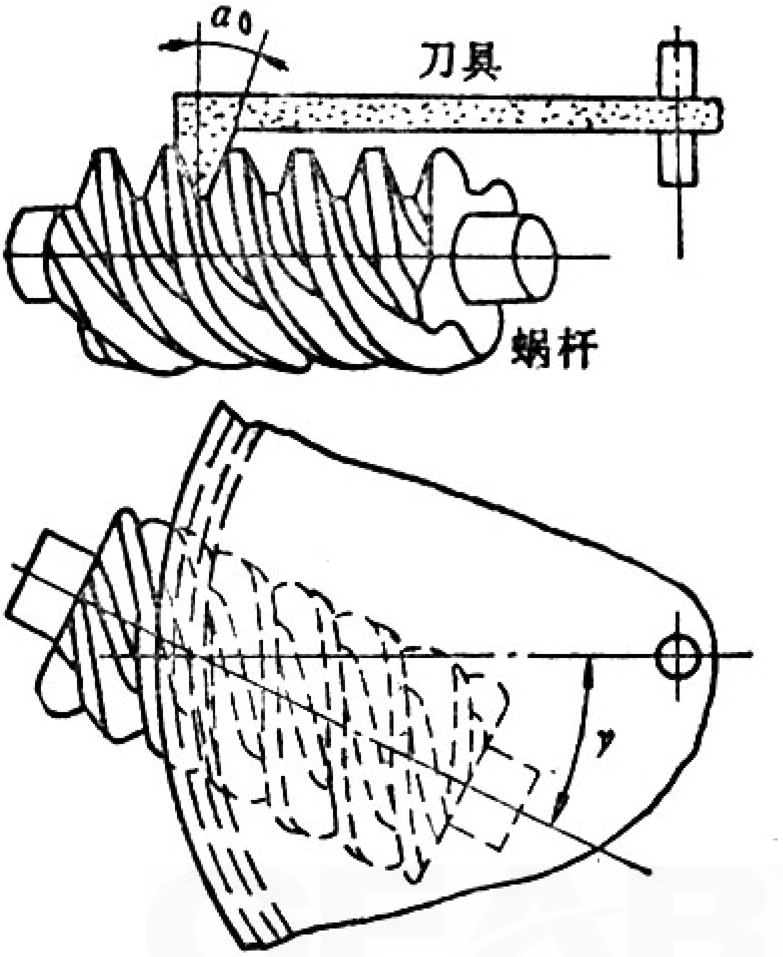


图 5-162

Arc-contact Hollow Flank Worm/ZC-worm

When the axis plane or normal plane of a cylindrical worm is arc or enveloping surface of toroid, then this kind of cylindrical worm is called arc-contact hollow flank worm ZC worm. Generally, ZC worm refers to the worm with concave tooth profile and the worm whose generating tooth flank of tooth surface is toroid. According to GB10086—88, there are three forms for the worm:

They are enveloping worm with toroid, cylindrica1 worm with toroid and cylindrical worm with axial circle-arc tooth.

Besides, there are also double-arc-contact hollow flank worm; enveloping worm with transverse toroid; normal arc-contact hollow flank worm; base cylinder tangent arc-contact hollow flank worm. These worms can compose into arc-contact hollow flank worm with their matching worm wheel and have good meshing performance.

ZC_1 (Enveloping Worm with Toroid)

Enveloping worm with toroid belongs to curved-profile enveloping worm gear. The tool is toroid grinding wheel (or hobbing). In the axial plane of the tool, generating shape line is a section of convex arc of the tracing circle of the toroid.

Putting the axial line of tool in the normal plane of the imaginary spiral line which crosses the central point of tooth space and is parallel to the spiral line of the reference circle, then the shaft angle between the axial line of tool and worm is γ_1. When the tool rotating about its own axle and at the same time, making spiral movement against worm, then the enveloping surface of the active face of cutter is called spiral surface of worm. ZC1 worm has good grinding performance, with which case-hardened worm with high accuracy can be acquired. This kind of worm is one of the most promising worms in cylindrical worm (Figure 5-163).

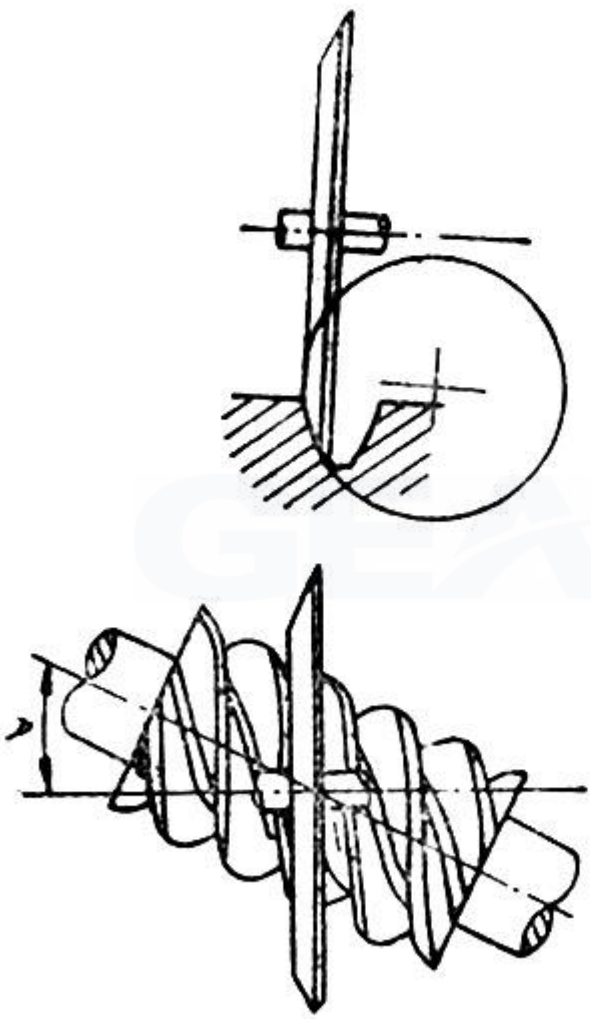


图 5-163

Cylindrica1 Worm with Toroid

Cylindrica1 worm with toroid belongs to curved-profile half-enveloping worm. The tool is toroid grinding wheel (or hobbing). In the axial plane of the tool, generating shape line of tool is a section of (convex) arc of the tracing circle of the toroid. Putting the tool at the position of shaft angle between the axle of tool and the axle of worm where $\gamma_0 = \gamma_1$. At this position, the center of tracing circle of active face of the tool falling in the meshing shaft Ⅱ—Ⅱ must be satisfied, which means that the center of tracing circle must be falling on the line of centers between the axial line of worm and tool (Figure 5-164). Now, making the tool rotating about its own axle and at the same time, making spiral movement against the blank worm, then the half-enveloping surface of the active face of grinding wheel will form into the spiral surface of worm. During the worm manufacturing process, the deduction of the dressing diameter of grinding wheel would not affect the shape of spiral surface of worm. In the axial plane of the cutter, the tooth profile of worm is a concave arc which is consistent with the tracing circle arc of the tool. The grinding technology of worm is relatively good and case-hardened tooth surface can be applied. But in practical manufacturing process, there are some difficulties in assuring the theoretical installing position (Figure 5-164).

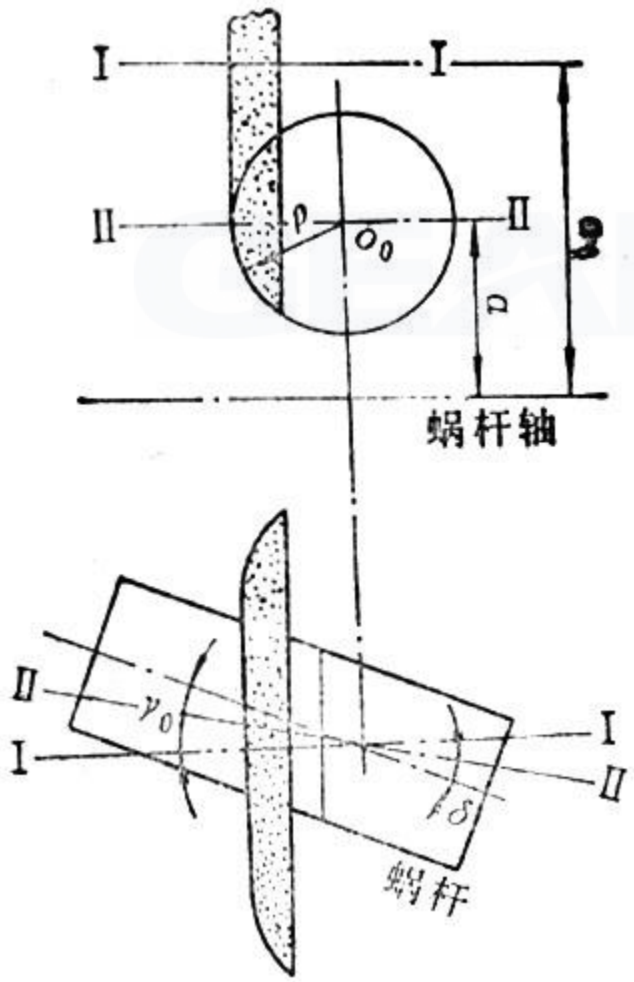


图 5-164

ZC$_3$ (Cylindrical Worm with Axial Circle-arc Tooth)

Cylindrical worm with axial circle-arc tooth belongs to curved-profile tuning typed cylindrical worm. On common engine lathe, putting the active face of lathe tool of convex arc's cutting edge profile in the axial plane of blank worm a making the turning tool making spiral movement against the blank worm, then the trace surface of the blade profile is called spiral surface of worm. ZC3 worm has good turning technology but relative poor grinding technology. In the axial plane, ZC3 worm has concave arc tooth profile (Figure 5-165).

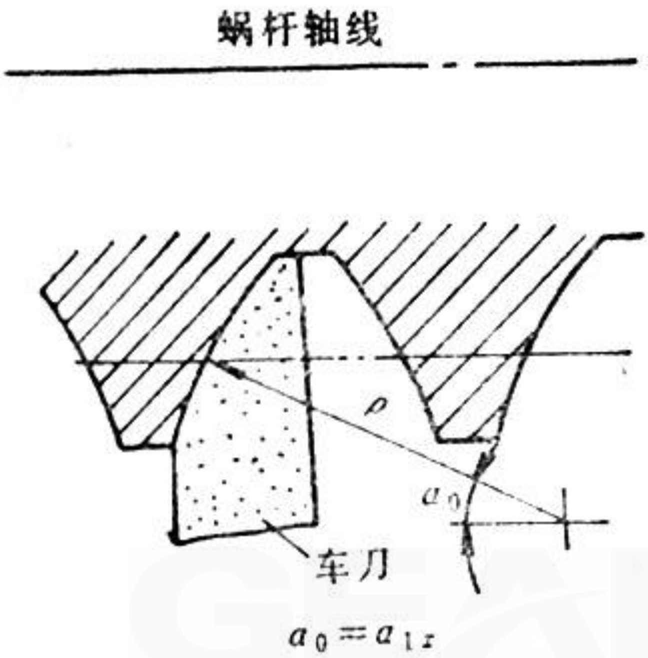


图 5-165

Cylindrical Worm with Base Cylinder Tangential Circular-arc Tooth

Cylindrical worm with base cylinder tangential circular-arc tooth belongs to turning typed curved-profile cylindrical worm. Its tooth profile in the tangential plane of base cylinder is concave arc. On common engine lathe, putting the active face of lathe tool of convex arc's cutting edge profile in the tangential plane of the base cylinder and making the cutter making spiral movement against the blank worm, then the trace surface of the blade profile is called spiral surface of worm. This kind of worm has good turning technology but relative poor grinding technology (Figure 5-166).

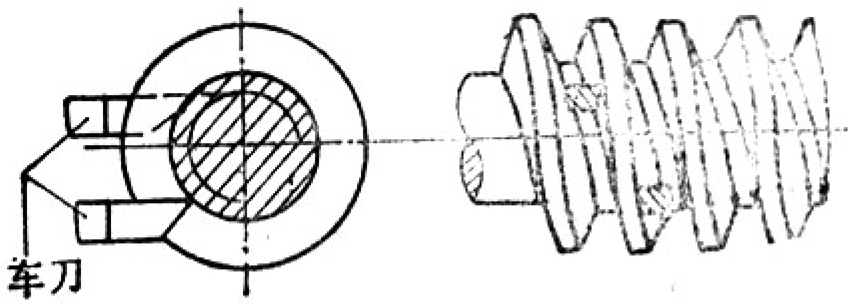


图 5-166

Circular-arc Tooth Cylindrical with Normal Tooth Space

Circular-arc tooth cylindrical with normal tooth space belongs to turning typed curved-profile cylindrical worm. On common engine lathe, putting the blade profile of convex arc in the central point of tooth space, and make it parallel to the normal plane of imaginary spiral line of spiral line of reference cylinder, making spiral movement against blank worm, then the trace surface of blade profile is the tooth profile of the worm. When the angle γ is relatively large, the turning technology has good performance. Circular-arc tooth cylindrical with normal tooth space can replace the ZC_3 worm but has relatively poor performance (Figure 5-167).

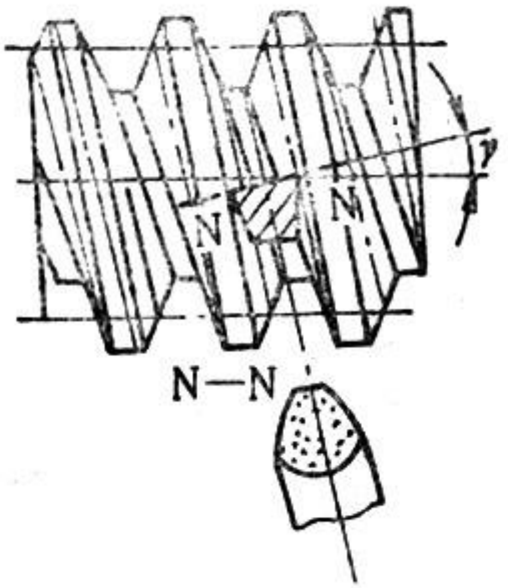


图 5-167

Variable Lead Worm

Variable lead worm refers to the worm whose lead would change gradually or the two sides of the worm gear teeth have different lead, for example, dual lead cylindrical worm and fully modified enveloping worm.

Dual Lead Cylindrical Worm

Dual lead cylindrical worm refers to the cylindrical worm whose lead of the two sides of the spiral plane of worm wheel teeth is not equal. The tooth thickness of worm changes accumulatively along the gear helix and form gradient tooth thickness. Therefore, this kind of gear is also called variable thickness cylindrical worm gear. Dual lead cylindrical worm is same with single lead cylindrical worm. The most commonly used tooth profile are A, I, N and K etc.

Crowned Cylindrica1 Worm

The reference surface of worm is crowned cylinder. As the picture shows, the formation of spiral surface can be turning type or enveloping type, but the technology of the two are inferior to that of cylindrical worm (Figure 5-168).

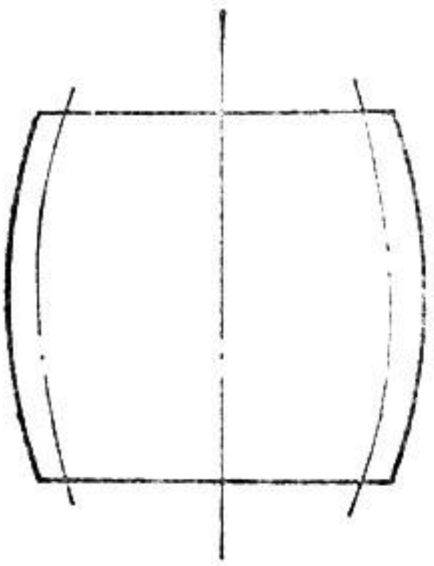


图 5-168

Style of Worm Whee1 Tooth of ZC Worm Gear Pair

With regard to circular-arc tooth cylindrical worm gear pair, if the parameters are not well-chosen after the worm taking shape, there would be obvious situation on the worm tooth flank, as shown in the Figure 5-169. This is called style of tooth. At the dedendum of tooth flank, there are undercutting areas (concave); the two ends have distinct tool marks. The larger the modification coefficient is, the clearer this phenomenon will be, and the tool marks and contact line has positively intersecting tendency. There are also subtle traces in the conjugate area, which is also called the sign of contact line.

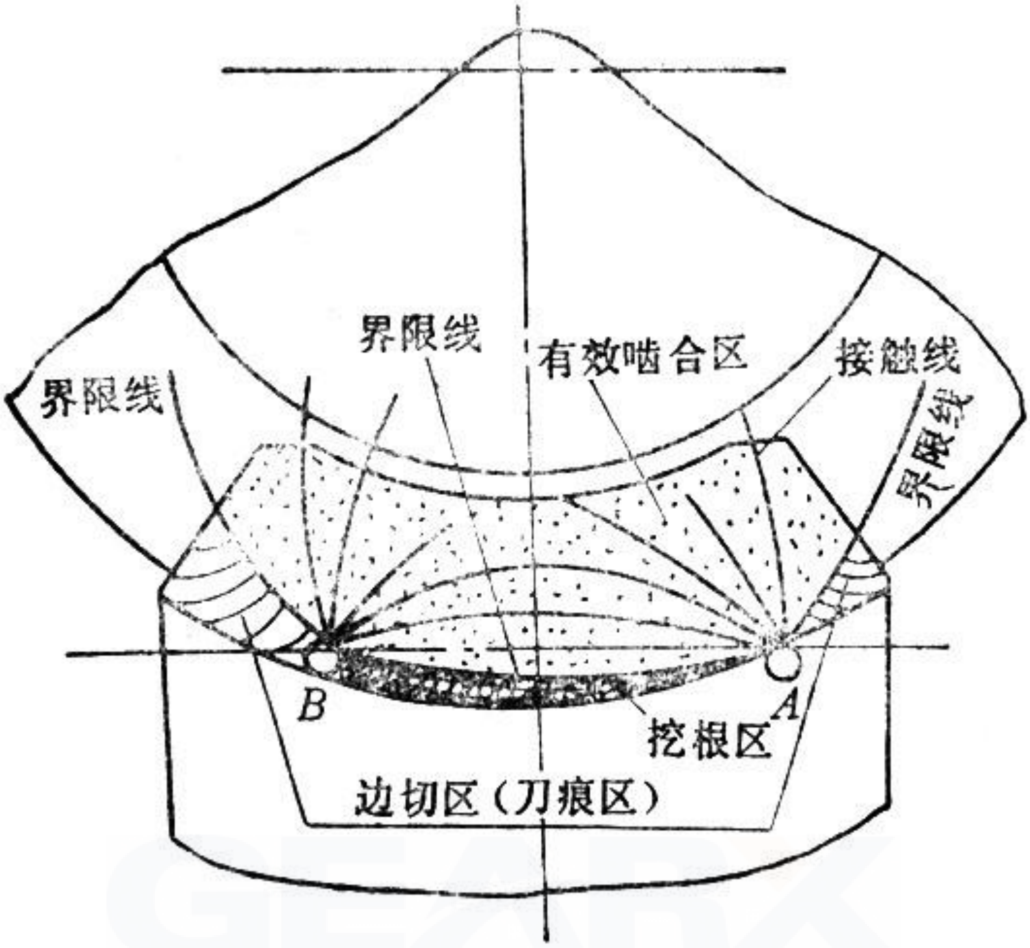


图 5-169

Tip Relief of Cylindrical Worm

As shown in Figure 5-170a, in order to mesh on the tooth surface of worm, the addendum of worm must be avoided from participating in the meshing process. Therefore, making tip relief is quite necessary (Figure 5-170b). The relief value Δa of circular arc tooth cylindrical worm can be two thirds of the deviation of center distance. For ruled-surface cylindrical worm, the relief methods and value are same with that of gears (Figure 5-170).

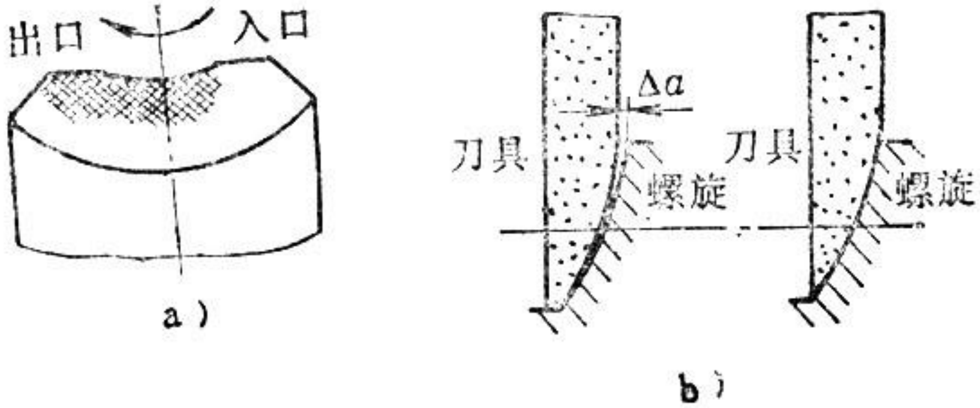


图 5-170

Modified Circular Arc Radius

When processing circular-arc tooth cylindrical worm (ZC worm), the circular arc of the generating line of tool used is ρ, the circular arc radius of generating line of the hobbing used is $\rho_0 = \rho - \Delta\rho$, $\Delta\rho = (0.04 \sim 0.07)\pi m$. This result will make both the addendum and dedendum of worm cutting a layer of metal (Figure 5-171).

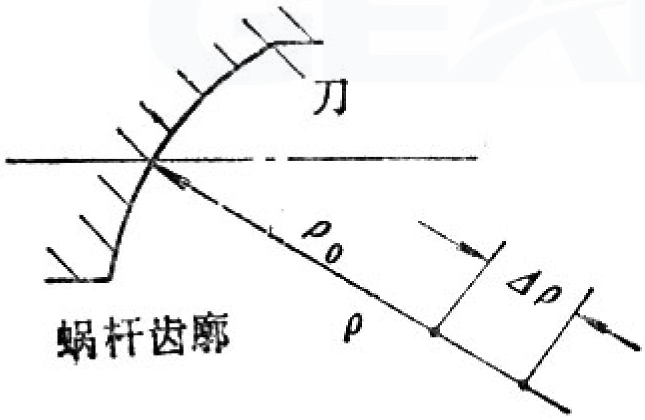


图 5-171

Basic Worm

Basic worm is used to confirm the size and shape of worm gear tooth. Basic worm is an ideal worm without any manufacture error.

5.4.4 Toroid helicoids worm

Throat lead angle

Throat lead angle refers to the lead angle whose toroid helicoids worm is located at throat. Toroid helicoids worm is variable diameter worm. The lead angle is different at various positions. It has minimum diameter of reference circle and largest lead angle at the part of throat.

Worm throat

In toroid helicoids worm, the position of the inner circle of addendum circle torus is called the throat of toroid helicoids worm. Located at the calculated plane, worm throat is the smallest part on the size of worm outline.

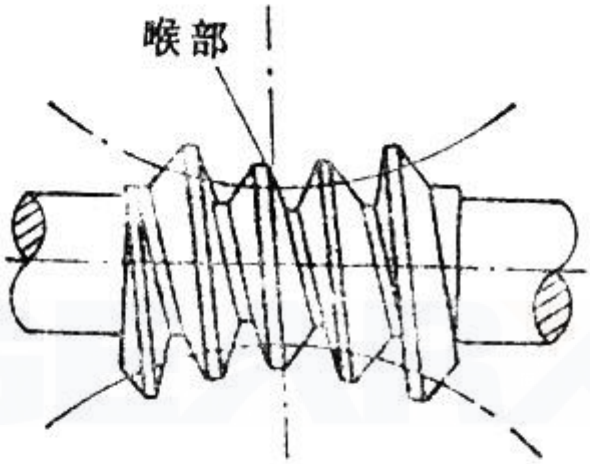


图 5-172

Gorge plane of worm

Gorge plane of worm refers to the transverse plane of worm containing line of centers (Figure 5-173).

It is overlapped with the calculated plane of toroid helicoids worm. That calculated plane refers to the flat surface where the inner circle of torus located in.

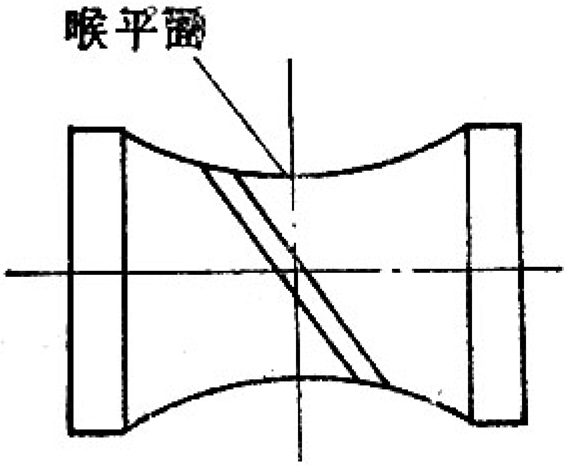


图 5-173

Gorge—normal plane of worm

Gorge—normal plane of worm refers to the plane that passes the crossing point of midpoint of the worm gear tooth helix and the gorge plane, it is also vertical to the helix at the central point of gear teeth of worm.

Tip cylindrical surface of enveloping worm

Tip cylindrical surface of enveloping worm refers to cylindrical shaped tip surface on the tip curved surface of worm (Figure 5-174).

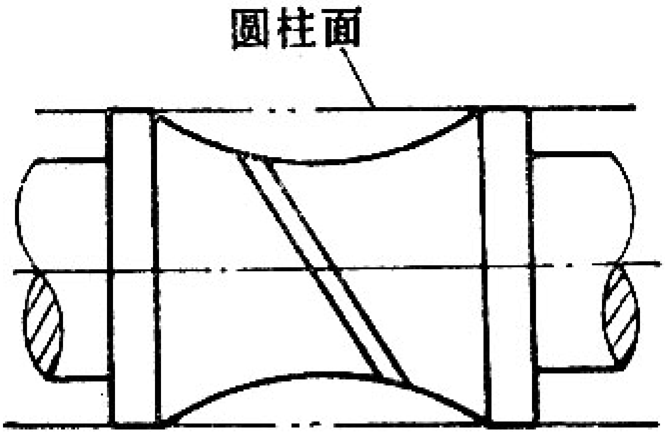


图 5-174

Tip circle of enveloping worm

Tip circle of enveloping worm refers to the inner circle of tip circle torus of enveloping worm. When $\Sigma = 90°$, it also refers to the line of intersection between tip surface of worm and the calculated plane. Diameter of the circle $r_{a1} = \frac{d_{a1}}{2} = d_1 + 2h_a^* m$ (Figure 5-175).

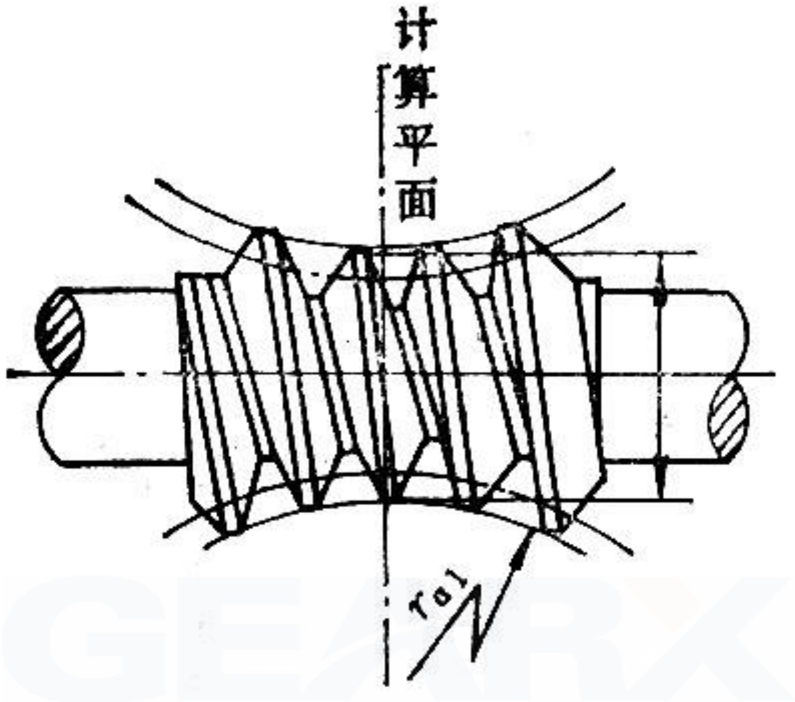


图 5-175

Reference circle of enveloping worm

Reference circle of enveloping worm refers to the inner circle of reference circle torus of enveloping worm. When $\Sigma = 90°$, it also refers to the intersecting circles formed between the reference surface and calculated plane. (Figure 5-176)

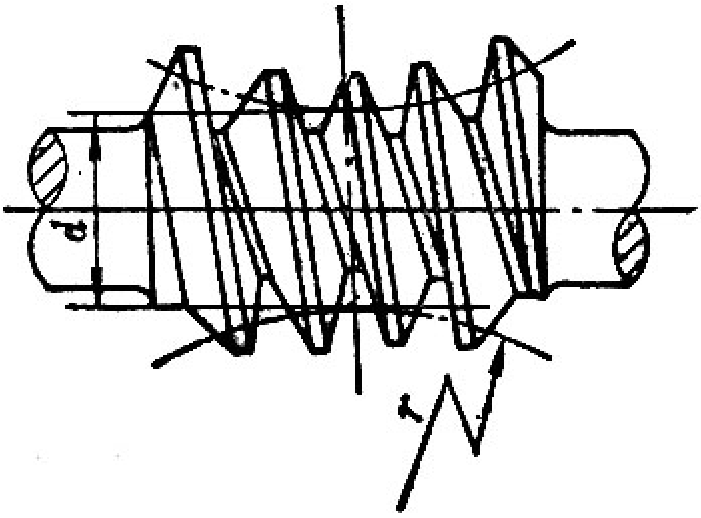


图 5-176

Root circle of enveloping worm

Root circle of enveloping worm refers to the inner circle of root circle torus of enveloping worm. When $\Sigma = 90°$, it also refers to the intersecting circle formed between the root surface and calculated plane (Figure 5-177).

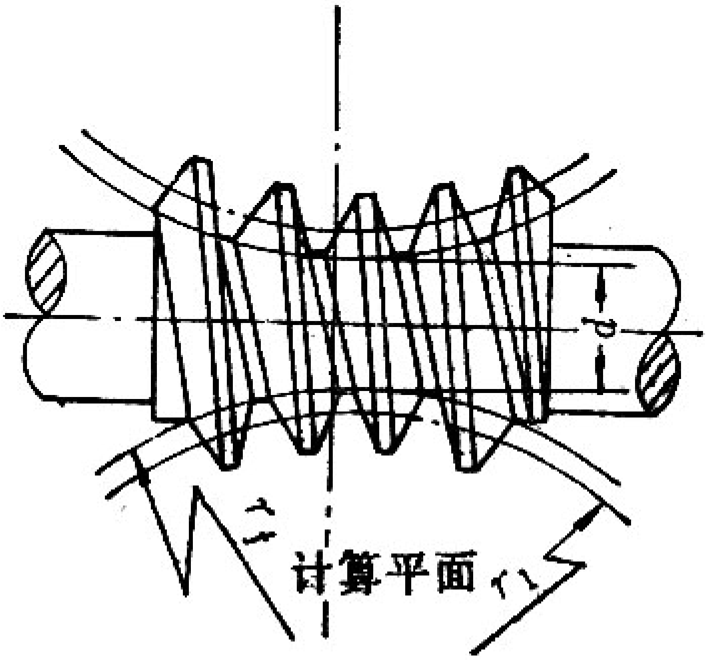


图 5-177

Crest toroid of worm

Crest toroidal surface of worm refers to the enveloping worm whose tip surface of gear tooth is toroid. It has the same neutral circle and axis (worm axis) with reference toroid. The radius of generating circle is $r_a = a - r_{a1}$.

Reference toroid

When reference surface of worm wheel of enveloping worm is toroid, then this kind of toroid is called reference toroid. As for worm wheel matched with enveloping worm (or cylindrical worm), reference toroid refers to a stipulated toroid that has the same axis with worm wheel. Its generating circle is the pitch circle of the meshed worm. As for enveloping worm, reference circle refers to a stipulated imaginary toroid that has the same axis with worm. Generating circle is a circle belonging to one of its meshed worm wheel. The circle is tangent to the reference circle of worm. Under the standard meshing circumstance, the generating circle of worm and worm wheel refers to the corresponding reference circle (Figure 5-178).

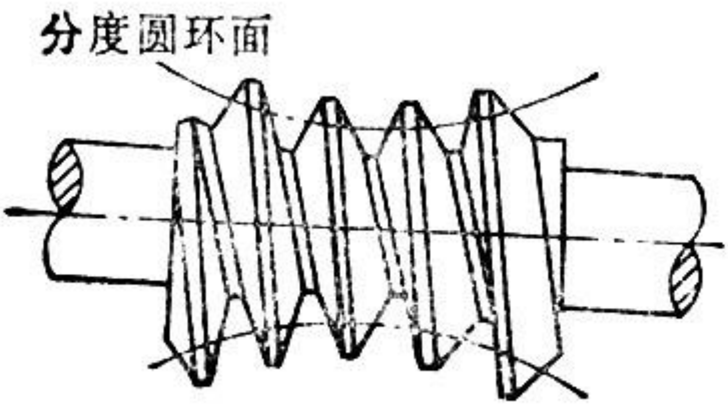


图 5-178

Root toroid of worm

In enveloping worm, toroid that is tangent to the bottom of tooth space is called root toroid of worm. It has the same neutral circle and axis (worm axis) with the reference toroid. The radius of generating circle is $r_f = a - r_{f10}$.

Shoulder width of worm

Shoulder width of worm is half the length of tip cylinder of enveloping worm (Figure 5-179).

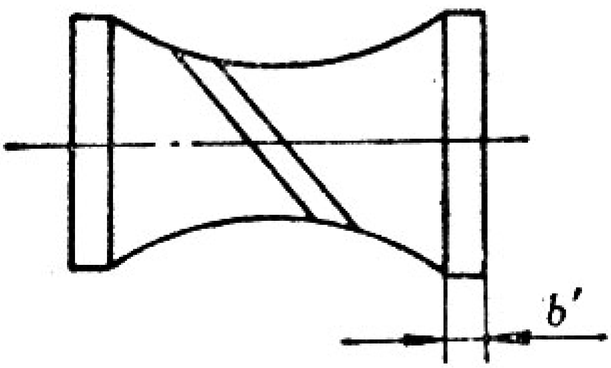


图 5-179

Maximum circle of worm

The circle formed by the intersection of the solid part of tip toroid of enveloping worm and its transverse plane (Figure 5-180).

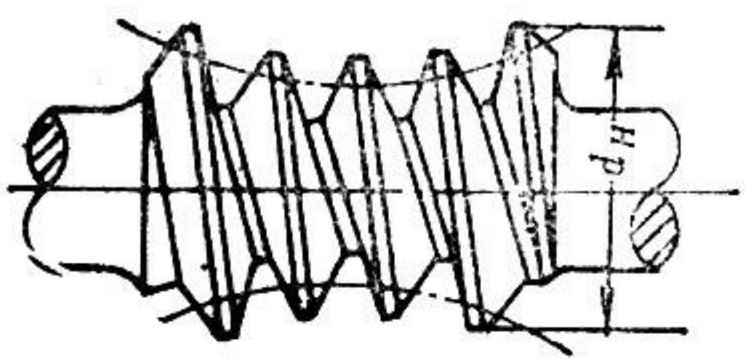


图 5-180

Theoretical contained teeth

In enveloping worm gear pair, the relation between teeth number of worm wheel z_0 contained by the theoretical wrapped angle and the working contained teeth is roughly: $z_0 = \frac{z'}{0.9^\circ}$.

Theoretical wrapped angle

In the central plane of enveloping worm pair, the central angle $2\varphi_0$, which is tangent to the two lines of formed-circle vertical worm shaft and corresponding to the reference circle arc is called theoretical wrapped angle. And φ_0 is called half of the theoretical wrapped angle.

Working contained teeth

In enveloping worm pair, teeth number of worm wheel in working wrapped angle, or namely, the running teeth number of worm wheel z', are called working contained teeth. As a rule, the relation between working contained teeth and teeth number of worm wheel is $z'=z_2 / 10$.

Working wrapped angle

Working wrapped angle refers to the central angle of worm wheel corresponding to the reference circle arc formed between the transverse planes at the two ends. The same with half of the angle is called half of the working wrapped angle (Figure 5-181).

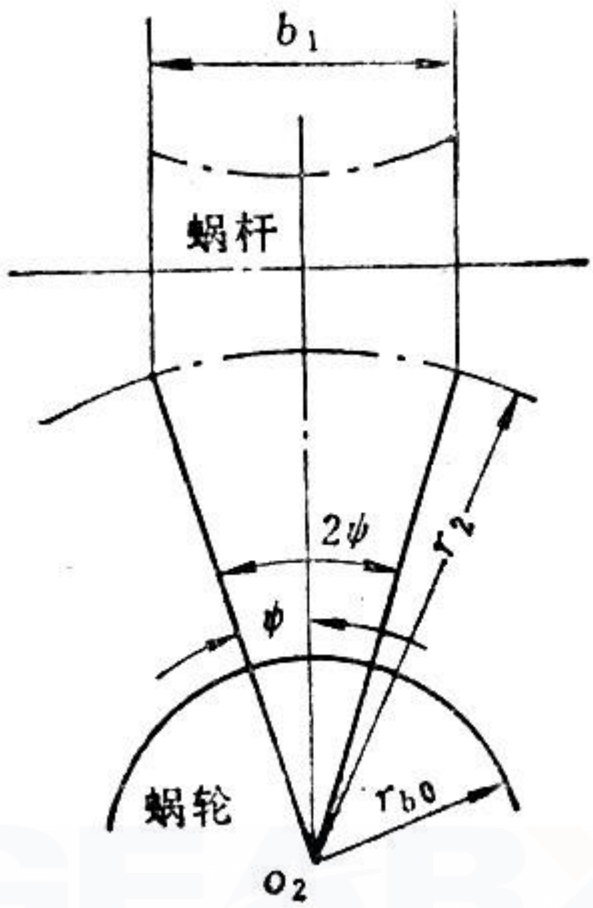


图 5-181

Formation circle of hindley-worm

In the central plane of hindley-worm pair, the circle that is tangent by the extended line at the two sides of gear teeth is called formation circle of hindley-worm. Generally, formation circle of hindley-worm is homocentric with worm wheel. Formation circle is also a circle that is tangent to the two cutting-edge- profile straight line of forming lathe tool (Figure 5-182).

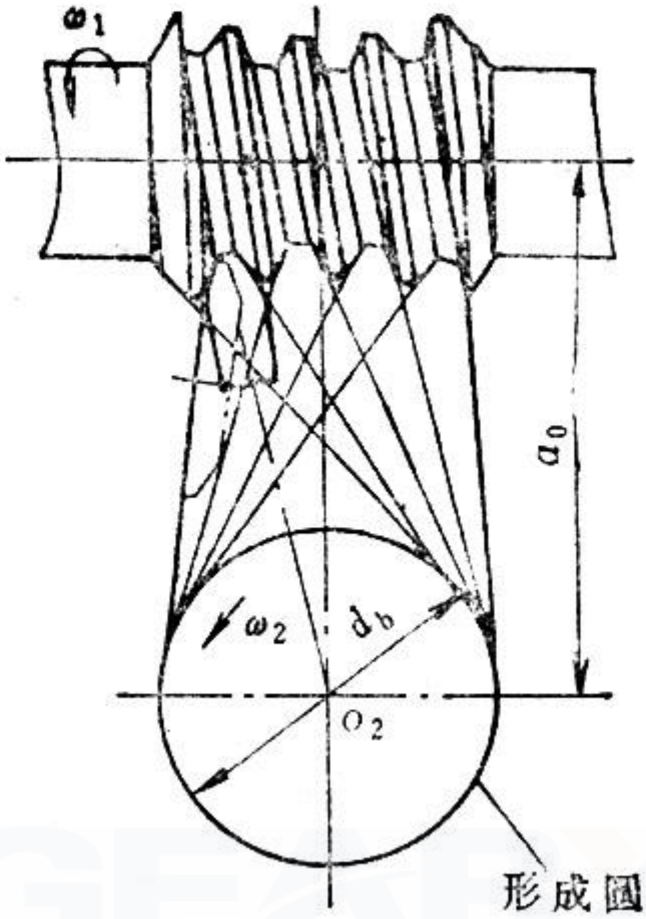


图 5-182

Working face width of worm

The chord length of reference circle of worm wheel corresponding to the actual contained teeth number measured from the axial direction of worm is called working face width of worm.

Start working angle

During the process of processing hindley-worm with shaping lathe tool, an acute angle will be formed by the straight line and the line of direction which is vertical to the axis of worm within the mid-plane when the cutting start going on. This acute angle is called the start working angle. The value is equal to the difference of pressure angle and working wrapped angle.

Depression

See “original hindley-worm matched tooth flank of worm wheel”

Calculated plane

In enveloping worm pair, calculated plane refers to the plane that is vertical to the axis of worm and containing its line of centers (when Σ=90°, axis of worm wheel is also included). Calculated plane is a transverse plane of worm. It is vertical to the mid-plane. The minimum diameter of worm is contained in this plane. Geometrical sizes can be calculated here. Therefore, this plane is called the calculated plane of enveloping worm pair, shortly, calculated plane.

Formation cylinder

See "planar worm wheel".

Formation cone

See "planar worm wheel".

Enveloping worm

Enveloping worm refers to the worm whose reference surface is toroid. What the reference surface of this kind of worm use is just part of the inner surface of the toroid, in which the whole inner circle of the toroid is contained.

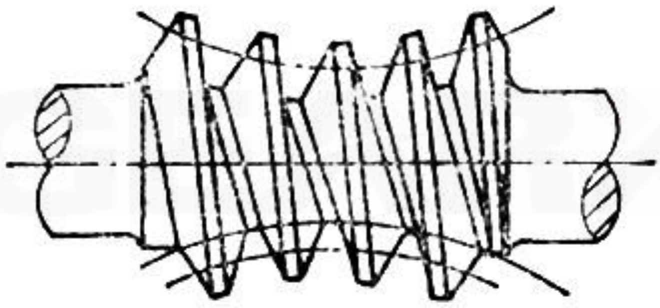
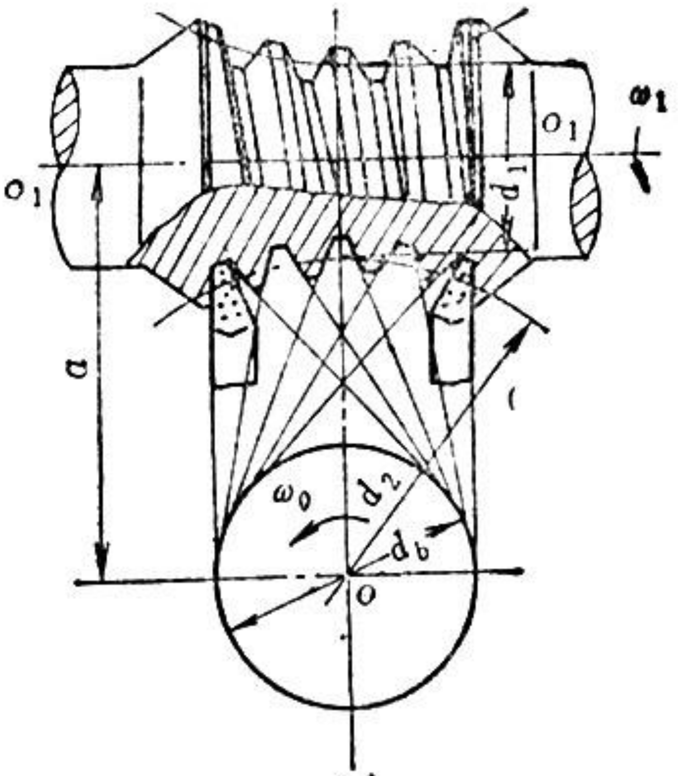


图 5-183

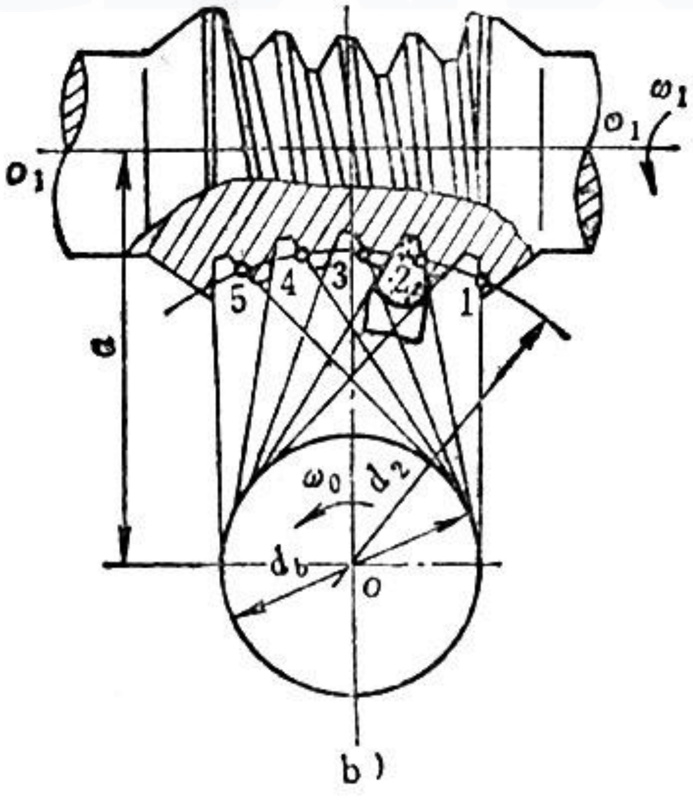
Enveloping worm can be divided into turning-typed and enveloping-typed.

Double enveloping worm with straight line generatrix, TA-worm

Double enveloping worm with straight line generatrix refers to the enveloping worm with straight lined axial tooth profile (Figure 5-184). The upper part of a formation circle, locating in the same plane with worm axis, links two tangent edges with fixed angle 2α. When worm and formation circle rotate respectively around its axis and center in a given angle's ratio, the trace surface of the two tangent edges is called helical surface of worm, which is a type of turning-typed worm. The tooth flank of worm is undevelopable surface. Double enveloping worm with straight line generatrix can be divided into "original-typed" and "modified-typed".



a）



b）

图 5-184

Non-expansion enveloping worm

Making hindley-worm with two formed turning tools on special purpose machine based on trace principles. The tooth flank is non-expansion ruled surface. This kind of worm is called non-expansion enveloping worm.

Double enveloping worm wheel with straight line generatrix

Taking double enveloping worm with straight line generatrix as tool, double enveloping worm wheel with straight line generatrix is helical surface gear manufactured in direct generating method. The reference surface of tooth is toroid, and its theoretical tooth flank is the envelope surface of helical surface of hindley-worm.

Basic hindley-worm

When cutting the helical surface of worm with straight-edged formed turning tool, the manufactured enveloping worm is called basic hindley-worm if the center distance α_0, transmission ratio i_0 of formation circle and worm is the same to the center distance α and transmission ratio i of worm gear pair. The main character is that the angular velocity ratio of worm blank and tool is a constant.

Mating worm wheel flank of basic hindley-worm

The worm wheel flank is manufactured with the tool of basic hindley-worm. It can be divided into three areas along the tooth length direction. The dividing line $c'-c'$ exiting between the area of Ⅱ and Ⅲ is just right in the central part of worm wheel, so it is called the middle ridge (a contact line) (Figure 5-185). The area of Ⅱ is conjugate area, which is, the valid working area. The area of I and Ⅲ are trimming area. The area of Ⅱ is relatively concave comparing to the area of Ⅰ and Ⅱ, and it is called “depression” (Figure 5-185). Depressing is quite critical to influence the bearing capacity and transmission efficiency. The “amendment-type” can expand the Ⅱ area apparently (Figure b), that means the valid working area can be enlarged.

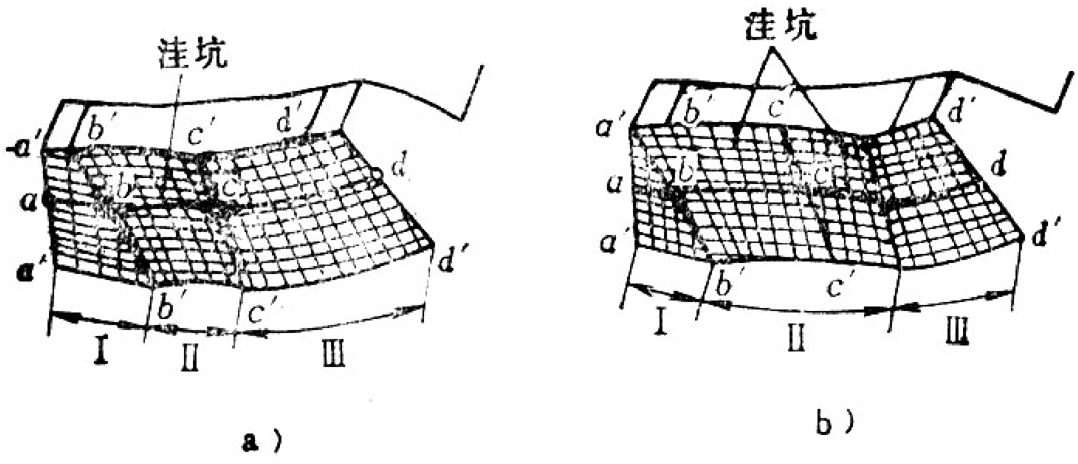


图 5-185

a）原始型　b）修正型

Expansion enveloping gear

Enveloping worm manufactured with face gear for generating wheel is called expansion enveloping worm. Its tooth flank is developable surface.

Wildhaber worm，TP-worm

Enveloping worm generated by taking straight tooth or helical face gear as generating wheel (tool wheel) is called Wildhaber worm. To be concrete, the envelope surface of active face formed when the active face of generating wheel, which is equivalent to the tooth flank of Wildhaber worm, makes movement corresponding to the worm blank based on the given transmission ratio and center distance, is called the helical surface of worm. Generating wheel can be disc milling tool and grinding wheel whose active face is tangent to the formation cylinder (or formation cone) (Figure 5-186).

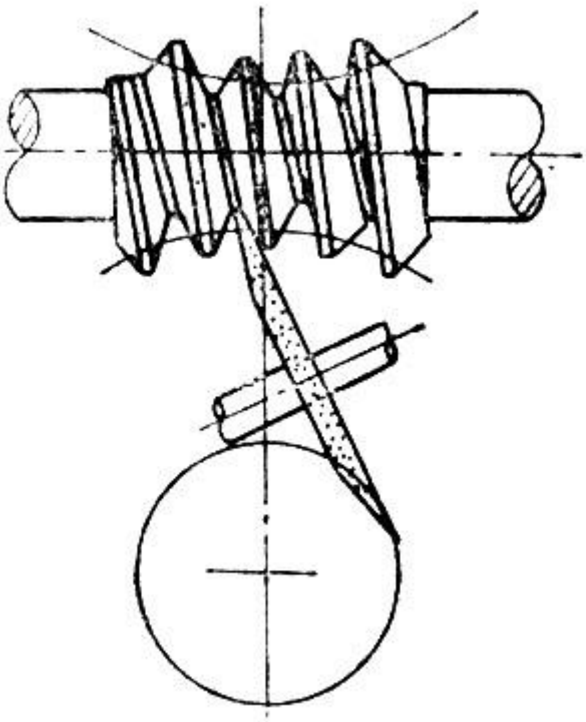


图 5-186

Wildhaber worm can be divided into two types: Wildhaber worm with straight tooth and Wildhaber worm with helical tooth. Worm with high precision hard tooth flank can be manufactured because of the simple process and high precision of generating gear.

Surface construction of once envelop

Given that there is no singular point on the tooth flank $\Sigma^{(1)}$, when using $\Sigma^{(1)}$ to generate the tooth flank $\Sigma^{(2)}$, if enveloping line $\overline{N_1N_1}$ of contact line exists on the tooth flank $\Sigma^{(1)}$ (Figure 5-187a), then $\overline{N_1N_1}$ is the second boundary line of tooth flank $\Sigma^{(1)}$. It divides the tooth flank into region of engagement and region of non-engagement. Points inside the region of engagement can become the second application point. On the tooth flank $\Sigma^{(2)}$, the envelope line of contact line is a ridge line $\overline{GG}$ (Figure 5-187b).The ridge line $\overline{GG}$ divides the tooth flank $\Sigma^{(2)}$ into two parts, one part is related to the entity of $\Sigma^{(1)}$. $\overline{GG}$ The conjugate line on $\Sigma^{(1)}$ is called the first class conjugate line.

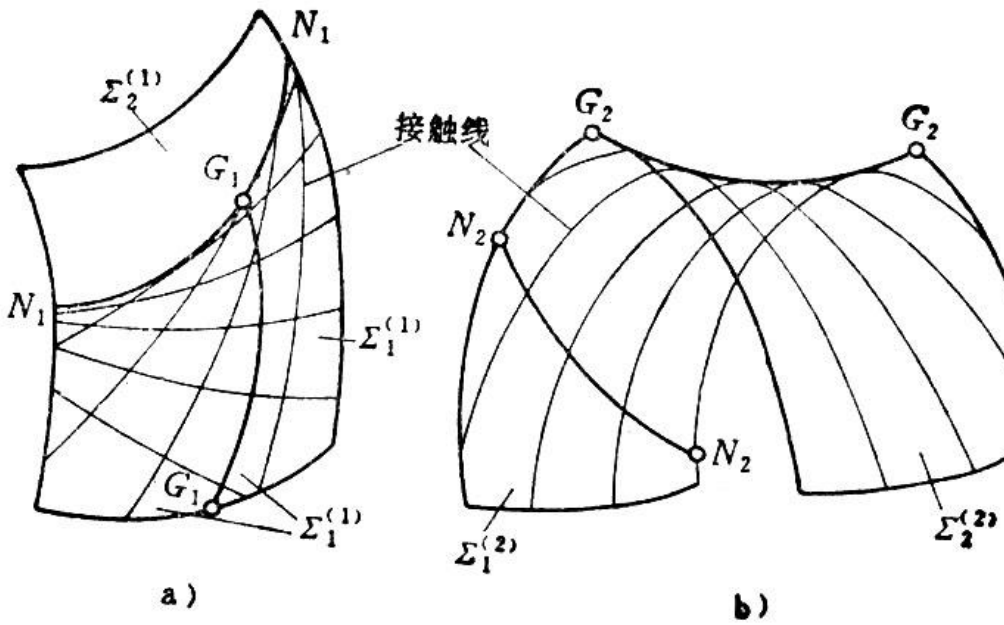


图 5-187

Surface construction of secondary envelope

Tooth flank $\Sigma^{(2)}$ is enveloped for the first time by tooth flank $\Sigma^{(1)}$. Points on the second class conjugate line of the tooth flank $\Sigma^{(2)}$ are both the points of first class boundary points and second class boundary points. When enveloping the tooth flank $\hat{\Sigma}^{(1)}$ with tooth flank $\Sigma^{(2)}$, part of the tooth flank $\hat{\Sigma}^{(1)}$ can be enveloped because of the symmetry of the meshing region of $\Sigma^{(2)}$. This part is called the original tooth flank (actually, it is part of $\Sigma^{(1)}$); the non-meshing area on tooth flank $\Sigma^{(2)}$ can be used to envelope another part of $\hat{\Sigma}^{(1)}$, which is called new working region; therefore, tooth flank $\hat{\Sigma}^{(1)}$ is enveloped for two times, composed by original part and the new part. There are two groups of contact line on the tooth flank $\hat{\Sigma}^{(1)}$. One group is called the original contact line group, the other is called new contact line group. The two contact lines intersect on the line of $\overline{N_1N_1}$.

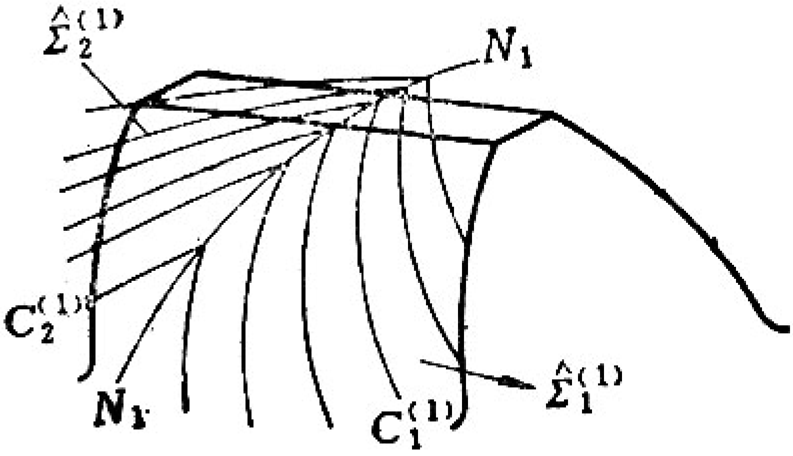


图 5-188

TK-worm

TK-worm is a kind of enveloping worm generated by generating gear whose tooth flank has the shape of cone. That means the tooth flank of worm is the enveloping surface of conical straight profiled circular cutter or disc grinding wheel. This kind of worm has good grinding performance, with which hard tooth surface worm with high precision can be gained.

The formation of this kind of tooth surface can be divided into three typed: if the axis of disk milling cutter is located on the same side with the axis of worm wheel, then the tooth flank is convex conical surface; if the axis of conical surface is not on the same side with the axis of worm wheel, the tooth flank is concaved conical surface, and the axis of cone is vertical to the axis of worm wheel and the axis of worm at the same time. In some documents, this kind of worm can be divided into three types: type Ⅰ, type Ⅱ and type Ⅲ(namely, TK_l, TK_2, TK_3). Currently, what China use is just the type Ⅰ of conical enveloping worm. The shaping process of the tooth flank of worm is the meshing process of generating worm gear (gear) and worm according to the given speed ratio and center distance (Figure 5-189).

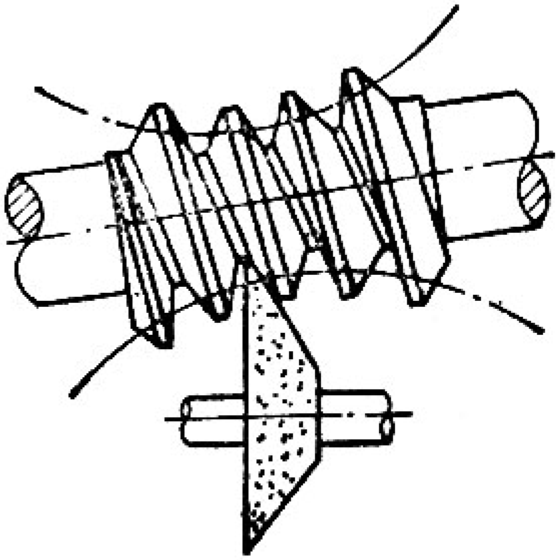


图 5-189

Basic Wildhaber worm, basic TP-worm

During the process of generating enveloping worm with planar generating gear, if the given center to center distance α_0 and speed ratio i_0 are equal to the nominal center to center distance α and speed ratio i of worm gear pair respectively, then the manufactured enveloping worm is called the basic Wildhaber worm. The defects of this kind of worm are that the correct tooth profile cannot be gained easily and short on gear grinding. The meshing process of worm gear pair combined with this kind of worm can hardly meet people's satisfaction. Therefore, the most commonly adopted are those of "modified-typed" rather than the "basic-typed".

Single-envelope enveloping worm

Single-envelope enveloping worm refers to that can be used to compose single-envelope enveloping worm gear pair. See "single-envelope enveloping worm gear pair".

Double-enveloping worm

Double-enveloping worm refers to those that can be used to compose "double-enveloping worm gear pair". See "double-enveloping worm gear pair".

Wildhaber-worm wheel, P—worm wheel

Wildhaber-worm wheel refers to the gears whose shape of tooth flank is plane (gear whose tooth profile is s straight line). When it composes worm gear pair with intersecting axles with enveloping worm, then the face gear is called wildhaber worm wheel.

The tooth flank of wildhaber worm wheel can be divided into two types: straight tooth and helical tooth. The tooth flank of wildhaber-worm wheel is parallel to its axis. The extended tooth flank can be tangent with the cylinder that has the same axis with worm wheel. This cylindrical surface is called "formation cylinder". When the tooth flank of face gear with helical gear is not parallel to its axis and the extended tooth flank is being tangent with the conical surface that has the same axis with the worm wheel.

The most prominent advantage of wildhaber-worm wheel is that it can be equipped with high precision after grinding with surface grinding wheel. When adopting steel worm wheel, hard tooth surface can be used to improve the bearing capacity and transmission efficiency.

Double wildhaber-worm wheel

Taking flat cylindrical gear with straight tooth (or helical tooth) as generating gear to generate wildhaber worm, then taking the worm as generating wheel (tool) and processing the worm wheel with direct generating method, then what we get is double wildhaber-worm wheel. The tooth flank of the worm wheel is composed by two parts: plane (the original tooth flank) and curved surface (the second tooth flank). They are divided by a middle ridge. Both of the two tooth flank are active zones. Its contact line is straight and curve respectively. The contact line on the two tooth flank is tangent on the ridge line.

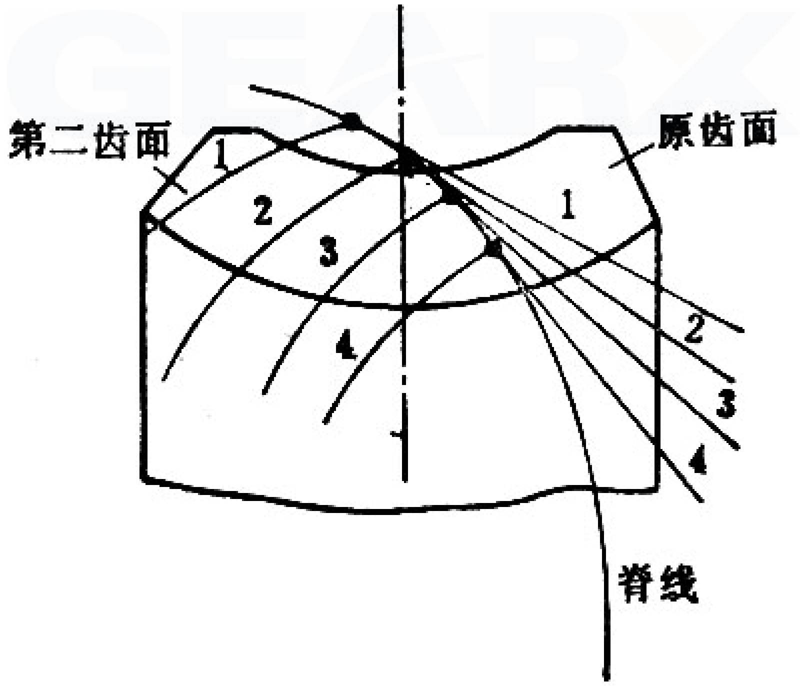


图 5-190

TI-worm

TI-worm is a kind of enveloping worm generated by taking straight-toothed (or helical-toothed) involute gear as generating gear. The tooth flank of worm is the envelope surface of tooth surface of straight-toothed (or helical-toothed) involute cylindrical gear. The formation process of the tooth flank of worm is the meshing process of worm gear pair under the condition of given transmission ratio and center to center distance. Generating gear has good performance but has some difficulty in gear grinding.

Straight-sided normal enveloping worm

Straight-sided normal enveloping worm is a kind of turning-typed enveloping worm.

When putting the active side of formed turning tool on the normal plane of worm tooth space, if the turning tool and worm rotates across the formation circle and the axis line of worm respectively based on the given transmission ratio and center distance, then the trace surface of blade profile is the helicoid of straight-sided normal enveloping worm. The turning workmanship of this kind of worm is good.

Lorenz worm

Lorenz worm is a kind of worm that is basically the same with hindley-worm. It is no longer used now.

Hindley worm，TA-worm

Double enveloping worm with straight line generatrix was used to be called Hindley-worm.

It was invented by Hindley in Britain in 1865. Therefore, double enveloping worm with straight line generatrix can be called Hindley-worm.

Cone worm

Cone worm is a variable form of double enveloping worm with straight line generatrix.

Cone worm is invented by Cone in 1930, United States, using the gear cutting method. It is developed on the basis of Hindley-worm.

Circle-arc enveloping worm

Circle-arc enveloping worm is a kind of enveloping worm taking straight toothed or helical toothed cylindrical gear whose tooth profile is circle arc (or convex arc, or concave arc or bi-arc)as generating wheel. Its tooth flank is the envelope surface of arc tooth surface. The workmanship of this kind of generating gear has good performance but short in gear grinding.

Wear-out curve of basic hindley-worm

After a long time running of basic hindley-worm gear pair, the abrasion loss of the tooth flank changes along with the change of position. That means, abrasion loss is the function of coordinate position of tooth flank $\Delta\varphi = f(\varphi)$. The curve painted on the basis of this function is called wear-out curve of basic hindley-worm(currently, the curve is acquired through experiment).In the Figure 5-191,$\Delta\varphi$ is abrasion loss, φ_x refers to the central angle corresponding to the relative reference circle arc at different point of the tooth flank. From the figure, we can see that the abrasion at the entrance is much serious than that at the exit. The point of minimum abrasion is deviate to the exit. Experiments have proved that hindley-worm is variable lead (tooth thickness) worm after long term running. After the abrasion of tooth flank, the meshing zone of enveloping worm gear pair increases, with its bearing capacity notably improved. Obviously, what the curve shows is an ideal condition of tooth thickness; it is also the theoretical basis for cutting "modified" worm.

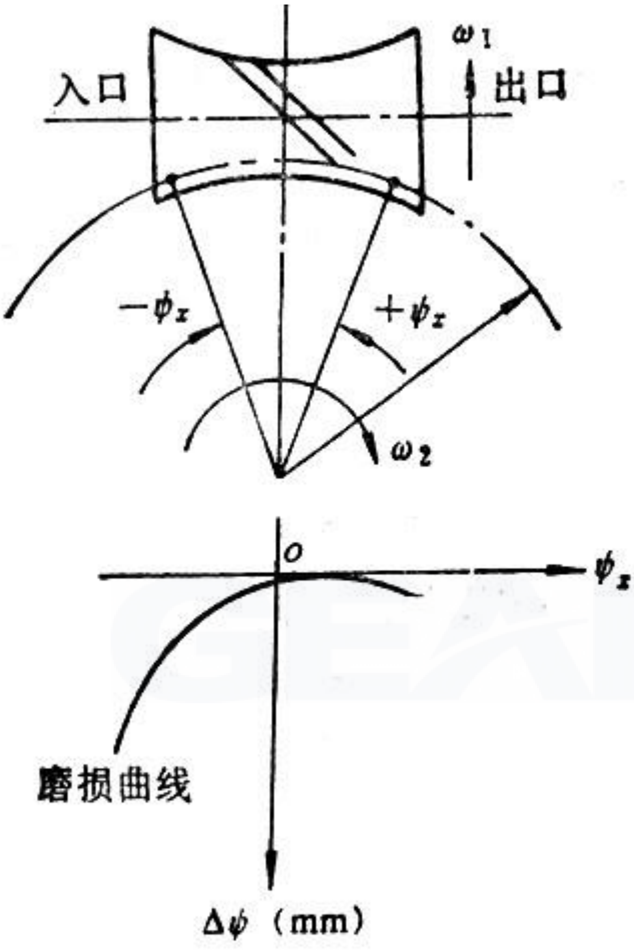


图 5-191

Correction hindley-worm

With the method of changing the tooth cutting parameter of worm, the teeth of basic hindley-worm can be increasingly thinned from the middle throat to the two ends，then correction hindley-worm will be obtained. Correction hindley-worm can be divided into two types: "backward correction" and "complete correction". Also, backward correction can be divided into "two-section backward correction" and "three-section backward correction". What is commonly used at present is "variable parameter correction" (also called symmetrical correction), which is similar to the "complete correction".

Double enveloping worm with parabolic modification

Double enveloping worm with parabolic modification refers to the enveloping worm manufactured on the basis of parabolic modification. See “parabolic modification”.

Parabolic modification

When processing enveloping worm, one should make the helix of the worm on the reference toroid change under the correction workmanship, in accordance with the parabolic modification method. This correction method of worm is called parabolic modification.

Complete correction

Complete correction is the most ideal correction method for Hindley-worm, in which the correction curve of tooth thickness coincides with the wear-out curve of tooth thickness. By adding special mechanism on the lathe, making the tool produce variable movement corresponding to the worm, this method comes into action. The method and workmanship is very complicated and it is hard to realize. That is why it is hardly applied currently. In order to realize the artificial oil culvert at the entrance, tip relief is needed at the entry end. (Figure 5-192)

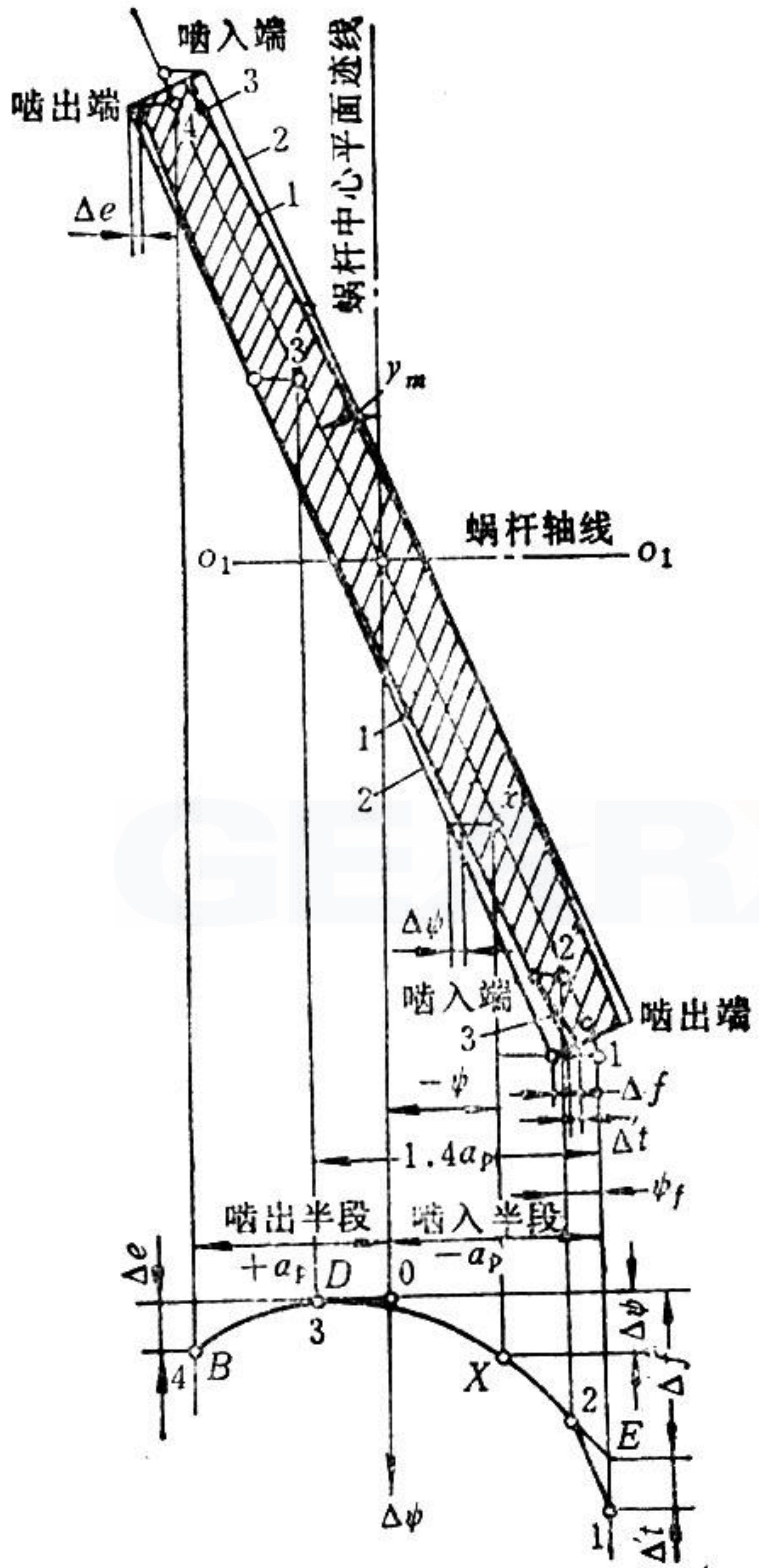


图 5-192

1—"全修形"齿厚曲线 2—"原始型"齿厚曲线

3—齿厚修缘曲线

Symmetrical correction

See “variable parameter correction”.

Backward correction

Backward correction is correction method for hindley-worm. The most ideal result is that the change law of tooth thickness is in accordance with its “wear-out curve”. The correction method of using broken line to replace “wear-out curve” is called “backward correction”. It can be divided into two types: “the second backward correction” and “the third broken correction”. Backward correction can be realized by changing the center to center distance α_0 and moving the worm in a given value along the axial direction. This method has bad performance so it is rarely used. In the Figure 5-193, ①is the second backward broken line, ②is the third broken line and ③ is the wear-out curve.

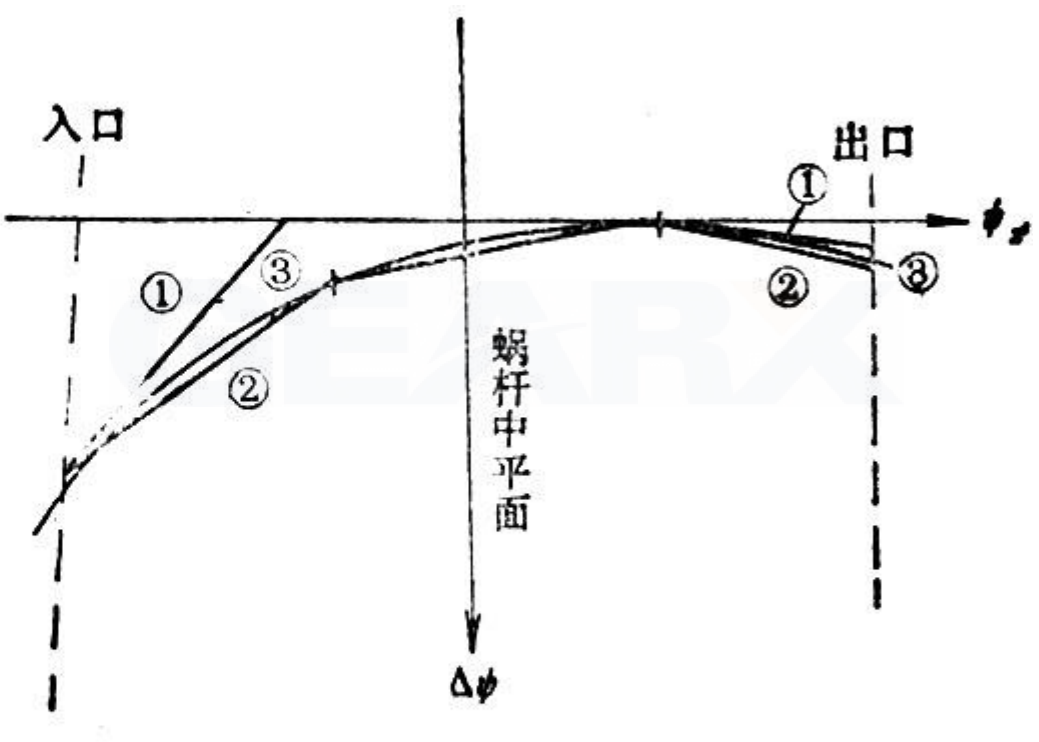
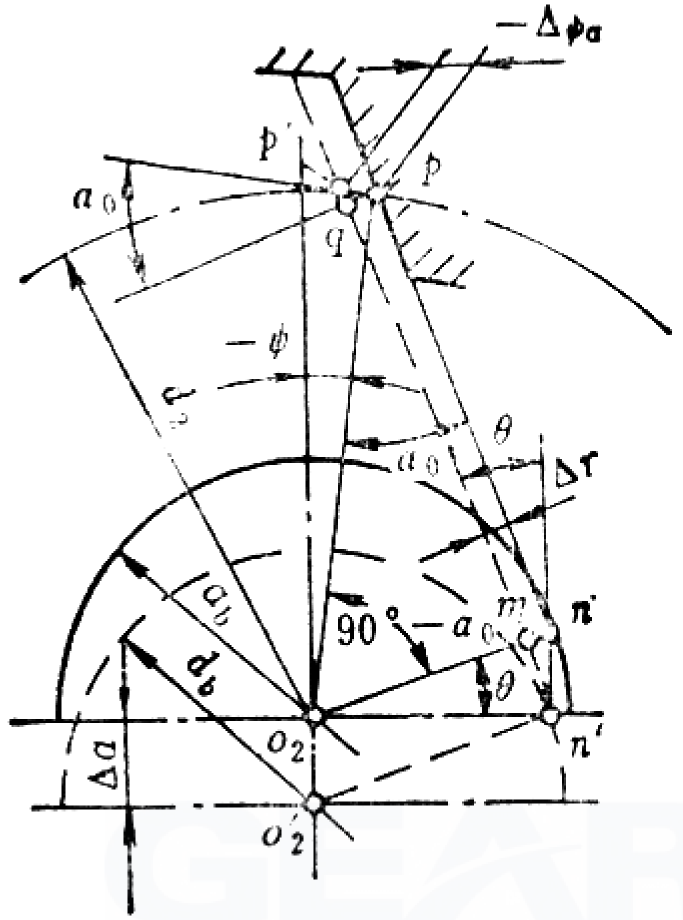


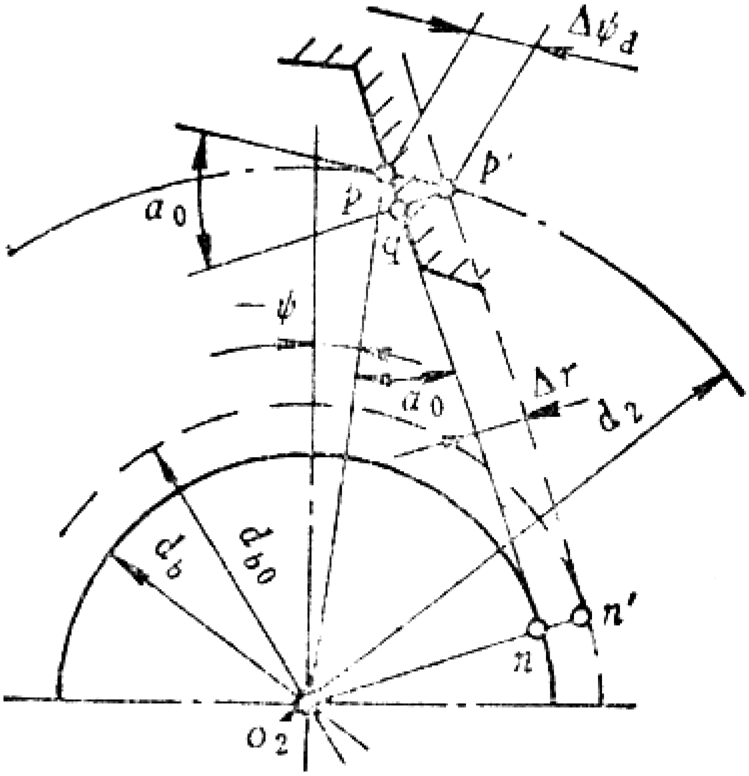
图 5-193

Variable parameter correction

Variable parameter correction is also called “symmetrical correction”. It is the most commonly used method for enveloping worm. By changing the center to center distance α_0, diameter d_b of formation circle and the speed ratio of reference change gear, this method can realize its function similar to “complete correction”. The correction results are very close to that of “complete correction”. Its correction workmanship, however, is superior to that of “complete correction”.



a)



b)

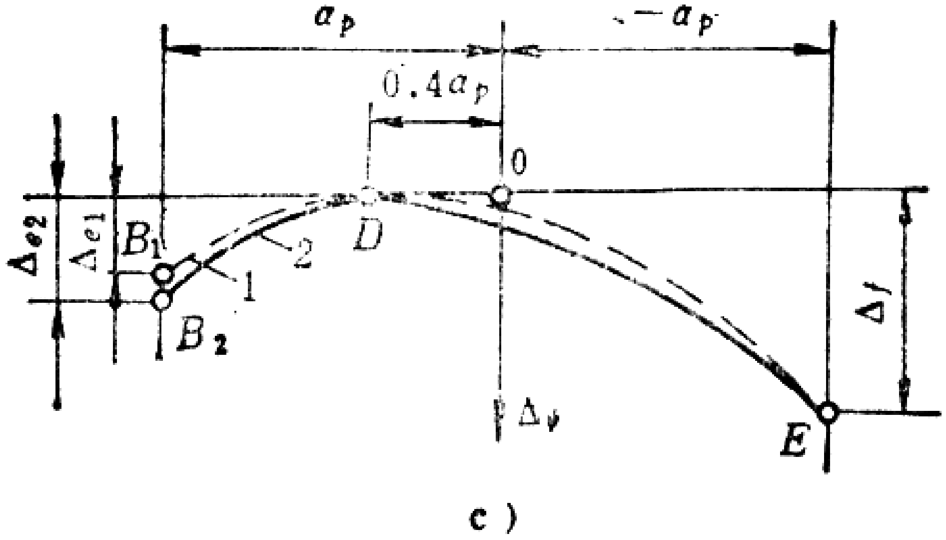


图 5-194

a）改变中心距的齿厚修形量 b）改变成形圆直径的齿厚修形量 c）“变参数修形”

Modification with varying instantaneous ratio

When processing enveloping worm, the adopted worm blank and the speed ratio i_0 of tool is different from the transmission ratio i of worm gear pair. Worm manufactured with this method is “modified typed”, namely, modification with varying instantaneous ratio.

Amendment velocity ratio

When cutting correction enveloping worm, the quotient of the difference of the transmission ratio of lathe i_0 and the transmission ratio of worm gear pair i divided by the transmission ratio of lathe is called amendment velocity ratio, which is $K_i=(i_0—i)/i_0$.

Modification curve of enveloping worm tooth

In order to improve the transmission quality of enveloping worm gear pair, people defined the curve that changes the tooth thickness of worm on the reference surface of worm. This curve is called modification curve of enveloping worm tooth. This curve is similar to the second curve of parabola.

Relation angle of worm end relief

Relation angle of worm end relief refers to the central angle of worm wheel corresponding to the length of helical burr at the entry relief of worm.

Wildhaber worm of variable parameter correction

Wildhaber worm of variable parameter correction belongs to correction wildhaber worm. When generating enveloping worm with planar generating gear, the adopted center distance α_0 and transmission ratio i_0 is different from the nominal center distance α and transmission ratio i of worm gear pair. Besides, as for straight tooth wildhaber worm, what commonly used is angle correction. This kind of wildhaber worm processed by changing the workmanship parameter is called wildhaber worm of variable parameter correction. As for wildhaber worm with helical tooth, what adopted are two kinds of correction form, $i_0<i$, $\alpha_0<\alpha$ and $i_0>i$、$\alpha_0>\alpha$, rather than angle correction.

Double enveloping worm pair modified with various instantaneous ratio

Double enveloping worm pair modified with various instantaneous ratio refers to the hindley-worm manufactured with the method of various instantaneous ratio. See “modification with various instantaneous ratios”.

Double enveloping worm modified with varying of position and ratio

Double enveloping worm modified with varying of position and ratio refers to the enveloping worm manufactured under the guide of varying position and ratio of modification method. See “modification of varying position and ratio”

Angular correction straight-sided normal enveloping worm

When processing straight-sided normal enveloping worm with formed turning tool, make the turning spindle axis of tool unparallel to the axis of worm wheel, then an angle would form, which is $\Delta\gamma$. Enveloping worm produced under the guidance of this method is called angular correction straight-sided normal enveloping worm.